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Forest structure and litter production of naturally re-generated white mangrove *Avicennia marina* in sub-tropical estuarine coast

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Abstract

The present work deals with plant structure, phenology, litter production and decomposition of mangrove *Avicennia marina* in the newly re-generated mangrove forest in sub-tropical coast. The natural generation in this accreted coastal land of mono-specific *A. marina* forest stand was prominent, with 45% seedlings and 32% saplings. Peak flowering and fruiting were noticed in May and August, respectively. Reproductive components contribute countable percent into the total litter production during the peak flowering (60%) and fruiting (86%) season. The percentage of leaf litter fall fluctuated throughout the year and contributed 13-99% (73% in average) of the total litter production of 11.53 tones $ha^{-1}yr^{-1}$. The total litter production differed with season and influenced by local climate, pore water salinity and phenology of the mangrove. The naturally generated young (7 years) *A. marina* with 1.8 m height produced more leaf litter as compared to similar tree height elsewhere. Decomposition rate was related to season, with higher litter loss during rainy season which could help cycling nutrients and support estuarine food web by supplying organic matter into the sub-tropical coastal environment.

Key words

Avicennia marina, Mangrove litter, Newly re-generated forest

Introduction

Mangroves are normally characterized by high productive ecosystems in any estuarine environment. They export high amount of organic matter that supports variety of living organisms, including fishery into nearby ecosystems (Nagelkerken *et al.,* 2008). This is the result of high litter production and rapid break down of detritus (Aksornkoae, 1993). Primary productivity of mangroves varies with geographical locations, type of forest and sediment, water stress due to seasonal changes, coastal climate, fresh water flow and tidal amplitudes (Cox and Allen, 1999). Studies by Sharma *et al.* (2012) reported that litter fall is about 52.8%-67.9% of the total primary production and has significant importance on detritus based food webs in coastal environment (Hoque *et al.*, 2015). In general, quantification of true primary production of mangroves is often complex and time consuming. Nevertheless, litter fall has been broadly used as an indicator of productivity of mangrove elsewhere (Arreola-Lazarrga *et al.*, 2004).

The amount of organic matter export to aquatic ecosystem from mangroves depends on the litter decomposition rates, while decomposition rates depend on the degree and frequency of tidal inundation, climatic and edaphic factors and presence or absence of litter consuming fauna within the mangrove forest (Sharma *et al.*, 2012). Characteristically, the dynamics of litter breakdown not only varies with species but also geographically (Ashton *et al.*, 1999) and is affected by leaf composition like nutrients and lignin content (Tam *et al.*, 1998). Significant amount of nutrients and organic matter is released during the process of mangrove litter decomposition and has an important role in internal nutrient cycling (Mahmood and Saberi, 2005), tree productivity and mangrove related food chain (Ashton *et al.*, 1999).

Mangrove forests in the estuarine habitat of Bangladesh contribute significantly in nutrient input to the coastal and estuarine environment. The studies on tree structure, litter production and phenology for naturally newly re-generated mangrove forests in this region, as well as worldwide are meagre. In light of the above, the objective of the present study was to investigate reproductive biology and litter production in stands of newly re-generated (7 years old) white mangrove *Avicennia marina*.

Materials and Methods

Study area : The study area is located in the intertidal area of Bakkhali river estuary, Cox's Bazar situated in the southeastern part of Bangladesh (Fig. 1). The tides of this sampling area were semi-diurnal with two high and two low water during lunar day. The tidal range at the adjacent coastal area was strong, ranging from 0.07 m at neap tide to 4.42 m at spring tide at the Bakkhali river and climatology, directed by monsoon wind. Its bottom consists of muddy and sandy substrates (Abu Hena, 2013; Abu Hena *et al.,* 2013). The dominant mangroves species of the Bakkhali river estuary were naturally re-generated 7 year old mangroves *Avicennia marina* of inundation Class-IV; i.e., mangroves were inundated 2-20 times per month (Watson, 1928).

Observation of forest structure : Mangrove forest structure was observed along the three (3) 60-80 m transects in the inter-tidal area, set perpendicular to the estuary. Relative density and relative dominance were calculated, following Curtis and McIntosh (1951). At every ten meter interval, a quadrate of 25 m^2 (5 m x 5 m) was placed along transect. In each 25 m^2 quadrat, the total number of mangrove trees, saplings (height >1 m and diameter < 4 cm) and seedlings (height < 1 m) were counted.

