Litterfall production, decomposition and nutrient accumulation in Sundarbans mangrove forests, Bangladesh

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ABSTRACT
Litterfall production and litter decomposition are the principal factors for controlling the functions of mangroves to store and cycle carbon and nutrients within the ecosystem. We analyzed the litterfall production, its seasonality, patterns and changes of mass loss, carbon, and nitrogen content of litterfall decomposition in different locations as well as different position of decomposers bags in Sundarbans Reserve Forest (SRF). Total annual litterfall production was 1005.9 ± 7.0 g m⁻² yr⁻¹ and leaves being the principal contributor of all the studied location throughout the study period. During the decomposition experiment, the litterfall lost 20% of its original mass in the first 60 days, and this loss continued to 50% of its original weight by the end of the experiment (196 days). There was not significant difference in the mass loss at different positions or sites during the experiment period. Monthly mean total carbon and nitrogen mass in litterfall accounted for 344.6 ± 28.7 kg ha⁻¹ and 8.7 ± 0.7 kg ha⁻¹, respectively. The pattern for nitrogen content showed increasing trend throughout the experiment period. Mangrove communities growing along the oligohaline zone showed higher nutrient concentration than other mangrove areas indicating their ecological significance and also efficiently retain C and N.

1. Introduction
Mangrove forests are among the world’s most productive ecosystems, as well as unique wetland ecosystems in intertidal coastal regions of the tropics and subtropics (Lugo and Snedaker 1975; Nagarajan et al. 2008). Litterfall is one of the important components to be taken into account in estimating primary productivity, especially in view of its contribution to estuarine ecosystems (Bunt 1995; Woodroffe et al. 1988; Tam et al. 1998; Metcalfe et al. 2011). Mangrove litterfall consists primarily of leaves, which become available to consumers and decomposers. Mangrove plants uptake all of their essential nutrients from sediment. Carbon, nitrogen and phosphorous are the essential nutrients for mangroves and these nutrients are brought back through the litterfall and deposited on to the sediment (Alongi et al. 2003; Reef et al. 2010; Srisunont et al. 2017). Nutrients are released through decomposition of litterfall, and these nutrients are also absorbed by the trees for growth. Therefore, nutrient enrichment by litterfall does not only promote nutrient recycling in mangroves but also provides complex marine food web and house for an aquatic nursery (Srisunont et al. 2017). In tropical and subtropical coastal regions throughout the world, mangroves contribute considerable quantities of organic matter and also as sources of nutrients through leaching to adjacent water systems (Rao et al. 1994).

Quantification of litterfall and decomposition is important for assessing the productivity of a mangrove ecosystem (Lee 1999; Imgraben and Dittmann 2008). Decomposition rates of litterfall will be varied with the function of analytical methods, tidal inundation, because submergence is known to accelerate decay process (Wider and Lang 1982z; Robertson 1988; Gladstone-Gallagher et al. 2014). Whereas litterfall in buried condition (which occurs when litterfall is retained within the forest) and this creates anoxic conditions which slowed the decomposition process and that has been demonstrated in different ecosystems (Fourqurean and Schrlau 2003). To understand the differences between forest floor and burial conditions, litterfall decomposition experiment should be investigated in these two conditions.

In this respect, litter production, as well as litter decomposition study, is important for assessing productivity and function of the mangrove ecosystems. There are several kinds of research on mangrove litterfall production, decomposition, and nutrient analysis of tropical and subtropical mangrove ecosystems (e.g. Subtropical: Twilley et al. 1986; Mackey and Smal 1996; Tam et al. 1998; Mfilinge et al. 2002; Khan et al. 2007; Imgraben and Dittmann 2008; Sánchez-Andrés...
et al. 2010; Kamruzzaman et al. 2012, Gladstone-Gallagher et al. 2014, Tropical: Flores-Verdugo et al. 1987; Robertson 1988; Rao et al. 1994; Wafar et al. 1997; Ochieng and Erftemeijer 2002; Davis et al. 2003; Bosire et al. 2005; Silva et al. 2007; Srisунont et al. 2017). However, there have been no previous studies which examined litterfall production and nutrient analysis of the Sundarbans mangrove forests in Bangladesh.

