Quantification of Litter Fall and Estimation of Nutrient Release Through in-Situ Decomposition of Leaf Litter From Some Important Mangrove Species of Indian Sundarbans

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Abstract

Looking into the importance of mangrove leaf litter in regulation of sediment carbon sequestration and nutrient flux in Sundarbans ecosystem, an experiment was conducted at Jharkhali island of Sundarbans. In this experiment, collection of leaf litter-shedding from nine dominant mangrove species during December 2012 to November 2013 was donemonthly using 'litter traps' (1 m^2) in Eco-garden on the bank of Herobhanga creek.Seasonal litter fall was highest in Geon (*Excoecariaagallocha*)(103 gm^{-2}) followed by Keora (*Sonneratiaapetala*) (98.5 gm^{-2}). Kal Bain (*Avicennia alba*) produced the highest amount (414.37 gm^{-2}) of total annual leaf litter followed by *Bruguieragymnorrhiza* (410.43 gm^{-2}). Kankra (*Bruguieragymnorrhiza*), Garjan (*Rhizophoramucronata*) and Geon (*Excoecariaagallocha*) dry leaf litters contained more than 50% carbon (oven dry basis). Litter from *Avicennia* group contained more nitrogen and carbon. Decomposition rates of various mangrove litters were estimated through twoshort-term (30 days and 52 days) in-situ experiments using mangrove leaf litter in nylon net bags (0.6 mm mesh) subjected to periodical diurnal submergence by tidalriver water at Jharkhali. During decomposition process,observation said thatmost susceptible and resistant litter with respect to mass loss were Geon (*Excoecariaagallocha*) (81±5.5%) and Taura (*Aegialitisrotundifolia*) (26±4%) respectivelyafter 30 days. The biomass retained after decomposition losses (average45±15.2%after 30 days and 56±20.2 % after 52 days) indicated the amount of carbon retained in mangrove soil and ultimately determines the carbon sequestered in soil through mangrove litter fall. The study gives important insight into contribution of different mangrove species in carbon sequestration and nutrient dynamics in mangrove ecosystem of Indian Sundarbans.

Introduction

Mangrove forests, a productive ecosystem, support wildlife of high abundance and diverse variety (Ong 1995). The contribution of mangrove in the Global carbon cycle is quite significant. Researchers calculated the total global mangrove biomass estimate as approximately 8.7 gigatons dry weight, which is equivalent to 4.0 gigatonnes of carbon (Twilley et al. 1992). Mangrove ecosystems are considered highly productive because of their efficiency in trapping suspended material from the water column. The detritus developed from mangrove serves as a useful food source for many macroinvertebrates,e.g., sesarmid crabs, which can consume mangrove litter (Fratiniet al. 2000; Cannicciet al. 2008). Degradation of litter by microbes involves both aerobic and anaerobic pathways. A significant portion of the organic matter present in detritus is generally "exported" to adjacent coastal water through regular tidal flooding of the forest floor. The undegraded fraction of litter gets permanently buried under the sediments of the same system or any adjacent ecosystem. Mangrove productivity indirectly measured by its annual litter fall; however, this, in reality, underestimates the net primary productivity (NPP) because it excludes the biomass produced from underground roots and wood. Nevertheless, nutrients, e.g., carbon, nitrogen, and phosphorus, are recycled back to the mangroves through the litter fall when it undergoes decomposition in the sediments where it gets deposited first. Besides, this also gives support tomarine food web by providing ahouse for an aquatic nursery (Srisunontet al. 2017). Different stages of leaf litter break down are (i) loss of weight due to physical fragmentation (abiotic), (ii) feeding by animals and (iii) microbial activity and leaching (Steward and Davies 1989). Three significant factors generally control the litter decomposition rates, viz., temperature, moisture, and litter quality, and sometimes an additional fourth factor of influence of earthworm also got importance (Bohlen et al. 1997;Dechaineet al. 2005). Soil microbes, which do the heterotrophic decomposition of litters, are influenced by both temperature and moisture; microbial activity has a positive correlation with temperature, and sometimes a doubling of activity was noted with a 10°C increase of temperature (Kirschbaum 1995).Soil moisture (and precipitation) also play an essential role in the maintenance of higher microbial activity at enhanced temperature (Peterjohnet al. 1994; Meentemeyer 1978).

Besides temperature and moisture, chemistry and some other physical characteristics of litter also decide how susceptible that is to decomposition. Three hypotheses are available in the literature to explain the influence of initial litter quality on litter decomposition. According to the first hypothesis, C:N ratio can better predict mass loss and release of nitrogen from litter. The second one, the decay filter hypothesis states that in the early stages, decomposition and release rate is guided by the initial litter quality, like the ratio of lignin and nitrogen or lignin and cellulose. Lastly, the third hypothesis talked about the negative correlation of litter decomposition rates with N-based estimates of initial litter quality (Karberget al. 2008).

Productivity and also to a good extent, functions of mangrove ecosystem may be better assessed through the estimation of litter production followed by litter decomposition study. Several pieces of literature are available describing research findings on litter fall production from mangroves, its decomposition study and also the nutrient analysis in subtropical(Twilley et al. 1986; Tam et al. 1998; Sánchez-Andréset al. 2010; Kamruzzamanet al. 2012) and tropical (Robertson 1988; Wafaretet al.1997; Silva et al. 2007; Srisunontetet al.2017)ecosystems. However, similar study is lacking in world's largest mangrove ecosystems, the Sundarbans. So,the present experiment was planned in the middle part of Indian Sundarbans to get an estimate of leaf litter fall from the predominant mangrove plants of the area and nutrient flux through *in-situ* litter decomposition study.

