Indian Journal of Marine Sciences
Vol. 31(2), June 2002, pp. 130-135

Decomposition and seasonal changes in nutrient constituents in mangrove litter of Sundarbans mangrove, Bangladesh

M. Enamul Hoq, M. L. Islam, H. K. Paul & S. U. Ahmed
Bangladesh Fisheries Research Institute, Mymensingh 2201, Bangladesh
and
M. N. Islam
Department of Fisheries Technology, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh

Received 18 June 2001, revised 6 March 2002

Decomposition of *Heritiera fomes, Xylocarpus mekungensis, Bruguiera gymnorhiza* and *Avicennia officinalis* leaf and non-leaf litter was studied using litter bag in Sundarbans reserve forest. During 45 days decomposition experiment both in field and lab, 43-78% weight loss of fresh mass was recorded. Proximate and micro-nutrient concentrations were similar among different classes of leaf and non-leaf litter. Concentrations of nutrient constituents were higher during the monsoon, and winter showed the highest level of heavy metal concentrations in mangrove litter of Sundarbans. Decomposition of mangrove litter resulted in a decrease in lipid content, and increased the metal concentrations, than fresh one.

[**Key words** : Mangrove litter, decomposition, nutrients, Sundarbans]

Mangroves are very productive coastal ecosystems and the production through litter fall becomes available to the surrounding waters. A large proportion of the leaf litter is retained within the mangroves, physically by the aerial root masses, hydrodynamically by a lateral-trapping effect, and biologically by crab grazing. This establishes a key detritus-based food chain within mangroves and the immediate inshore waters. The degrading leaf-litter forms a high-protein material that is consumed by a wide variety of organisms and releases nutrients to the mangrove ecosystem for recycling as well. Chemical and organic constituents of leaf litter of different species of mangroves was reported earlier[1-3], although reports on these components for litter from mixed mangrove communities are limited[4], in spite of their significance in determining mangrove productivity.

World wide management of mangroves has generally resulted in monoculture stands of *Rhizophora* spp.[5] Since leaf degradation plays a key role in ecosystem function, species richness of leaf litter may be important in determining the species diversity of mangrove ecosystems. In the present study decomposition of mangrove litter, seasonal effect on nutrient constituents of multispecies leaf and non-leaf litter were assessed in Sundarbans mangrove ecosystem.

Materials and Methods

The study was conducted in the Sundarbans mangrove forest- a tropical moist forest with an area of one million hectares, located between 21°30′N and 22°30′N, and 80°E and 89°55′E, on the south-west coast of Bangladesh. The area under study is located at Paikgacha Thana in Khulna- a south-western district of Bangladesh, between 89°25′E and 22°25′-22°30′N, and is a polyhaline zone (1-18 ppt). Unlike most mangrove forests of the world, the Sundarbans is not dominated by members of the family Rhizophoraceae. The forest vegetation of the area comprises of sundri (*Heritiera fomes* Buch.-Ham.-Sterculiaceae), passur (*Xylocarpus mekungensis* Meliaceae) and kankra (*Bruguiera gymnorhiza* Lamk-Rhizophoraceae) with scattered baen (*Avicennia officinalis*-L. Avicenniaceae). The Sibsa River is the largest coastal river in Sundarbans and the sampling area is about 30 km upstream of Bay of Bengal.

The Sundarbans is a deltaic swamp and the climate is generally humid. The predominant feature of the climate in the Sundarbans, as that of Bangladesh as a whole, is the southeast monsoon which effectively divides the year into four distinct seasons- premonsoon (March to May); monsoon (June to August); postmonsoon (September to November) and winter

(December to February/March). The Sundarbans receives large volumes of freshwater from inland rivers flowing from the north and of saline water from the tidal incursion from the Bay of Bengal. The relative contribution from the two sources of water are not constant throughout the year.

The leaf litter was either collected from the mangrove floor or from the river during high tide using a long-arm scoop net. Litter or leaves were then sorted into 5 classes on the basis of leaf development- young (greenish in color), senescent or mature (yellowish), old decayed leaves, fruits and flowers including twigs, and combination of all those-mixed. The litter was then air dried for 24 hours and weighed. Litter bags (200 mm × 250 mm size) were made of high strength nylon with 2 mm mesh size. Leaves or litter materials were cut to pieces of about 10 mm^2 and 50 g of each group was placed in litter bag in flat position to prevent from folding and clumping. Fifteen litter bags (3 for each group) were securely placed on the river bank at high and low tidal levels in such a position that the bags lay flat on the sediment and were flooded by normal spring tides. These bags were removed after 45 days and in the laboratory they were gently washed in a sieve (mesh size 250 μ) to remove sediment. The resulting litter was air dried for 24 h and weighed.