Thus, the objectives of this study were to quantify the litterfall production, investigate litterfall decomposition rates and nutrient accumulation as an important indicator for Sundarbans mangrove forest ecosystems. Initial observations of different locations of the Sundarbans mangrove forests suggested that stand structure and species composition of the mangrove communities are different. Therefore, we hypothesized that, based on stand structure and litterfall production, litterfall decomposition would be different in different locations of the Sundarbans Reserve Forest (SRF). Overall, the present study provides information regarding litterfall production and nutrient recycling in the Sundarbans Reserve Forest (SRF).

2. Methods

2.1. Study area

The Sundarbans, the world’s largest continuous patch of mangrove forest, is located in the estuary of the river Ganges–Brahmaputra. The forest is distributed over two neighboring countries, Bangladesh and India. In Bangladesh, the forest covers 6017 km² (21 30’–22 30’ N, 89.00’–89 55’ E). Sundarbans mangrove forest is divided into three ecological zones viz. fresh water (oligohaline, salinity <2 dsm⁻¹), moderately saline water (mesohaline, salinity 2–4 dsm⁻¹), and salt water (polypaline, salinity >4 dsm⁻¹) zones (Chaffey et al. 1985; Siddqui 2001). Changes in salinity might be responsible for the spatial distribution of plant communities (Ahmed et al. 2011).

Our study was conducted in a mangrove community within the oligohaline zone of the Sundarbans, Bangladesh. This area receives regular tidal inundation through the River Passur. The study revealed that all locations had similar vegetation cover and inundated regularly. Six mangrove species grow at the study site: Heritiera fomes Buch-Ham., in the family Malvaceae, Excoecaria agallocha L. in Euphorbiaceae, Bruguiera sexangula (Lour.) Poir. in Rhizophoraceae, Aglaia coccilata (Roxb.) Pellegr. and Xylocarpus mekongensis J. Koenig are in Meliaceae, and Avicennia officinalis L. in Avicenniaceae. The mean densities of H. fomes, E. agallocha, X. mekongensis, B. sexangula, A. officinalis, and A. coccilata were 1248, 533, 229, 176, 110, and 24 ha⁻¹, respectively.

The mean annual rainfall in the region varies from about 2000 mm in the east to 1600 mm in the west (Rahman and Asaduzzaman 2010). The rainy season is from June to September. The period between October and February is considered winter. Higher temperature (26–34 °C) occurs between March and June, and lower temperature (12–25 °C) between December and February. The annual relative humidity varies from 70 to 80% (Rahman and Asaduzzaman 2010).

We established 21 plots (10 m × 10 m) in SRF, which are contiguously arranged at three separate locations in our study area. Therefore, the total area of the study plots was 2100 m². All the trees in the study plots larger than 1.8 cm in diameter at breast height (DBH) were numbered and height (H) and DBH were measured at March 2016 and 2017, respectively. There is no distinct species zonation within the mangrove community of the study area and apparently there is no difference in habitat condition within the three locations of the study area.

2.2. Litterfall collection

Litterfall was collected using litter traps made of 1-mm mesh cloth and having a reverse case shape, 70 cm × 70 cm × 70 cm, with the collection area of 0.42 m². They were suspended below the canopy from stems of mangroves at a height above the level of the highest tide to prevent inundation. Two litter traps were placed in each plot, i.e. a total of 42 litter traps were placed within the 21 plots. Litterfall was collected monthly from May 2016 and continued up to April 2017. The litter traps were emptied monthly; the collected litterfall was kept in a cotton bag and carried to the laboratory where it was separated into leaves, stipules, branches, flower buds, flowers, fruits, and propagules for each species. Individual litterfall components were dried at 80 °C for 48 h, desiccated at room temperature, and then weighed using a digital balance (EK-600H, A & D Co., Ltd., Tokyo, Japan).