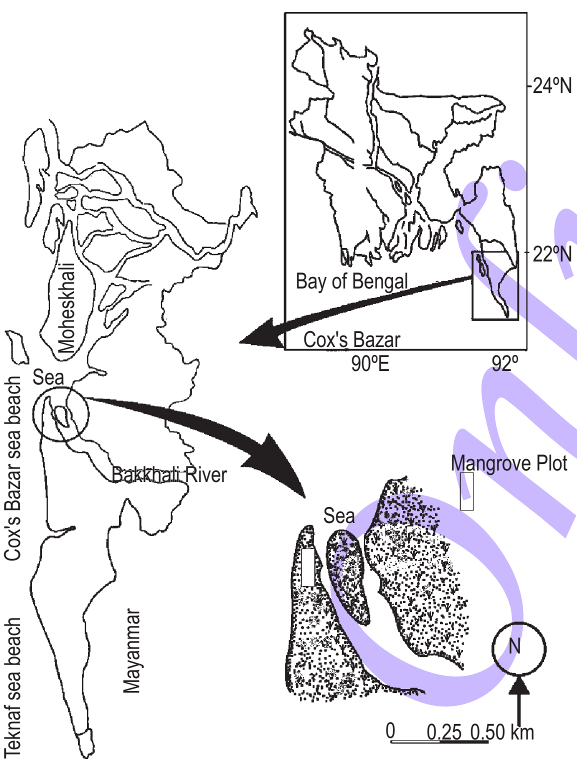

Fig. 1 : Location of the study area showing the mangrove plot for litter traps and decomposition studies in the Bakkhali estuary, Cox's Bazar, Bangladesh

Collection of mangrove litter : Ten (10) litter traps of 0.5 m^2 were hung randomly beneath the canopy in the 1 ha forest. Litter fall was collected at an interval of 2 weeks for 1 year from April 2009 to March 2010. The litter falls were sorted into leaves, flower, fruits and twigs. Leaves, flower, fruits and twigs were dried in an oven to constant weight at 80°C and recorded as dry weight in grams.

Decomposition rate of mangrove *Avicennia marina* leaf : The yellowish senescent leaves of *Avicennia marina* were collected from study area. All the leaves were oven dried (80°C till constant weight) and weighted. Five leaves with recorded weight were placed in 20 micron mesh nylon bags of 20 x 15 cm. Thirty sets of bags were prepared and the bags were prevented from folding and clumping, and placed on soil surface in the mangrove forest. The experiment was only conducted for 5 months from March to July, and three bags were collected monthly. The collected bags were brought to the laboratory for further analysis. All the samples were washed carefully and oven dried at 80°C, and weighted. The percentage of losses in initial dry weight in bags was calculated.

Soil and environmental parameters : At the forest floor, pH of wet soil was recorded *in situ* using a pH meter (soil pH tester, TAKAMURA electric works Ltd., Japan). Air temperature was recorded using a thermometer. After digging soil sample, accumulation of pore water could be observed at the basin of ditch. Once the basin of small ditch/hole was filled with water then the pore water pH and salinity in forest floor were measured *in situ* using a pen pH meter (S237734, HANA Instruments) and refractrometer (News-100, TANAKA, Japan), respectively. Rainfall data was collected from the local environmental department at Cox's Bazar.

CANOCO 4.5 version software was used for Canonical Correspondence Analysis (CCA), performing step-wise regression. Using CCA routine executed in CANOCO linking total litter production with environmental parameters (pore water pH, air temperature, pore water salinity and soil pH) for different months.

Results and Discussion

Average mangrove tree height was 1.8 m followed by 1.37 m and 0.38 m for saplings and seedlings. The diameter at breast height (DBH) for mangrove trees and saplings were 5.24 cm and 2.77 cm. Average pneumatophores height and density were 0.08 m and 4331.11 individuals 10 m^{-2}. The density of mangrove tree, sapling and seedling were 27 individuals 10 m^{-2}, 37 individuals 10 m^{-2} and 53.5 individuals 10 m^{-2}, respectively in this coastal area (Table 1).