In situ litter materials were also allowed to decompose in the laboratory using fiber glass tanks. Air dried pre-weighed leaves/litter from each group stated above were placed in triplicate in fiber glass tanks. The tanks were then filled with river water (salinity 16 % and temp. 29°C) transported from the experimental site and at least 6 hours/day aeration was provided to each tank through air pumps. The lab trial also continued for 45 days. The experiment commenced in April-May, the premonsoon season, towards the end of leaf fall period in Sundarbans.

Surface water temperature and salinity were measured using an Alkaline Thermometer and a Salinity Refractometer (ATAGO S/Mill-E), respectively. The *p*H of the water was measured using a portable *p*H meter (pH Scan-2, sensitivity 0.1±0.02), which was calibrated with *p*H buffer, 4.0 and 7.0 before every use. Dissolved oxygen was measured using a HACH kit (FF-2). Sediment samples (the top 3 cm) from the study area were collected using an Ekman grab and analyzed for *p*H, organic carbon[6] and available nutrients- N[7] and P, K, Ca, Mg, Na and Fe[8] using an atomic absorption spectrophotometer (Perkin-Elmer 2380). Proximate composition of the litter materials was determined following the methods of the AOAC[9]. Nutrient composition was determined from predigested samples, using an atomic absorption spectrophotometer following the modified method of Cresser & Parson[10]. Statistical analysis was performed using a PC software package- STATGRAPHICS.

Results

Water and soil properties—Figure 1 shows monthly mean salinity, temperature, dissolved oxygen and *p*H values of mangrove water. In the river, the highest salinity was observed during May. Salinity was then gradually reduced by the rainy season to August, and approximately constant salinity was recorded from August to November. After November water salinity gradually increased. The highest water temperature of 30.6°C was recorded in June and the lowest 20.4°C in January. Dissolved oxygen content was highest (7.1 mg/l) in August and lowest (4.9 mg/l) in May. The *p*H of water was neutral to alkaline (7.4-8.1) throughout the study period. In the laboratory, water salinity was initially 16 ppt, which increased to 25 ppt in the 45 days of the decomposition trial. Water temperature was about 29°C, DO ranged between 4.9-7.2 mg/l and *p*H 8 to 9.7.

The *p*H of the mangrove sediment was consistently above 8. The organic carbon ranged between 1.22-1.51 g/100g. Total nitrogen were 0.11-0.13 g/100 g, phosphorus varied from 2.61 to 11.3 μg/l and was high in postmonsoon season. Potassium values ranged from 0.1 to 0.3 m.eq/100 g, Ca 15 m.eq/100 g, Mg 3.6-6 m.eq/100 g, Na in the sediments was high in the premonsoon and dry winter seasons between 0.38-1.71 m.eq/100 g.

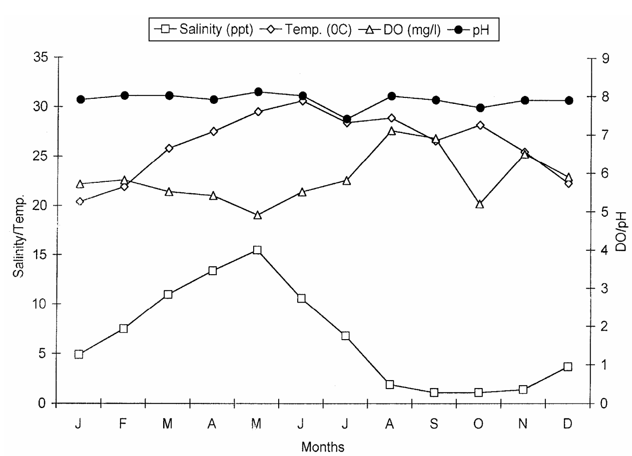

Fig. 1—Monthly water quality parameters in Sundarbans

Table 1 — Loss of weight during decomposition of different classes of mangrove litter in Sundarbans

Leaf litter classes	Weight loss (%)	Decomposition rate
Field trial		
Young (greenish)	77.7^{a}	Full
Mature (yellowish)	45.0^{c}	Partial
Old decayed	62.2^{b}	Full
Fruits, flowers and twigs	50.42^{c}	Partial
Mixed	77.72^{a}	Full
Lab. trial		
Young (greenish)	75.4^{a}	Full
Mature (yellowish)	51.95^{b}	Partial
Old decayed	56.6^{b}	Full
Fruits, flowers and twigs	43.0^{c}	Partial
Mixed	44.6^{c}	Partial

Figures in the same column with same superscript letter did not differ significantly at 5% level.