2.3. Litterfall decomposition

Freshly fallen litter was collected from litter traps, as mangroves have nutrient resorption during senescence (Twilley et al. 1986). Once collected, litterfall components were air-dried for 48 h. The dried litterfall were thoroughly mixed so that each components had equal chance to become samples, and then 10 g dry litterfall mass was picked up randomly and placed in nylon bags (20 cm × 16 cm) made of 0.5 mm mesh. In addition, the air-dried weight of the initial 10 g sample converted to an oven dry weight (at 65 °C) in order to calculate the % mass loss through time. In order to estimate decomposition rates of the aboveground litter at different sites within the oligohaline zones of Sundarbans mangrove forests, the litterbags were placed at three different locations, such as Dhangmari, Gharamari and Karamjol areas. These three sites were randomly selected to represent the mangrove communities within the oligohaline zones of Sundarbans mangrove forests. We had the opportunity to compare three locations simultaneously, which allowed systematic randomized sites to represent the ideal characteristics of the oligohaline zone of the Sundarbans mangrove forests. Decomposition experiment was started in November 2016 and continued up to May
2017. To investigate variation in litterfall decomposition rates with the duration of submergence, two positions were differentiated at each site: forest floor and burial conditions. At each location we placed the litter-bags at two different positions, namely, forest floor and 10 cm depth in soil. Bags were placed buried condition to test the effect of burial condition on decomposition rates. To compare decomposition over different exposure time intervals and position of litter bags, each experimental location received 30 bags (2 different exposure time intervals and position of litter rates). To compare decomposition over duration of the experiment. At each time, three (3) bags were collected randomly from each experimental site at 60, 106, 117,163, and 196 days after the beginning of the experiment. After the bags were rinsed in water to remove most of the soil, they were opened and the collected samples were rinsed gently with tap water to remove any extra soil particles and placed in paper bags. Samples were dried to constant weight for 48 hours at 65 °C, weighed and then samples were prepared for nutrient analysis. All the litterfall components from each bag was ground to a fine powder and used around 30 mg of it as sample for analyzed C and N. So each component of litterfall had equal chance to become a homogeneous sample for analysis, because the C and N content will be different for different litterfall components (Enriquez et al. 1993). Total carbon and total nitrogen were measured with a CN analyzer model JM 1000 Macro Corder, J-Science Lab. Co. Ltd., Japan.

Mass loss of the litter during decomposition was compared to its initial dry weight at the various experimental sites and for different intervals.

2.4. Data analysis

Annual mass of each litterfall component was calculated by summing the monthly data of each plot. The number of replicates for litterfall was 42 (2 traps × 21 plots). Monthly litterfall data was obtained from average value of the two-litterfall traps in each plot and then also the average value of 21 plots. A two-way ANOVA was run to test significant differences among the locations and litter bag positions for mass loss, C%, N%, and C:N ratio, where response variables were mass loss, C%, N%, and C:N ratio and independent variables were locations and litter bag position. Bonferroni’s multiple comparisons were used for post hoc tests using SPSS software (v.11.5; SPSS, New York, USA).

3. Results

3.1. Litterfall production

Mean total litterfall (±SE) was 1005.9 ± 7.0 g m⁻² yr⁻¹. Young, tender, green and yellow leaves contributed the most of total litterfall. Mean leaf litterfall was 587.5 ± 4.9 g m⁻² yr⁻¹, which represents 58.4% of the total litterfall (Table 1). Mean value of the vegetative organs litterfall was 836.1 ± 6.4 g m⁻² yr⁻¹, which represents 83.1% of the total litterfall. Similarly, mean of the sum of the litterfall for reproductive organs was 169.9 ± 2.4 g m⁻² yr⁻¹, representing 16.9% of the total litterfall. Leaf litterfall was the greatest in December and May, i.e. it showed a bimodal pattern (Figure 1). Branch litterfall was always small but during a rainy season the branch litterfall constituted a large portion of monthly total litterfall. Branch litterfall was highest in June and July, i.e. during the rainy season. Reproductive organs also exhibited a multimodal pattern. The highest litterfall of the reproductive organs were observed in March, August, and November. Litterfall of mostly flowers and flower buds of H. fomes and X. mekongensis was observed in March. Mature propagules of the major species of the studied mangrove communities was included in August, while immature propagules and fruits were observed in the November (i.e. beginning of winter season).