Materials And Methods

Study Area

Study area was situated in the Sundarbans, the world's most substantial 'mangrove chunk'. The Sundarbans mangrove forest covers an area of about 10,000 km^2 (3,900 sq mi), and in West Bengal, they extend over 4,260 km^2 (1,640 sq mi) across the South24 Parganas and North 24 Parganas districts.Sundarbans wetland has been given the recognition of 'Ramsar Site' (Site No.2370),*i.e.*, Wetland of International Importance. The Indian Sundarbans, covering the south-westernmost part of the delta, constitutes over 60% of the country's total mangrove forest area and includes 90% of Indian mangrove species. The sites werechosen in the middle part of Indian Sundarbans for our study, and selected Jharkhali as the working station(GPS:22°01.135'N; 88°40.370'E). Jharkhali village comes under the Basanti CD block in the Canning sub-division of district South 24 Parganas, West Bengal, India.Jharkhali is a flat, low-lying area in the South Bidyadhari plains. The Matla River is prominent, and there are many streams and water channels locally known as *khals*. The experiments were conducted in Jharkhali Mangrove Eco-Garden (a planted mangrove area), situated near the Jharkhali Jetty, and by the side of Herobhanga creek connecting the Matla and Vidyadhari rivers. Jharkhali was in the mesohaline zone, and sometimes in summer, it also shifted to polyhaline zone. The map of the study area is shown in Fig. 1.

Estimation of Litter fall

We had surveyed the experimental site and selected nine predominant mangrove species for our studies. Those are *Avicennia alba* (AA), *Avicennia officinalis* (AO), *Avicennia marina* (AM), *Bruguiera gymnorrhiza* (BG), *Excoecariaag allochha*(EA), *Ceriops decandra*(CD), *Rhizophora mucronate* (RM), *Sonneratia apetala* (SA), and *Aegialitisrotundifolia* (AR).Then three representative plants from each species were selected with similar height and diameter at breast height (DBH). For the collection of litter fall, we got prepared litter traps indigenously. First, 1 m^2 frame was prepared with wood sticks available locally; the frames were reinforced with the help of nails and ropes. Then mosquito nets of < 1 mm mesh size was fixed to the frame with the help of nails (Fig. 2). We then fixed litter traps below canopies of the selected mangroves by hanging those from tree branches, maintaining heights above the reach of the highest tide to prevent inundation of traps (Fig. 3). Plants were selected in such a way that all 27 traps (nine mangrove

species × three replications for each species) were distributed in about 2000 m^2areaof the monitoring site.Litter fall in the traps was collected monthly from December 2012 to November 2013. As in this experiment, we were concerned only with leaf litters; therefore, the collected total litter fall from each trap was taken to the laboratory, and leaves were separated from the mixed litter (stipules, branches, flowers, and flower buds, fruits, and other parts of plants). The leaves were first air-dried and weighed on a digital balance to get replication-wise litter fall estimate. Thereafter a portion of litter from each replication was dried at 65–70°C, cooled to room temperature in a desiccator and weighed on a digital balance. The dried litter was then ground to fine powder, and kept for nutrient analysis.

Litter decomposition study

Senescent leaves were collected from different traps installed for litterfall study;those are freshly fallen leaves from mangrove plants. The leaves were collected for eight species except for Keora(*S. apetala*). These leaves were air-dried in the laboratory for 48 hours. The dried leaves were mixed thoroughly for individual species, and then 50 g sample picked up and put in litterbags (Stewart and Davies, 1989). Litterbags (20 cm × 25 cm) were made of high strength nylon mosquito net of 2 mm mesh size (Fig. 4). For each mangrove species, three litter bags were taken as replications for each test species making the total number of litterbags to 24. The litterbags were then placed on the sediment in the Jharkhali Mangrove Eco-garden itself in August 2013, where those were exposed to periodical tidal inundation. Bags were little pushed in the soft soil and tied with the nearby mangrove trunks or roots to prevent their flowing away with the tide. After 30 days,the litterbags were collected from the site and taken to the laboratory. In the laboratory, first the litterbags were carefully washed with tap water to remove the soil particles sticking to the bags. Then the inside samples were gently washed to remove additional soil particles before putting those in paper bags. Samples were then dried in a hot-air oven at 60°C for 72 hours till the materials reached a constant weight. The dried litter samples were weighed on an electronic balance.

A part of dried samples from each bag was ground to a fine powder. The powdered samples were used for the analysis of carbon and nitrogen. Estimation of carbonwas performed by dichromate digestion (Walkley and Black 1934), and nitrogenin ground litter samples were analyzed by Kjeldahl N-analyzer (Pelican Equipment Pvt. Ltd., India; Models: Kelplus® – KES 12L VA for digestion, Kelplus® –Classic DX for distillation, and Kelplus®–Kelvac VA for scrubbing acid fumes). The loss of mass from the leaf litter was determined by comparing it with its initial dry weight.Lignocellulose estimation in selected leaf litter was carried out following the detergent approach, developed by Van Soest and coworkers for the analysis of fiber-rich forages and feed, which is currently most frequently used one (Van Soest et al. 1991). The fractions of the fiber that are insoluble either in neutral detergents or in acid detergent are measured, and the residue after treatment of the ADF fraction with 12 mol/L sulfuric acid is considered to be acid detergent lignin (ADL). By difference, hemicellulose (NDF – ADF) and cellulose (ADF – ADL) were calculated.