Litter decomposition — The weight loss of different classes of leaf and non-leaf litter varied from 43 to 78%, as partial decomposition occurred in some cases, and the decomposition rate was found to be slower for non-leaf litter (Table 1). The decomposition rate was treated as partial depending on weight loss (i.e. 43 to 52%) for mature leaves, fruits/flowers/twigs etc. from both field and lab trials, mixed from lab trial, and fully decomposed for the rest of the litter classes (weight loss 57 to 78%). The decomposition rate was high in young leaves of both field and lab trials. Although old decayed leaves in the lab trial fully decomposed, the rate of decomposition was less than field trial. Analysis of variance (ANOVA) showed that decomposition rates were not significantly different between field and lab trials ($F = 0.86$), but significant ($P < 0.05$) differences were observed between different classes of litter materials ($F = 2.32$).

Chemical constituents — The chemical constituents of mangrove litter in different seasons are presented

Table 2 — Proximate composition, micro-nutrients and heavy metals in mangrove litter of Sundarbans [Premonsoon (March to May); Monsoon (June to August); Postmonsoon (September to November); Winter (December to February)]

Litter class /Season	Proximate composition (g/100g dry weight)				Micro-nutrient (g/100g)						Heavy metal (μg/g)	
	Protein	Lipid	Ash	Moisture	N	P	K	Ca	Mg	Na	Cu	Zn
Young												
Premonsoon	7.59	11.00	10.15	62.86	0.48	0.0057	0.86	0.7	0.49	1.2	17.3	60.5
Monsoon	10.00	11.33	7.16	65.92	0.58	0.0037	0.66	0.7	0.82	2.5	11.9	47.2
Postmonsoon	11.85	9.65	14.00	60.42	0.8	0.0123	0.54	0.9	0.56	1.6	27.8	52.9
Winter	7.56	12.49	14.52	68.6	0.53	0.014	1.18	0.5	0.6	2.3	44.5	72.1
Mature												
Premonsoon	4.23	16.81	10.81	59.31	0.29	0.0037	0.26	0.8	0.6	1.7	18.5	42.5
Monsoon	8.14	12.68	7.11	62.18	0.52	0.0014	0.38	0.8	0.6	2.4	24.4	41.9
Postmonsoon	9.28	11.63	16.96	60.78	0.62	0.0046	0.09	0.8	0.42	1.4	23.4	45.1
Winter	3.52	11.91	17.86	64.22	0.21	0.0046	0.24	1.1	0.69	1.7	32.7	53.2
Old												
Premonsoon	6.11	10.33	13.8	66.3	0.35	0.0022	0.4	0.6	0.58	1.4	8.7	48.8
Monsoon	8.42	12.26	7.81	66.97	0.47	0.0029	0.35	0.8	0.78	2.3	20.7	61.6
Postmonsoon	13.76	10.35	14.63	60.76	0.92	0.0057	0.28	0.8	0.35	0.4	10.4	50.7
Winter	5.85	14.95	11.42	65.15	0.35	0.0072	0.39	0.8	0.61	0.6	33.4	76.6
Non-leaf												
Premonsoon	7.24	8.03	10.18	70.73	0.36	0.0063	0.4	0.7	0.53	1.9	19.1	39.1
Monsoon	5.31	10.1	5.7	69.13	0.28	0.01	0.64	0.8	0.59	2.3	30.1	50.0
Postmonsoon	13.73	4.49	13.82	65.26	0.81	0.01	0.58	0.4	0.31	0.9	23.3	46.6
Winter	5.76	13.43	12.0	64.92	0.34	0.0092	0.61	0.5	0.38	1.4	50.4	65.7
Mixed												
Premonsoon	6.64	7.24	10.81	65.04	0.39	0.0037	0.42	0.8	0.57	1.4	12.5	40.0
Monsoon	10.89	8.72	7.09	62.62	0.69	0.0129	0.67	0.6	0.49	2.4	16.9	50.6
Postmonsoon	13.45	9.47	13.87	61.35	0.88	0.0075	0.35	0.6	0.34	0.9	21.6	60.0
Winter	5.00	10.57	14.45	62.35	0.32	0.0057	0.7	0.8	0.61	1.9	39.4	63.5