Table 1. Annual amount of vegetative and reproductive litterfall of Sundarbans mangrove forests.

| Litterfall components | g m⁻² yr⁻¹ | Litterfall components | g m⁻² yr⁻¹ |
|-----------------------|------------|-----------------------|------------|
| Leaf                  | 587.5 ± 4.9 (58.4) | Flower bud            | 11.0 ± 0.5 (1.1) |
| Stipule               | 118.6 ± 0.5 (11.3) | Flower                | 97.6 ± 1.9 (9.7) |
| Branch                | 129.9 ± 2.4 (12.9) | Fruit                 | 9.4 ± 0.3 (0.9) |
| Sum of the vegetative organs | 836.1 ± 6.4 (83.1) | Propagule             | 51.8 ± 1.4 (5.1) |
| Total                 | 1005.9 ± 7.0 | Sum of the reproductive organs | 169.9 ± 2.4 (16.9) |

Values are represented as mean ± standard error. Numerals in parenthesis represent the percentage of the total amount.

Figure 1. Changes in the contribution of various litterfall components to total litterfall production during the study period. (C): Reproductive organs; (L): Leaf; (B): Branches.
3.2. Litterfall decomposition

The dry mass remaining in the litterfall after 196 d of decomposition was 40.1% for the forest floor condition at Dhangmari area, compared to 51.7% and 53.4% at Karamjol and Ghagramari areas, respectively (Figure 2(a)). Whereas, the dry mass remaining in the litterfall after 196 d of decomposition was 49.6% for the burial conditions at Dhangmari area, compared to 52.5% and 40.4% at Karamjol and Ghagramari areas, respectively (Figure 2(b)). During the early phase of the litterfall decomposition experiment (60 d), the rates of mass loss were much higher than that during the following phases for every location and for both litterbag conditions. There were differences in the initial rates of mass loss in the litterfall decomposition experiment between the forest floor and burial conditions. However, the mean rates of mass loss in three different locations and two different burial conditions were similar for the last phases of decomposition (Figure 2(a,b)). At the end of the decomposition experiment, forest floor and burial conditions showed mass loss rates of 51.6 ± 4.2 and 52.5 ± 3.6% of their initial dry mass, respectively. Mean rate of mass loss in dry weight over time was greater in the forest floor condition than the burial condition but these did not differ significantly (Table 2).

The time courses of carbon %, nitrogen %, and C:N ratio from litterfall decomposition showed variations both in the forest floor and buried conditions (Figure 3(a–f)). During the course of decomposition, the concentrations of C and N in the litterfall (mg g⁻¹ dry) were increased compared to the beginning of the experiment. At the initial phase of the decomposition experiment, total C remaining (%) at forest floor conditions increased rapidly in the Ghagramari area than in the other areas, then decreased at the middle of the experimental phases. However, at the end of the decomposition experiment, it again increased than other areas (Figure 3(a)). Similarly, the pattern of total C remaining (%) at buried conditions followed a pattern similar to the forest floor conditions (Figure 3(b)). However, there were no significant differences in total C remaining % (Table 2). Initially, total N remaining (%) at forest floor conditions decreased more rapidly in the Dhangmari area than in other areas but at the end of the decomposition experiment, it increased at the highest level than the other areas (Figure 3(c)). Similarly, the pattern of total N remaining (%) at burial conditions followed a pattern similar to the forest floor conditions (Figure 3(d)). However, there were no significant differences in total N loss. The C:N ratio of the litterfall decomposition experiment at forest floor showed an overall increase over the first 60 days, declined at all three locations on 106–117 days, increased again at day 163, and then finally declined on day 196. Carbon and nitrogen content in the decomposition experiment varied through time, but generally C and N increased in litter after 196 days. We are unable to detect any statistically significant differences in C:N ratios of the litterfall decomposition between forest floor and burial conditions (Two-way ANOVA p > 0.05; Table 2). Whereas, changes in the C:N ratios at burial conditions did not follow the same pattern to that at the forest floor. There were no significant differences in the mean weight loss, carbon %, nitrogen % and C:N ratio among the locations and litterbag conditions, and there were also no significant main effects nor interaction involving locations and litterbag conditions (Table 2).