Water quality parameters

Water samples were collected from adjacent Herobhanga creek during peak high tide and peak low tide.The water from this creek was actually responsible for periodical wetting of the litter bags through tidal cycles during the whole decomposition process. Surface water temperature, pH, transparency, salinity, dissolved oxygen, and total alkalinity were measured onboard, and nutrients (nitrate, phosphate, silicate, sulfate) were analyzed in the laboratory following recommendations of APHA (2012). Water temperature was measured by using a degree centigrade thermometer; pH with a digital pH meter (HANNA instruments), and transparency was measured by employing a Secchi disc (Strickland and Parsons 1972). The dissolved oxygen, salinity, and total alkalinity were determined by titrimetric methods (APHA 2012).

Statistical analysis

The litterfall data were subjected to one-way analysis of variance (ANOVA) and post hoc tests using SPSS v.21. The mean values of water quality parameters (overall annual and related to two litter decomposition periods)with standard deviations. These basic descriptive statistics (mean and standard deviation) and column diagrams were performed in MS Excel 2010.

Results And Discussion

Litterfall Estimation

It was observed from analyzed data in Table 1 that,the highest total litterfall from all nine mangrove specieshappened during March 2013(971.7 g), and the lowest was in September 2013 (176.3 g). Similarly, as individual mangrove species, Jat Bain (*Avicennia officinalis*) produced the most substantial quantity of leaf litter (746.2 g), whereas Taura (*Aegialitis rotundifolia*) gave the lowest biomass (297.3 g); all the figures given are the dry weights of leaf litters only. From Table 1, it could be noted that during the month ofhighest leaf litter production, the maximum contribution was made by *Rhizophora mucronata* (173.0 g) followed by *Bruguiera gymnorrhiza* (148.3 g), but post hoc test showed these two mean values were not significantly different at 5% level. Those were only significantly different from *Avicennia marina* (45.7 g) which contributed the least. The top litter producer amongst the nine species, *Avicennia officinalis*, produced higher leaf litter during consecutive three months of December 2012 (85.9 g), January 2013 (113.3 g) and February 2013 (115.5 g), which were significantly different (5%) from the rest of the year (Table 1). Overall *Avicennia alba* produced highest amount of leaf litterfall during the collection period (414.37 gm^{-2} or 4.14 Mg ha^{-1}) followed by *Bruguiera gymnorrhiza* (410.43 gm^{-2} or 4.10 Mg ha^{-1}).

Table 1
Variations of litter fall (g m^{-2}) among different species (One way ANOVA)

Months	AR	CD	RM	AO	EA	SA	AA	AM	BG
Dec	17.96^{a}	43.50^{bc}	21.93^{ab}	85.93^{d}	48.87^{c}	26.66^{ab}	28.16^{abc}	16.45^{a}	20.24^{a}
Jan	19.15^{ab}	55.23^{bc}	44.66^{abc}	113.3^{d}	63.66^{c}	65.33^{c}	60.33^{c}	11.33^{a}	104.3^{d}
Feb	13.65^{a}	40.67^{ab}	44.66^{abc}	115.5^{d}	71.33^{bcd}	87.0^{cd}	89.66^{d}	16.33^{da}	110.5^{d}
Mar	116.0^{abc}	70.33^{bc}	173.0^{c}	137.3^{abc}	91.67^{abc}	104.6^{abc}	84.66^{abc}	45.66^{a}	148.3^{bc}
Apr	108.3^{ab}	42.0^{ab}	55.67^{ab}	75.33^{ab}	68.66^{ab}	47.0^{ab}	32.33^{a}	113.33^{b}	84.66^{ab}
Jun	55.66^{c}	34.0^{b}	27.66^{ab}	21.66^{a}	35.33^{ab}	54.66^{c}	$42.0b^{c}$	25.66^{ab}	$41.0b^{c}$
Jul	19.33^{ab}	19.66^{ab}	30.0^{b}	10.33^{a}	31.33^{b}	47.33^{a}	21.66^{ab}	12.82^{a}	47.83^{c}
Aug	38.66^{bc}	17.66^{ab}	57.66^{c}	16.0^{ab}	15.66^{ab}	17.66^{ab}	58.83^{c}	3.0^{a}	12.0^{ab}
Sep	17.33^{a}	24.0^{ab}	18.0^{a}	18.83^{a}	17.66^{a}	38.0^{b}	16.33^{a}	8.50^{a}	17.66^{a}
Oct	20.83^{a}	86.33^{b}	28.83^{ab}	74.66^{b}	39.16^{b}	76.0^{b}	29.16^{ab}	22.66^{ab}	31.33^{ab}
Nov	48.66^{abc}	79.0^{c}	34.83^{ab}	77.33^{c}	57.16^{bc}	58.33^{bc}	54.0^{bc}	21.50^{a}	54.16^{bc}
Note: Values are means; those followed by the same letters are not significant									

Globally, the litter production for mangrove forests had various ranges, e.g., 1.20 Mg $ha^{-1}yr^{-1}$ for scrub mangroves in South Florida, whereas, the value was23.4 Mg$ha^{-1}yr^{-1}$ for a 20years old managed forest in Malayasia (Twilley et al. 1986). Mangrove litter fall rate was also considered as a function of water turnover within the forest (Pool et al. 1975). In general, higher litterfall was observed during dry summer months as this time reduced canopy volume helps in decreasing the rate of transpiration; also, in the rainy season, when the plants receive more nutrient supplements(Wafar et al. 1997). In our experimental result, we, observed bimodal pattern of total litterfall, first peakin March and another smaller peakin November also. However, contrary to the general observation, during raining months, litter fall did not increase but somewhat decreased. In this connection, we found mention in the literature about variations in litter fall quantity was also dependent on individual species besides ambient conditions (Kathiresan 2012).