Table 1 : Naturally generated mangrove forest structure in the intertidal area of Bakkhali estuary, Cox's Bazar, Bangladesh

Tree parameter	Tree	Sapling	Seedling	Pneumatophores
Height (m)	1.8	1.37	0.38	0.08
DBH (cm)	5.24	2.77	-	-
Density (no.10 m^{-2})	27	37	53.5	4331.11
Relative density (%)	23	32	45	-
Relative dominance (%)	65	35	-	-

DBH = Diameter at Breast height

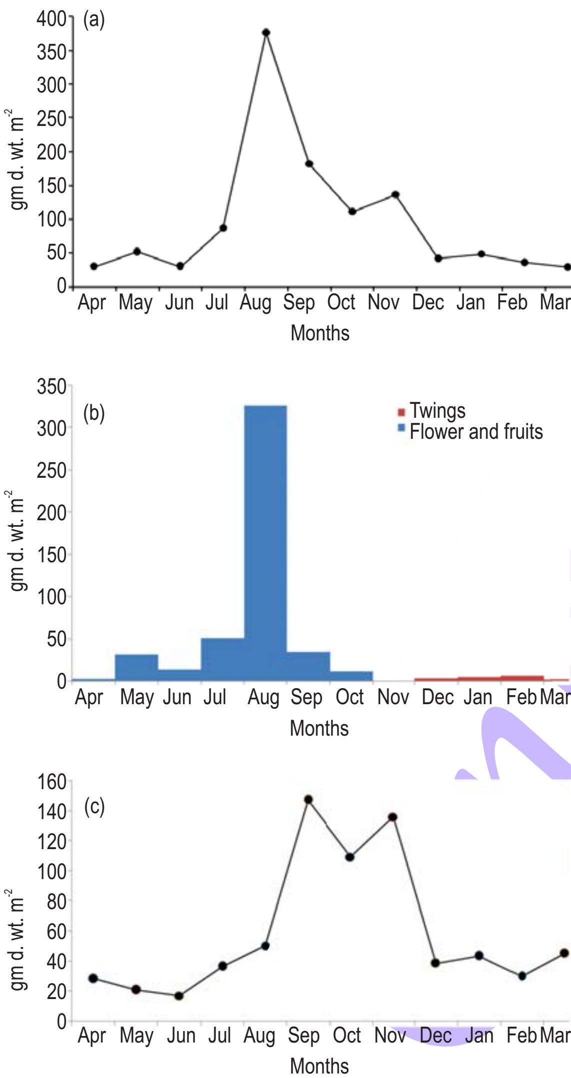

Fig. 2 : Monthly production of newly re-generated mangrove *A. marina* in the coastal area of Bakkhali, Cox's Bazar, Bangladesh (a) total litter (b) leaf litter (c) flower, fruits ans twigs

Flowering started in early April (end of spring) and continued till the middle of June (summer). The peak flowering time for *A. marina* was in May. Fruiting season for *A. marina* started at the end of June and existed till the middle of October (pre-winter).

The average total litter production and leaf litter fall was observed 96.46 gm m^{-2} $month^{-1}$ (3.16 gm m^{-2} day^{-1} and 58.49 gm m^{-2} $month^{-1}$, respectively during the study period (Fig. 2a). Higher (375.6 gm m^{-2} $month^{-1}$ amount of total litter production was recorded in August while lower (29. 27 gm m^{-2} $month^{-1}$ was observed in March. The peak of total litter production was distinct in August compared to other months, which was derived from the fallen matured fruits constituting upto 86% to the total litter production (Fig. 2a and 3c). Twigs production was higher at the end of February (winter season). The production of leaf litter was higher at the end of September to November (wet season) and lower during flowering time (Fig. 2b). Flower contributes maximum 60% to the total litter production during the peak flowering season. The calculated monthly and annual total litter production was 946.6 kg ha^{-1} $month^{-1}$ and 11.53 tones ha^{-1} $year^{-1}$ respectively.

The first axis of CCA had an eigen value of 0.145 and biplot of the first 2 CCA axes (Table 2). Pore water salinity was related to dry period, while pore water pH and soil pH were related to monsoon. Flower and fruiting of this mangrove were dependent on rainfall and air temperature. In total litter production of mangroves, the production of twigs was influenced by pore water salinity, pore water pH and soil pH (Fig. 3).