Results from a nutrient analysis in litterfall reveal that carbon and nitrogen contents in the litterfall were 411.1 ± 6.6 mg C g⁻¹ and 10.4 ± 0.6 mg N g⁻¹, respectively. The monthly litterfall mass of each litter component was multiplied by the C and N content to obtain a total C and N accumulation in the forest. However, the C and N contents vary for different litter components (leaf, wood etc.; Enriquez et al. 1993). The monthly pattern of nutrient accumulation varied with
the monthly pattern of litterfall. Nutrient accumulation on the forest floor was observed throughout the year. Figure 4 shows seasonality of the carbon and nitrogen accumulation in the Sundarbans mangrove forests.

4. Discussion

4.1. Litterfall production

The mean total litterfall production (10.1 Mg ha\(^{-1}\) yr\(^{-1}\)) of the present mangrove forests was in the upper range of those reported for mangrove forests at Laguna de Términos, Mexico (Day et al. 1987), on Unguja Island, Zanzibar, Tanzania (Shunula and Whittick 1999), and at Central Java, Indonesia (Sukardjo 1996).

This study showed that maximum leaf litterfall of the mangroves was observed in summer (May) and winter (December). During the winter season (December) most of the deciduous plants withdrew their leaves so the total leaf fall in December was higher than that in other months and during the summer season (May) when almost all plants shed their older leaves and recruited new leaves due to favorable temperature and moisture for their vegetative growth. Maximum production of leaves, reproductive organs and leaf fall were in summer. This is a common characteristic for almost all mangrove species around the world because this pattern is influenced by the air temperature, sunlight, and rainfall. A bimodal pattern of leaf fall was also observed by Lee (1989), who reported that mangroves in Hong Kong had a bimodal pattern with peaks in spring and late summer. In contrast to the present study, Flores-Cardenas et al. (2016) reported that leaf litterfall of mangroves in Huizache-Caimanero Lagoon System, Mexico, showed a uni-modal pattern. The tropical climate could cause multimodal peaks of leaf litterfall in the mangroves in tropical areas. In case of branch litterfall, it was normally low but was high in the rainy season (June to September) when strong winds and storms occurred. Similar findings were observed at Mankong Wetland, Okinawa Island, Japan (Sharma et al. 2012), at Ohura Bay, Okinawa Island (Hardiwinoto et al. 1989), and mangroves along the Brisbane River, Queensland, Australia (Mackey and Smail 1995), who reported that branch litterfall was higher during typhoon months and correlated with storms. While there were no clear seasonal patterns in the litterfall of reproductive organs, it was high in some months, i.e. in March, August, and November. The studied mangrove areas are characterized by mixture of different mangrove species belonging to different families. Flowering, fruiting, and propagule dropping time may be species specific. Due to the difference in production of reproductive organs, seasonality in the litterfall of reproductive organs also varied. As a result, the study showed multiple peaks in the litterfall of reproductive organs. In contrast to the present study, May (1999) and Ochieng and Erflemeijer (2002), who reported that mangrove species have only one peak of the reproductive litterfall in a year. In the present study, each species followed a single annual peak of the production of its reproductive organs, but in case of litterfall, it was not possible to separate the reproductive organs at the species level. Reproductive organs litterfall was observed to have some peaks due to individual tree's reproductive phenophase and difference in the maturation period of reproductive organs. Our observation at the Sundarbans was similar to the findings of Coupland et al. (2005), who reported that production of reproductive organs of four mangrove species at northern Australia did not show any single peak for all the studied species. Our study was consistent with the finding of Kamruzzaman et al. (2012), who reported that none of the species showed a single peak in the production of the reproductive organs. It may be concluded that the seasonality of the vegetative and reproductive organs production is controlled by the species phenology.