Moreover, in our experiment, we had concentrated on leaf litters only, and so production was less than where all other plant components, e.g., twigs, barks, flowers, fruits, were also considered. The contribution of leaves in the total litter production of mangroves was reported as 58.4% (Wafar et al.1997). Lee (1989) reported a bimodal pattern of leaf fall in Hong Kong with two peaks, *i.e.* in spring and in late summer. But, Flores-Cárdenas et al. (2016) observed in a Mexican Lagoon system that the mangrove leaf litter fall showed unimodal pattern; highest litter production was from May to October. The mean total litter fall variation is presented graphically (Fig. 5). The maximum total mean litter fall was noted in March 2013 as 971.5 ± 72.5gm^{-2}air-dry leaf litter,and it was also observed that the litter fallwas significantly lower during monsoon months. Least productive month in this respect was September when total air-dry leaf weight obtained from the trees was 176.3 ± 28.3 gm^{-2}. Difference in productive months was observed by other workers; Ray et al. (2011) noted that the most productive months were December-January when

the mean dry litter production ranged 56.1 ± 35.81 g m^{-2} $month^{-1}$.Annual litter fall was estimated from that mangrove was 1173.85 g. m^{-2}(dry weight)in the riverine mangroves. The litter production from fringe mangroves (900 g m^{-2}) and shrub mangroves (186 g m^{-2}) were much less than the riverine mangroves as observed by Twilley et al. (1986) in southwest Florida.

Litter fall Decomposition

The mean decomposition percentages of various mangrove leaf litters (selected for the study) from two different periods were graphically presented in Fig. 2. The 30 days experiment was conducted during August-September and the 52days experiment was conducted during January-March. Interestingly, higher decomposition percentage was recorded in 30 days experiment as compared to 52 days experiment for all the species except Kalbain (*Avicennia alba*). The ambient temperature and humidity during period-1(70–90% RH, 32-37°C) was more than period-2(40–60% RH, 16-25°C) and that may justify the overall higher decomposition percentages during the earlier period. It was also observed by researchers earlier that,leaf litter decomposition of *Rhizophora mucronata* in Kenya was higher during the rainy season as compared to dry season (Woitchik et al. 1997). In both the experiments,maximum decomposition percentage was noticed for Geon (*Excoecaria agallocha*); mean decompositions were 81% and 69% for 30 days and 52 daysrespectively.In those experiments, Taura leaves (*Aegialitis rotundifolia*) was the most resistant to decomposition; only 26% decomposed during the 30 days period, whereas in 52 days experiment it was only 12%. A positive correlation between temperature and decomposition of plant material was reported by Montagnini and Jordan (2002), but in some other studies, higher air temperature reduced the rate of decomposition due to inhibition of bacterial and fungal activities (Ashton et al. 1999; Middleton and McKee 2001). Dry climate generally reduces the decomposition rate and interstitial salinity has an inverse relationship with decay rate as observed by various researchers (Alongi 2009;Keuskamp et al. 2015;Galeanoet al. 2010). But though salinity and water temperature were considered as most important determining factors to influence on litter decomposition rates, an integral approach might be required for better prediction about that (Loría-Naranjo et al. 2018). The carbon and nitrogen concentrations in the leaf litter increased as compared to the beginning of the experiment (Figs. 6a and 6b). This observation was similar to that noted by Kamruzzaman et al. (2019). The increase of N was due to microbial activity as reported by Holguin and Bashan(2007).The values of important water quality parameters at the site are listed in Table 2 to have an idea about the tidal water in which decomposition experiments were conducted.

Table 2
Variations in water quality parameters at the experimentation site (Jharkhali, Sundarbans)

Variables	Jharkhali (overall)	Jharkhali (30 days)	Jharkhali (52 days)
Water temp. (°C)	25.57 ± 3.87	30.74 ± 0.59	21.28 ± 0.26
Transparency(cm)	32.78 ± 12.78	31.50 ± 7.97	39.00 ± 8.49
pH	7.98 ± 0.13	7.84 ± 0.12	8.17 ± 0.03
DO (mgl^{-1})	6.56 ± 0.65	5.78 ± 0.33	7.16 ± 0.07
TA (mgl^{-1})	94.17 ± 7.94	87.44 ± 2.19	95.50 ± 1.29
Salinity (ppt)	18.18 ± 3.38	16.79 ± 1.83	21.69 ± 0.58
Nitrate-N (mgl^{-1})	0.44 ± 0.01	0.44 ± 0.08	0.58 ± 0.24
Phosphate-P(mgl^{-1})	0.04 ± 0.02	0.03 ± 0.01	0.06 ± 0.03
Silicate-Si (mgl^{-1})	5.18 ± 2.76	4.27 ± 0.17	2.71 ± 1.49
± values are standard deviation (SD)			