in Table 2. Protein percentage was generally high in the postmonsoon season and low in the premonsoon and winter. Lipid was high in winter and low in the premonsoon and postmonsoon seasons with the exception of mature leaves. Protein was more in young leaves, whereas lipid was more in mature leaves as compared to other litter classes. Ash content was generally high in the postmonsoon and winter seasons. The concentration of micro-nutrients in different classes of leaf litter and non-leaf litter was relatively constant and did not change with the season, with few exceptions. The nitrogen content varied from 0.21 to 0.88 g/100 g. Mangrove litter showed very low concentration of phosphorus; potassium conc. ranged from 0.09 to 1.18; calcium 0.4 to 1.1 and magnesium 0.31 to 0.82 g/100 g. Sodium concentration was comparatively high ranging from 0.4 to 2.5 g/100 g.

Heavy metal concentration in mangrove litter varies with the season and also among different classes of litter. Comparatively Cu and Zn concentrations were more in winter and less in the premonsoon period. Cu content was more in non-leaf litter, whereas both young and old leaves contained more Zn.

Table 3 shows the effects of season and litter class on micro-nutrient and heavy metal concentrations in mangrove litter of Sundarbans. The micro-nutrients like N, Na, Cu and Zn have significant relation between different seasons and only K has relation between different classes of leaf and non-leaf litter.

Protein and lipid percentages in decomposed litter were lower than in fresh litter (Table 4). Ash content was higher in decomposed litter than in fresh litter. Calcium, Mg and Na concentrations were higher in range in lab trials for decomposed litter, although heavy metal concentrations were higher in litter in the field experiment. On the other hand, N and Cu have significant relation between different classes of leaf and non-leaf litter of two decomposition trials (Table 3).

Discussion

The hydrology of the Sundarbans mangrove forest is regulated mainly by high rainfall during the monsoon and by tidal inundation. Using salinity as the basis for ecological zonation, Sibsa river basin is located in freshwater zone of the Sundarbans. A salinity regime of 10.6 to 15.5 ppt was recorded from March to June. Lower salinity of 1.9 to 0.4 ppt was recorded in August to November. Litter decomposition was recorded as being higher in brackishwater than freshwater[11] or in seawater[12]. Moreover, decomposition is facilitated in low salinity and aerobic conditions[13].

The micro-nutrients like N, P, K and organic C in the mangrove sediment of present study were lower than other mangrove habitats in southeast Asia[2,3]. The seasonal variations of element composition of Sundarbans mangrove sediments were generally not

Table 3 — ANOVA of effects of micro-nutrient and heavy metal concentrations in mangrove litter and in decomposed litter of Sundarbans

Nutrients	Source of Variation	Mangrove litter			Decomposed litter		
		SS	MS	*F*	SS	MS	*F*
N	Between seasons/ habitat	1.58	0.5	15.11*	0.00	0.00	0.96
	Between classes	0.35	0.09	2.50	0.21	0.05	12.35*
P	Between seasons/ habitat	4.87	1.62	1.85	1.66	1.66	3.44
	Between classes	9.94	2.48	2.82	5.39	1.35	2.79
K	Between seasons/ habitat	0.18	0.06	2.99	0.07	0.07	2.46
	Between classes	0.75	0.19	9.52*	0.06	0.01	0.53
Ca	Between seasons/ habitat	0.01	0.00	0.07	0.05	0.05	1.34
	Between classes	0.16	0.04	1.54	0.09	0.02	0.64
Mg	Between seasons/ habitat	0.18	0.06	6.62	0.15	0.15	3.53
	Between classes	0.07	0.02	1.99	0.05	0.01	0.29
Na	Between seasons/ habitat	4.63	1.54	11.43*	6.4	6.4	59.53
	Between classes	1.24	0.31	2.29	0.39	0.11	0.90
Cu	Between seasons/ habitat	1763.47	587.82	20.56*	725.9	725.9	54.97
	Between classes	326.07	81.52	2.85	335.81	83.95	6.36*
Zn	Between seasons/ habitat	1159.06	386.35	9.91*	285.16	285.16	3.37
	Between classes	512.36	128.09	3.29	769.85	192.46	2.27

[d.f= degrees of freedom, SS= sums of squares, MS= SS/d.f, F= MS Group/MS within group] * = P<0.05

Table 4 — Proximate composition, micro-nutrient and heavy metal in decomposed mangrove litter