Leaves constituted 58.4% of the total litterfall production, which was similar to the 61.2% and 61.0% reported for Rhizophora apiculata and R. mucronata Lamk, respectively (Wafar et al. 1997). The present value was higher than those recorded in a subtropical mangrove at Okinawa Island, Japan (mean value 54.3%; Kamruzzaman et al. 2012). The contributions of branches to total litterfall observed in the present study (13%) was lower than those recorded for other subtropical mangrove areas (less than 30% at Futian mangrove swamp, China; Tam et al. 1998). The present value was higher than the average value reported for the subtropical mangroves (4.0–15.8%) at Okinawa Island, Japan (Kamruzzaman et al. 2012). The contributions of reproductive organs to total litterfall observed in the present study (16.9%) was lower than those observed for other tropical and subtropical mangroves such as mangroves at south-west coast of India (21.8–23.2%; Wafar et al. 1997) and mangroves at Okinawa Island, Japan (23.0–40.0%; Kamruzzaman et al. 2012). Our results showed that the contribution of reproductive components of Sundarbans mangrove forests to the total litterfall was lower than mangroves growing in other tropical and subtropical areas. Coupland et al. (2006) reported that lower rate of fertilization might be due to limiting maternal resources

| Source of variation | df | Mean square | F ratio | p | Mean square | F ratio | p | Mean square | F ratio | p | Mean square | F ratio | p |
|---------------------|----|-------------|---------|---|-------------|---------|---|-------------|---------|---|-------------|---------|---|
| Location            | 2  | 27.17       | 0.15    | 0.86 | 2.06        | 0.41    | 0.67 | 0.07        | 1.08    | 0.36 | 48.75       | 0.72    | 0.50 |
| Litter bag position | 1  | 85.99       | 0.47    | 0.50 | 6.41        | 1.27    | 0.27 | 0.08        | 1.25    | 0.28 | 54.81       | 0.81    | 0.38 |
| Location & bag position | 2  | 23.24       | 0.13    | 0.88 | 10.16       | 2.00    | 0.16 | 0.05        | 0.82    | 0.45 | 15.45       | 0.23    | 0.80 |
| Error               | 24 | 184.3       | 5.06    |     |             |         |     |             |         |     |             |         |     |

Table 2. Summary of ANOVA for weight remaining, C%, N%, and C:N ratio in litterfall after 196 d of decomposition, comparing differences between location (Dhangmari, Ghagramari, and Karamjol) and litter bag positions (forest floor and burial condition).
and the lack of flower adaptation to either animal or wind pollination. The studied mangrove species are insect pollinated and depend mainly on *Apis* spp. Due to the proximity of human settlements in the study area, people have easy access to this area and they collect honey from Sundarbans by the use of smoking the honey bee, larva, and juvenile. As a result, population density of *Apis* spp. is reduced drastically. The

Figure 3. Carbon and nitrogen content, and C:N ratio of litterfall during 196 days of decomposition. (a) Carbon content at forest floor. (b) Carbon content under burial. (c) Nitrogen content at forest floor. (d) Nitrogen content under burial. (e) C:N ratio at forest floor. (f) C:N ratio under burial. (Symbol same as Figure 2).
unavailability of effective pollinators in the study area is a possibility for lower fertilization rate of flowers in the study area.

4.2. Litterfall decomposition

To our knowledge, this is the first study investigating litterfall decomposition and nutrient accumulation in Sundarbans mangrove forests. Decomposition experiment was carried out at three different locations within the oligohaline zone of the Sundarbans mangrove forest. Though there was a variation in the litter decomposition process at the forest floor and under the burial conditions, it is likely a common phenomenon found in other mangrove environments (Steinke and Ward 1988; Mall et al. 1991; Tam et al. 1998). However, the trend of the overall pattern of decomposition observed at different locations and conditions of the current study suggested that litter decomposition at different locations did not show any significant differences and had no significant interactions between locations and conditions. The litter samples in the decomposition experiment lost around 50% of its original dry weight after 196 days. This rate of original mass loss was low compared to the results of the mass loss of leaves of *Rhizophora mangle* leaves in other experiments (Silva et al. 2007), who reported that the leaves in the litter bags lost 50% of their original dry weight in 32 days. Silva et al. (2007) used only leaves, but the present litter used for the experiment contained dead leaves, twigs/branches, and reproductive organs. Wang et al. (2016) also reported that green litter decomposed faster than mixed litter. Due to the variation of structural tissues of different components used for the present decomposition experiment, the rate of mass loss was lower than the previous study. The low decomposition rates in the present study may have been due to the progressive accumulation of more recalcitrant compounds in the litter samples, such as lignin and cellulose, as decomposition progresses (Osono and Takeda 2004; Talbot and Treseder 2012; Wang et al. 2016). Our results also agree with the summarization by Gladstone-Gallagher et al. (2014), who reported that decomposition rates depended on litter type, with leaves decomposing faster (63 d to decay by 50%) than pneumatophore and wood material (316 and 460 d, respectively). It is concluded that the lower decay rates measured in this study compared to other tropical studies are likely because this study used mixed litter rather than just leaf material.