The decomposition of leaves and nutrient release also depends on the type of carbon compounds initially present in the litter. In our experiment, we considered three representative mangrove leaves based on their decomposition rate – *Excoecaria agalochha* (highest decomposition), *Avicennia officinalis* (intermediate decomposition) and *Aegialitis rotundifolia* (most resistant to decomposition) and analyzed the lignocellulose contents of those three plant leaves. The decomposition percentage of leaf litters (after 30 days) was dependent on its initial lignocellulose contents and they were in an inverse relationship as observed from result (Fig. 8). Researchers had studied the conversion of litters to soil organic matter with reference to limit values for litter decomposition and lignocellulose index (LCI) [the ratio of the acid non-hydrolysable/(non-hydrolysable + hydrolysable)products of proximate C analysis]and demonstrated that a correlationship existed between limit values for accumulated mass loss and initial LCI and lignin content of 14 litter types (Osono and Takeda 2005)

Projected carbon sequestration in Indian Sunderbansbased on observations of present study

From the experiment it was observed thatKalbain (*Avicennia* alba) produced highest quantity of leaf litter (4.14 tonnes ha^{-1} yr^{-1}), whereas, Geon (*Excoecariaagallocha*) had least leaf litter fall (2.26 tonnes $ha^{-1}yr^{-1}$). Average leaf litter fall from all nine mangrove species studied was 3.51 tonnes $ha^{-1}yr^{-1}$. From the litterbag study, we found that on an average, mangrove litters are lost 55% of biomass within 30 days and thus, average 45% residual biomass remained after that period. Estimated average organic carbon content in the residual litter after decomposition period was 62.3%. We assumed that the remaining residue would be buried under sediment and thus play a major role in soil carbon sequestration. From this assumption, we arrived an approximation estimate of carbon sequestered in mangrove zone of Indian Sundarbans through leaf litter only, considering the area of that zone in Indian Sundarbans was 2118 km^2; the calculation is given below:

Carbon sequestered in soil of Indian Sunderbans = 3.51×62.3×45×100×2118/(100×100) tonnes per year^{-1} = 208417.24 tonnes year^{-1}= 0.208 Mega-tonnes year^{-1}

Conclusion

Leaf litter fall from some predominant mangrove species of Indian part of Sundarbans were more in pre-monsoon or summer months as noticed from this short span experiment. Species-wise litter fall varied but majority of mangroves produced more litter in those months only and peak fall was in March. Litter bag study was used to know the decomposition rates of different mangrove leaves and also provided information on the nutrient flux through the process as well as amount of carbon remained in the soil after the decomposition period. The decomposition percentage of leaves depends on the nature of the carbon compounds present in leaf litter and so, had a role in controlling the pace of the decomposition process.

Declarations

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Code availability: NA

Authors Contributions

Sanjoy Kumar Das and Pranab Gogoi: Conceptualization, Sample collection, Statistical analysis, interpretation of data, and manuscript preparation; Ranjan Kumar Manna, Roshith C. M. and Sajina, A. M: Sample collection, interpretation of data, and manuscript preparation;Basanta Kumar Das:Overall guidance and corrections

Ethical Statement/ approval: The authors declare that they have strictly followed all the rules and principles of ethical and professional conduct while completing the research work. No specific permission was required to collect the water samples and litter fall at the study sites. Under this research no involvement of human and/ or animals.