Litter class / Season	Proximate composition (g/100g dry weight)				Micro-nutrient (g/100g)						Heavy metal (μg/g)	
	Protein	Lipid	Ash	Moisture	N	P	K	Ca	Mg	Na	Cu	Zn
Field												
Young	14.0	6.89	17.7	58.93	0.74	0.0086	0.75	0.7	1.19	0.6	51.0	86.6
Mature	4.61	6.72	18.02	65.31	0.27	0.0077	0.37	1.1	1.04	0.7	34.0	64.2
Old	4.05	6.61	17.9	62.96	0.26	0.0097	0.28	0.9	0.78	0.5	39.6	71.4
Non-leaf	7.59	4.41	18.84	64.17	0.46	0.0089	0.41	1.2	0.72	0.6	45.5	66.3
Mixed	8.7	3.98	18.43	64.84	0.52	0.0014	0.51	0.8	1.01	0.5	44.1	72.0
Laboratory												
Young	10.03	4.47	12.29	65.51	0.59	0.014	0.31	1.1	1.17	1.4	29.2	76.2
Mature	6.47	5.55	12.83	71.7	0.31	0.0086	0.28	1.2	1.18	2.3	13.7	70.8
Old	5.52	4.96	13.11	67.73	0.3	0.0083	0.46	1.2	1.17	2.3	29.0	67.4
Non-leaf	6.6	4.76	11.73	69.98	0.34	0.0109	0.24	0.9	1.4	2.5	33.1	48.0
Mixed	9.35	6.6	14.02	68.33	0.5	0.0074	0.21	1.0	1.04	2.4	24.0	44.7

significant[14]. There are both physical and biological factors associated with decaying mangrove litter but biological factors seem to be more important than physical factors. At the end of the decomposition trial, sediment and benthic fauna in litter bags were minimal due to flushing or tidal action. This suggests less interaction between litter materials and meiofauna. The export of organic material to the estuarine and offshore environment is an important function of mangrove ecosystems[15].

Although there have been a number of studies on mangrove litter decomposition elsewhere[4,16-18], litter decomposition studies of *Heritiera fomes* and *Xylocarpus mekungensis* species have not been reported. Although decomposition of these two species along with other was done, comparison with other litter bag studies on submerged mangrove leaves in the tropics reveals that the mean number of days (40 days) taken for a 50% reduction in weight for *Rhizophora* sp.[16] is similar to present study. Decomposition rate of mangrove litter in the present study is also comparable with the study of Boonruang[12], Woodroffe[19] and Ong *et al.*[20] although most of the studies were conducted using single species.

In the lab trial, non-leaf materials and mixed litter were partially decomposed with 43-47 % weight loss. In contrast, mature leaves in the field trial were also partially decomposed with 45 % weight loss. Mall *et al.*[13] showed that litter decomposition rates and soil respiration rates were higher in mixed species litter than monogeneric species litter, although a high diversity of leaf species has no effect on the rate of decomposition of mangrove litter[4].

Protein was more in active or young leaves, declines in mature leaves and increases in decaying or old leaves[21]. Similar trend was observed in the present study in litter classes and also for seasons. Litter decomposition did not show any significant increase in protein concentration, although lipid level significantly decreased. More ash content was found in decomposed litter from field experiment. The seasonal variations of litter element composition were generally insignificant except heavy metals. N and K content of litter materials from the present study are similar to those of mangroves in Thailand, whereas the P and Na content are in higher level in mangroves of Thailand[22], but Ca and Mg are higher in Sundarbans. Among heavy metal, copper level in mangrove leaves of Sundarbans was higher than *Aegiceras corniculatum* and *Kandelia candel* dominated mangrove of Futian, but similar in Zn level[2]. Cu content in the present study was higher especially in winter in both leaf and non-leaf litter. In contrast, the Cu level in decomposed litter was much higher than in fresh litter. However, Cu, Zn and Mn concentrations in plant materials were in the range of 15-25, 15-100 and 50-1000 μg/g, respectively[23] and as water and sediment samples were not monitored for any heavy metal rather nutrients[14], it is difficult to assess whether the plants in Sundarbans had been contaminated. More information will be needed on how functional attributes of species combine in diverse communities in understanding mangrove ecosystem processes.

Acknowledgement

The funding from World Bank financed ARMP (Agricultural Research Management Project-FRI part) is greatly acknowledged.

References

1 Basak U C, Das A B & Das P, Seasonal changes in organic constituents in leaves of nine mangrove species, *Mar. Freshwater Res*., 49 (1998) 369-372.