The C and N contents of the litter under decomposition increased depending on location of sample placement as well as geographical location. The carbon percentage of the litterfall increased highly in the initial phase and reached up to 46% to 49% relative to the initial C content over the 196 d period. This pattern was consistent with the findings of Davis et al. (2003), who reported that C-content of litterfall increased over the first three months of the study, but then declined, and approaching initial levels by the end of the experiment. The pattern for nitrogen percentage showed increasing trend throughout the experiment period. Total remaining nitrogen percentage increased up to 1.97% and initially, it was 1.04% of the dry weight of litterfall. This result was also consistent with the findings of Davis et al. (2003), who recorded that pattern for nitrogen % in leaves increased throughout the experiment period. Some previous studies indicated that increases in decomposition rates are also related to an enrichment of the decomposing litter by nitrogen during the decomposition process (Twilley et al. 1986; Wafar et al. 1997; Sánchez-Andrés et al. 2010). We also observed the increasing trend of nitrogen % throughout the decomposition experiment, but the rate of increase was not statistically significant. Increases or decreases in nitrogen concentrations of litterfall during decomposition are part of the nitrogen recycling capacity of the mangrove ecosystems, being considered as a within-system nutrient conservation mechanism (Vitousek 1984). The C:N ratio of litterfall was decreased due to the fact that nitrogen loss was higher than the carbon loss during the decomposition process. In Sundarbans mangrove

Figure 4. Accumulation of carbon and nitrogen in the Sundarbans mangrove forests during the study period.
forests, decomposition is continued throughout the year due to higher temperature, so nutrient accumulation will be sustained though the rate was slow in this region. Similar decreasing trend of C:N ratio had been observed in subtropical and tropical mangroves (Rich and Tenore 1981; Dick and Osunkoya 2000).

There were definite peaks in carbon and nitrogen accumulation in litterfall. The highest peak of carbon and nitrogen were in July, i.e. at the peak-growing season. The second highest peak was observed in February, because E. agallocha (second dominant species) started leaf shedding from February and X. mekongensis also shedded their leaves from December and continuing until March. Carbon concentrations for the studied mangrove forests was 411.1 ± 6.6 mg g⁻¹, which is almost identical to the values for Rhizophora apiculata leaves at tropical mangrove areas (412 mg g⁻¹; Duarte et al. 1998). The present value was lower than those recorded on carbon concentrations of leaves of other mangrove species at tropical areas (e.g. 419–486 mg g⁻¹; Alongi et al. 2002, 419–443 mg g⁻¹; Alongi et al. 2003) and subtropical areas (419–472 mg g⁻¹; Khan et al. 2007). The present study showed that the mean value of carbon % in litterfall decomposition experiment (41%) was lower than those reported for leaves in Rhizophora mangle L. in oligotrophic mangrove wetlands (48%). Whereas, the present mean value of nitrogen % (1.04%) was higher than that of the same species (0.6%; Davis et al. 2003). The monthly mean total nitrogen content in litterfall accounted for 8.7 ± 0.7 kg ha⁻¹, which may be the main source of the nutrient reservoir in the studied mangrove forests. The present nitrogen content in litterfall was closest to the higher range of 1.6–9.9 kg ha⁻¹ for the different litterfall components of Rhizophora stylosa stands along the northern coast of western Australia (Alongi et al. 2003). Due to the greater contribution of nitrogen in litterfall components, nutrient concentration on the studied mangroves was generally higher than other mangrove areas. It is known that a major portion of the litterfall of the mangroves is flushed by the tidal water and is transported by the water system of the mangrove ecosystem, then is consumed by the aquatic fishes and animals (Heald and Odum 1970; Ewink 1974).

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Disclosure statement

No potential conflict of interest was reported by the authors.

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