Consent to participate: No involvement of human and/ or animals in this research

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Figures

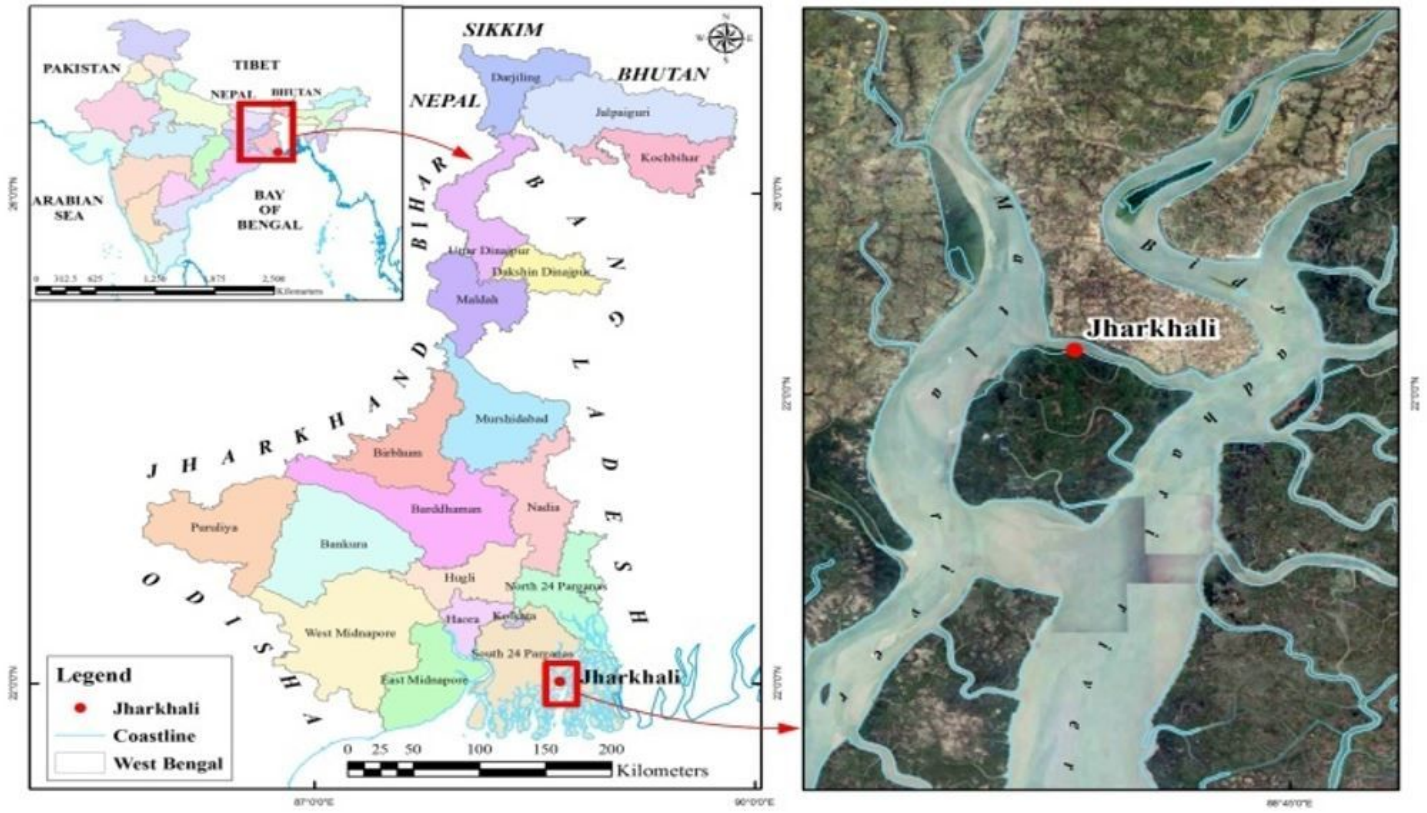


Figure 1

Map of the study area and location of experimental site (Jharkhali) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 2