Leaf decomposing materials of *A. marina* experienced an initial wetting period, especially between weeks 8 and 12, with 172 mm and 113 mm rainfall including tidal inundation for 20 days. The percent loss of leaf materials was higher after 2 months of the experimental period. About 60% of leaf materials were lost during

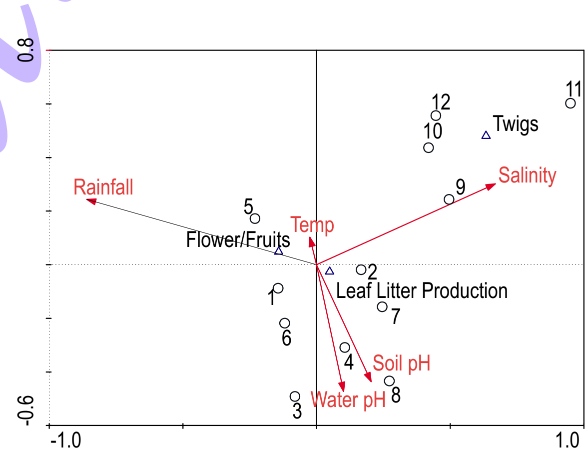

Fig. 3 : CCA showing scatter plot for total litter production vs 12 months ecological parameters at the newly generated mangrove forest at Bakkhali estuary, Cox's Bazar (1 = January to 12 = December)

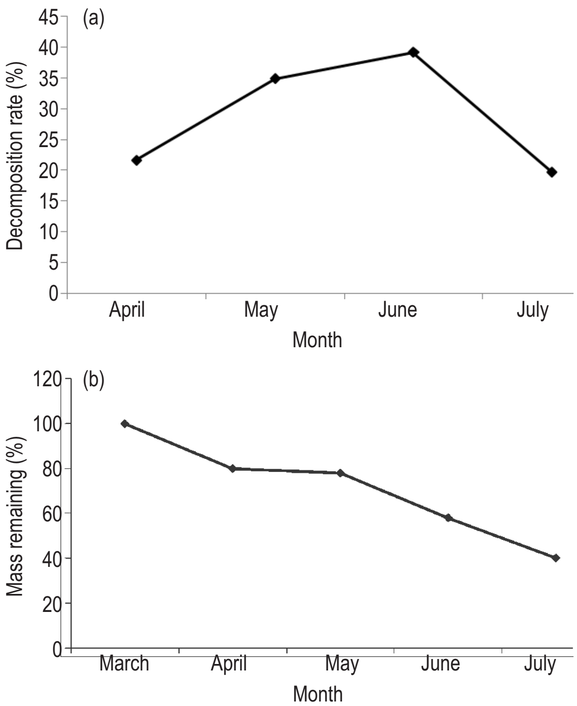

Fig. 4 : Percent decomposition rate (a) and precent dry mass (b) remaining during decomposition of mangrove forest of Bakkhali, Cox's Bazar, Bangladesh of young *A. marina* leaves during the study period

the 3rd month (Fig. 4b). The percentage of dry weight lost from *A. marina* was positively correlated with temperature during the sampling period (r^2 = 0.214, P > 0.05), and it was also influenced by rainfall. The mean temperature during that time was 33.50 to 34.80°C. Usually, between week 1 to week 7, still in the summer period, dry weather with no rain and maximum temperature was recorded 37.40°C. The leaves degraded rapidly during 8-12 weeks with loss of more than half of their weight. There after, the decomposition rate was slow (Fig. 4a).

The natural growth and re-generation of mangrove were relatively prominent with 45% of seedlings and 32% of saplings in this mono-specific *A. marina* forest stand. This appearance to be common in other sub-tropical mangrove coasts in India and Pakistan (Farooqui *et al*., 2012). Contrastingly, the natural generation, survival and growth of mixed mangrove forest ecosystems in tropical climate may be low due to inter-species competition for space and growth (Aldrie Amir, 2012). This could be probably due to forest structure and species composition bearing silt roots like *Rhizophora* species and knee roots like *Bruguiera* species within the forest ecosystems (Personnel observation based on Kuala Selangor natural mangrove forest, Malaysia and Sibuti wild life sanctuary, Sarawak). Besides, some ecological factors and dense forest canopy which prevent sun light penetration into the forest floor affecting seedlings photosynthesis; pneumatophores of mature *A. marina* in the forest floor may hinder seedlings from establishing in same forest ecosystems.

The flowering and fruiting season of *A. marina* in this coastal environment is similar to that of Pakistan (Faooqui *et al*., 2012), which probably be due to similar trends in climatic factors in this sub-tropical coast that induced this synchronous fruiting during May to August. However, in the tropical coasts, peak flowering and fruiting was recorded for *Avicennia* species in August and September (Shamsul *et al.*, 2005). The fruits fall was same for *A. marina* and occurred during July to September in Thailand . In tropical climate, mangrove species produced small amount of fruits all the year around (Azian *et al*., 2014), and with all the year round rainfall, constant temperature may govern the phenology of mangroves in tropical, and probably also in sub-tropical mangroves.