2 Tam N F Y, Li S H, Lan C Y, Chen C Z, Li M S & Wong Y S, Nutrients and heavy metal contamination of plants and sediments in Futian mangrove forest, *Hydrobiologia*, 295 (1995) 149-158.

3 Jagtap T G, Seasonal distribution of organic matter in mangrove environment of Goa, *Indian J. Mar. Sci.*, 16 (1987) 103-106.

4 Ashton E C, Hogarth P J & Ormond R, Breakdown of mangrove leaf litter in a managed mangrove forest in Peninsular Malaysia. *Hydrobiologia*, 413 (1999) 77-88.

5 Gong W K & Ong J E, The use of demographic studies in mangrove silviculture, *Hydrobiologia*, 295 (1995) 255-261.

6 Jackson M L, *Soil chemical analysis*, (Prentice-Hall India Pvt Ltd., New Delhi) 1973, pp. 498.

7 Nelson D W & Sommers L E, Total nitrogen analysis of soil and plant tissue, *Anal. Chem.*, 63 (1980) 770-778.

8 Hons F M, Larsson-Vollmer L A & Locke M A, NH_4OAc-EDTA-extractable phosphorous as a soil test procedure, *Soil Sci.*, 149 (1990) 249-256.

9 AOAC, *Official methods of analysis*, 13th ed. (Association of Official Analytical Chemists, Washington, DC) 1980, pp. 1094.

10 Cresser M S & Parson J W, Sulphuric-Perchloric acid digestion of plant material for the determination of N, P, K, Ca and Mg, *Anal. Chem. Acta*, 109 (1979) 431-436.

11 Herald E J, *The production of organic detritus in a South Florida estuary*, Technical Bull No. 6 (University of Miami Sea Grant, Miami, USA) 1971, pp.110.

12 Boonruang P, The degradation rates of mangrove leaves of *Rhizophora apiculata* (Bl.) and *Avicennia marina* (Forsk Vierh.) at Phuket Island, Thailand. *Phuket Mar. Biol. Cent. Res. Bull.* No. 26, (1978) 1-7.

13 Mall L P, Singh V P & Garge A, Study of biomass, litterfall, litter decomposition and soil respiration in monogeneric and mixed mangrove forests of Andaman Islands, *Trop. Ecol.*, 32 (1991) 144-152.

14 Hoq M E, Ahmed S U, Islam M L, Kawser M R, Islam M N & Wahab MA, Water and soil profile of mangrove and non-mangrove habitats in relation to shrimp farming on the Sundarbans, south-west Bangladesh, *J. Aqua. Tropic.*, 16 (2001) 411-426.

15 Lugo A E & Snedaker S C, The ecology of mangroves, *Ann. Rev. Ecol. Syst.*, 5 (1974) 39-64.

16 Robertson A I, Decomposition of mangrove leaf litter in tropical Australia, *J. Exp. Mar. Biol. Ecol*., 116 **(**1988) 235-247.

17 Mackey A P & Smail G, The decomposition of mangrove litter in a subtropical mangrove forest, *Hydrobiologia*, 332 **(**1996) 93-98.

18 Sumitra-Vijayaraghavan, Ramadhas V, Kumari L K & Royan J P, Biochemical changes and energy content of the mangrove, *Rhizophora mucronata*, leaves during decomposition, *Indian J. Mar. Sci.*, 9 (1980) 120-123.

19 Woodroffe C D, Litter production and decomposition in the New Zealand mangrove *Avicennia marina* var. *resinifera*, *NZ J. Mar. Freshw. Res*., 16 (1982) 179-188.

20 Ong J E, Gong W K & Wong C H, Ecological survey of the Sungei Merbok estuarine mangrove ecosystem, *Bull. Bio. Sci*. (Univ. Sains Malaysia, Penang, Malaysia) 1980, pp. 111.

21 Untawale A G, Bhosle N B, Dhargalkar V K, Matondkar S G P & Bukhari S, Biochemical changes in mangrove foliage during growth and decomposition, *Indian J. Mar. Sci*., 6 (1977) 104-106.

22 Aksornkoae S & Khemnark C, Nutrient cycling in mangrove forest of Thailand, *Proc. As. Symp. Mangr. Env. Res. & Manag*, (1984) 545-557.

23 Allen S E, Grimshaw H M, Parkinson J A & Quarmby C, *Chemical analysis of ecological materials*, (Blackwell Sci. Publ., Oxford) 1974, pp.126.