Fabrication of Litter trap

Figure 3

Litter trap installed on a mangrove plant

Figure 4

A sample litter bag used for study

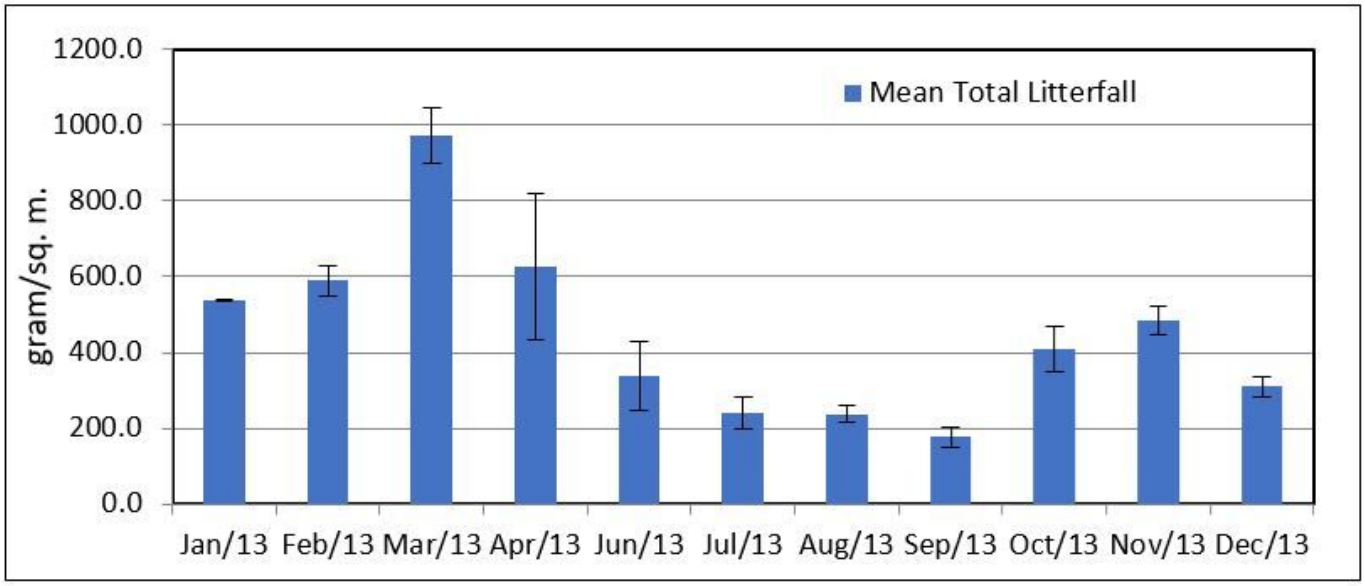
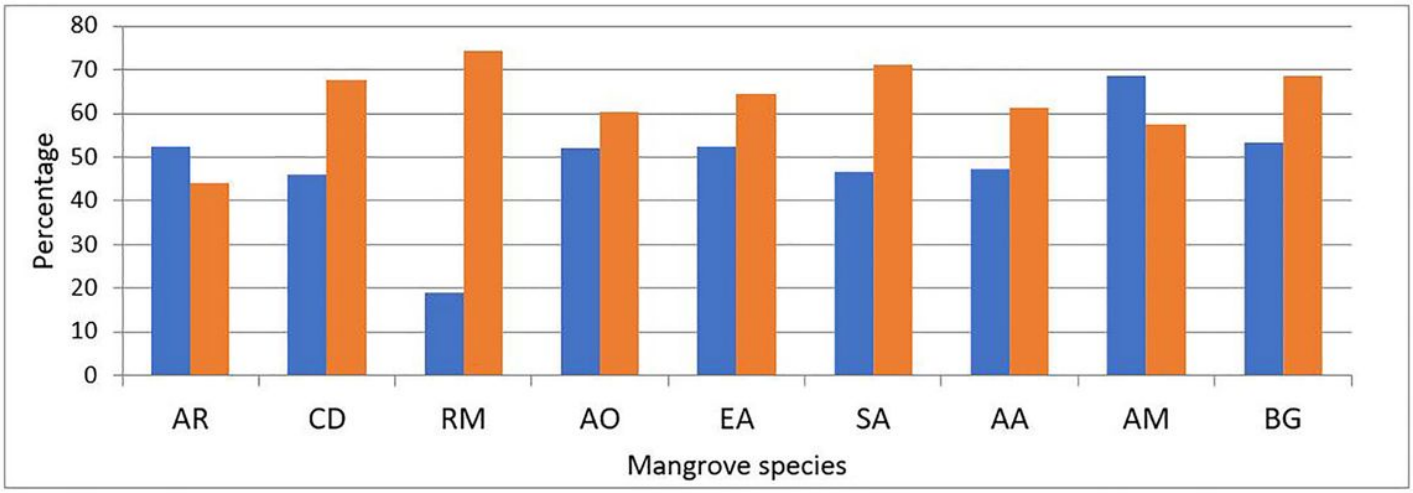
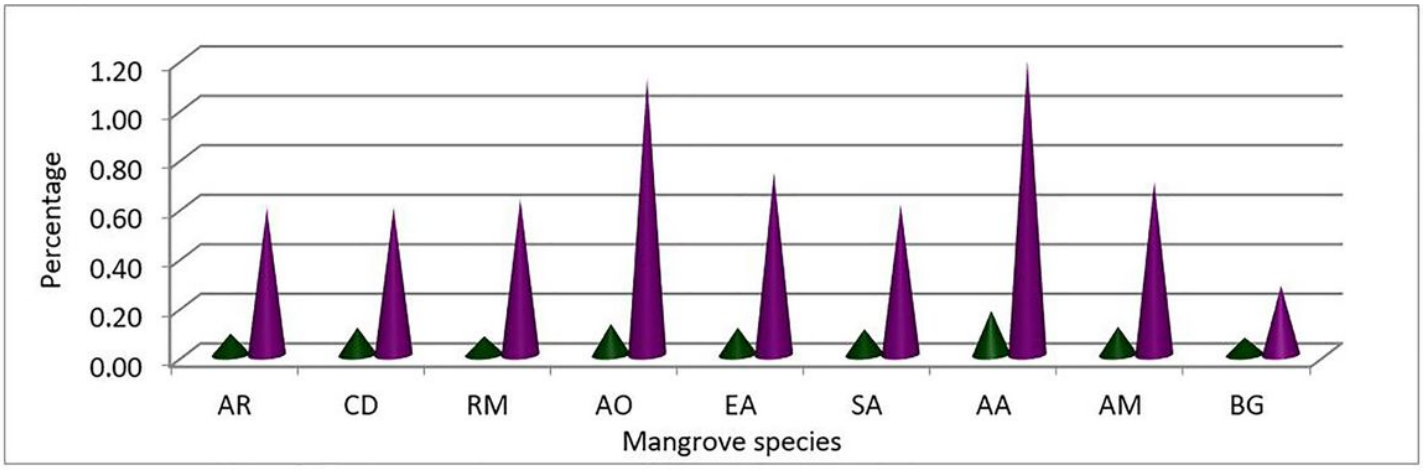