Leaf litter contributes 13-99% to total litter production in this area. This value is comparable with mangrove forests in South Africa and Pakistan (Farooqui *et al*., 2012). Total litter production in the present study area was influenced by seasons (dry and wet), pore water salinity and phenology of the mangrove. The estimated annual total litter production was 11.53 tones ha^{-1} $year^{-1}$ in this mangrove forest which was higher than the values found for same mangroves elsewhere. Numerous studies indicated that litter production of mangroves could vary in different regions due to mangrove biomass, variation of time, canopy height/gap, density, geographical differences, production of fruits, climate and soil nutrients (Farooqui *et al*., 2012).

Litter production of the present study was comparable with litter production for the same genus and other mangrove species in other areas elsewhere (Siddiqui and Shafique, 2000; Dehairs *et al*., 2000; Farooqui *et al*., 2012). However, litter production was higher for *Sonneratia alba* (17 tones ha^{-1} $year^{-1}$) for Indian mangroves. Twilley and Day (1999) reported that generally, litter production of mangroves was within 2 to 16 tones ha^{-1} $year^{-1}$ worldwide and suggested that height and growth of mangroves are major controlling factors in total litter production. Comparing this data with the present study, where naturally re-generated young *A. marina* height was 1.8 m more litter fall (11.53 tones $ha^{-1}year^{-1}$) was produced on the contrary than the expected in respect to tree height. This suggests that was litter production was higher in the fast growing naturally re-generated mangrove forest (7 years) stands in sub-tropical coast when all other environmental factors and tree species were taking into consideration. Total litter production for mature *A. marina* was calculated to be 4.0-4.7 tones ha^{-1} $year^{-1}$ in Pakistan (Farooqui *et al*., 2012) as compared with the average of 11.53 tones $ha^{-1}year^{-1}$ observed for the naturally re-generated mangroves in sub-tropical coast line.

Decomposition is an important stage in mangrove forest for nutrient cycling which occurrs through physical forces and

Table 2 : Summary of the biplot of the first 2 CCA axes: Eigen values, species-environmental correlations and percentage variance for mangroves litter production at Bakkhali estuary; weighted correlation coefficient between environmental variables and CCA axes

	Axes	
	1	2
Eigen values	0.145	0.043
Species-environment correlations	0.864	0.822
Cumulative percentage variance		
of species data	56.2	72.9
of species-environment relation	77.1	100.0
Correlation coefficient		
Pore Water pH	0.087	-0.388
Salinity	0.578	0.248
Air Temperature	-0.021	0.084
Soil pH	0.176	-0.359
Rainfall	-0.743	0.200

grazing action of macro and micro-fauna that utilizes energy sources and fragment the mangrove litter (Rashvand and Sadeghi, 2014). Decomposition of *A. marina* leaves showed to be a 2-step practice, with an initial fast leaching of water-soluble compounds and slower discharge of plant materials afterward, which is in agreement with the findings reported for the same species in New Zealand coasts. The same was reported from other parts of the worlds and was found that weight loss of mangroves litter was rapid during the initial period. In Thailand, rapid weight loss of *A. marina* leaves was recorded within 20 days. Usually, microorganisms start litter decomposition the beginning as leaves fall. The fungi, specially *Aspergillus*, *Alternaria*, *Penicillium*, *Fusarium*, *Drechslera*, *Rhizopus* and *Mucor* were the most significant initial stages of decomposer and initial litter invaders in the mangrove forest (Tariq *et al*., 2008; Nazim *et al*., 2013). Studies have reported that amphipods can also be useful mediator for decomposition of leaves at 6 weeks and play a significant role in breakdown of leaves (Mahmood and Saberi, 2005) along with leaching of more soluble leaf components.

Decomposition of mangrove leaves in the present study was related to temperature and rainfall. Leaf litter loss was higher when there was rain as compared to dry season in the present study. This was also known to occur in West Africa and New Zealand (Mahmood and Saberi, 2005). In contrast, leaves decomposition process was more active in summer than winter when considering decomposition performance for temperate countries. Studies also suggested that the rate of decomposition in mangrove forest ecosystems was related to tidal inundation and distance of tidal creeks (Mahmood *et al.,* 2014). Probably in areas with large tidal inundation rate, most of the litter produced might be exported from the forest floor; however, where tidal range was 2-20 times, a proportion of litters could accumulate into the systems and degrade *in situ* that might help in nutrient cycling and supply of organic matter to the estuarine food web in the sub-tropical coastal environment.

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