Figure 5

Monthly variation of total litter fall from all nine species



a



b

Figure 6

a: Organic carbon percentage in mangrove species before and after decomposition (52 days). b: Total nitrogen percentage in mangrove species before and after decomposition (52 days).

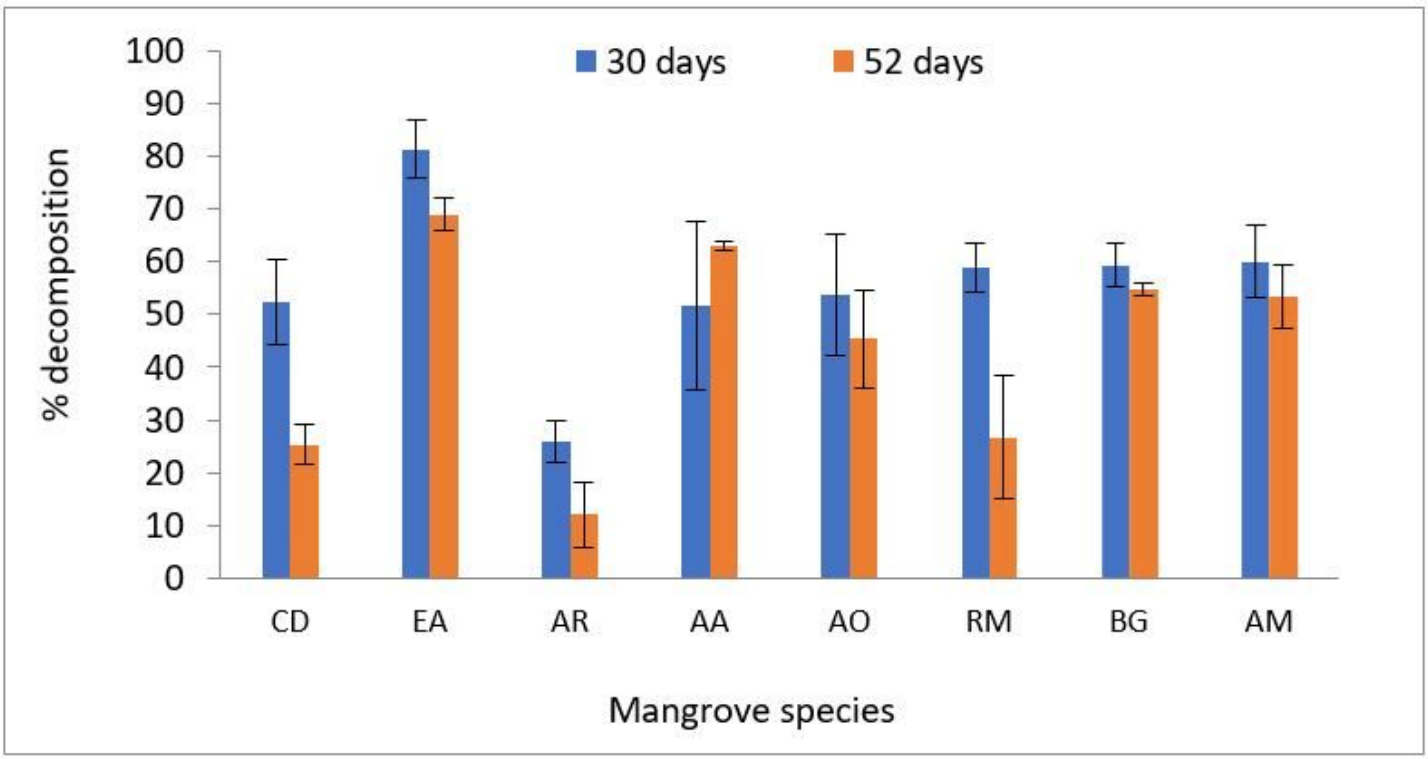


Figure 7

Mean rate of decomposition percentage of various mangrove litters in 30- and 52-days experiment

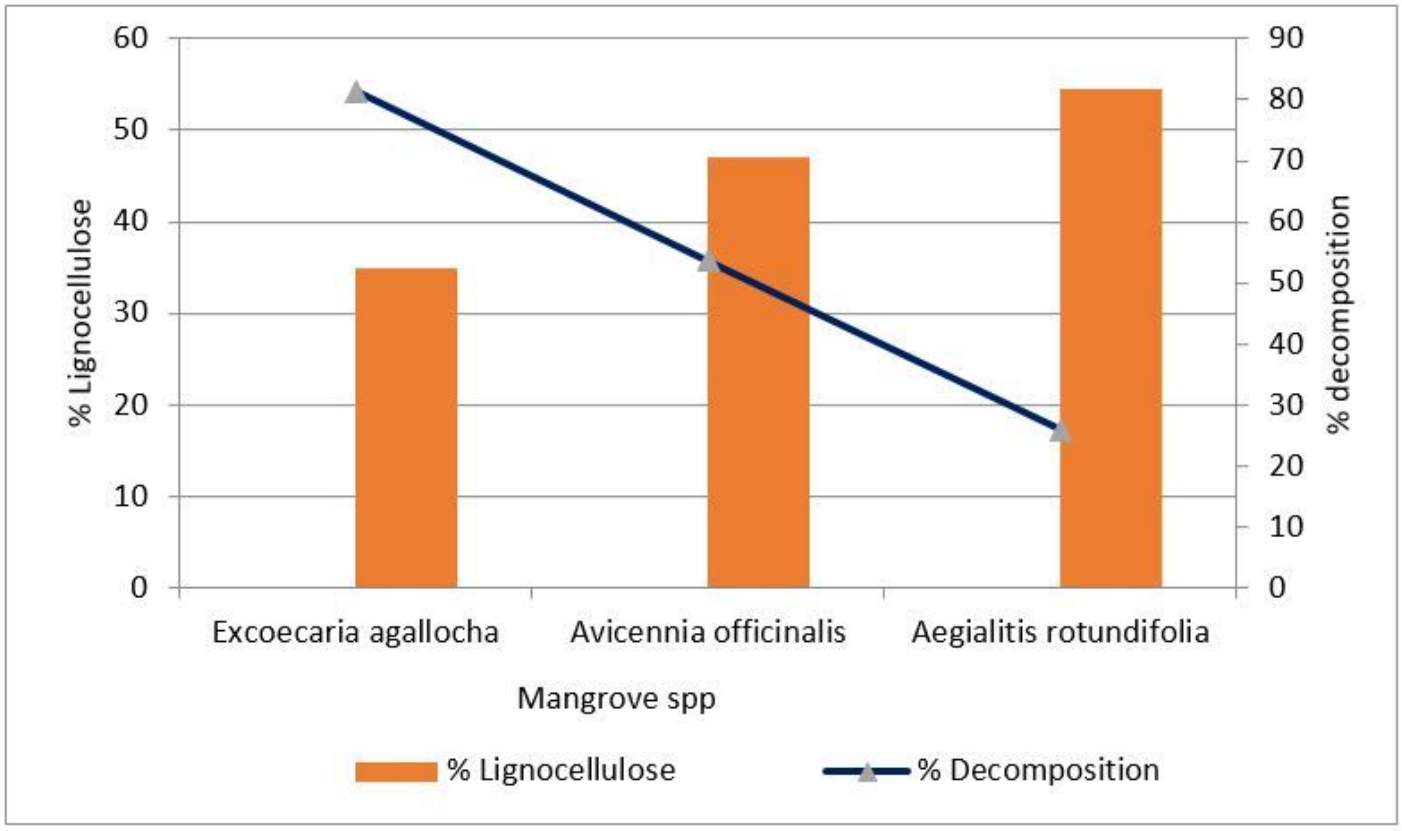


Figure 8

Relationship between lignocellulose content and decomposition percentage (after 30 days) of mangrove leaf litter under study