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THE FATE OF MANGROVE LITTER IN A MANGROVE FOREST ON KO YAO YAI, SOUTHERN THAILAND

By Hansa Chansang and Sombat Poovachiranon
Phuket Marine Biological Center, P.O.Box 60, Phuket 83000, Thailand

ABSTRACT

Leaf fall, litter decomposition and accumulation within the forest, and export were studied in a mangrove forest on an island in the Andaman Sea for a 2-month period. Frequency of tidal inundation played a significant role in the process of decomposition and accumulation at various localities within the forest. Export of litter and suspended particles were studied over complete cycles at spring and neap tides. Most of the export occurred during ebbing spring tides. Tides are thus an important factor controlling the fate of mangrove litter within the forest, and in terms of exporting mangrove production into the coastal waters of the Andaman Sea.

INTRODUCTION

There have been studies about the importance of mangrove litter to the estuarine food chain (Odum, 1971; Heald, 1971). It has been generally accepted that there are several factors which control mangrove productivity and contribution to their estuaries (Pool *et al.*, 1975). Twilley (1985) demonstrated that due to differences in tidal amplitudes, the export of mangrove litter varied among different forests in south Florida. Woodroffe (1985) detected a certain amount of litter recycling within the mangrove forest at Tuff Creater in New Zealand. Boto and Bunt (1981) assumed that most of the litter was exported from a mangrove forest on Hinchinbrook Island, Australia. Such information points to the importance of the tides in the decomposition, mineralization, and export of mangrove litter and calls for site specific studies of the dynamic processes characterizing each mangrove ecosystem for a better understanding of the role of mangrove litter in estuarine food chain. The objective of this study is to understand the fate of mangrove litter in a mangrove forest in the Andaman Sea including the factors which influence this process.

MATERIALS AND METHODS

Study site

This study was conducted during May-July 1983 in the mangrove forest at Yao Yai Island in the Andaman Sea (98° 35'E, 7° 55'N). The forest structure has previously been described by Chansang (1984a). The climate of the area is under monsoonal influences. There are 2 dominant seasons i.e., a rainy season when the Southwest Monsoon predominates (May-October) and a dry season when the Northeast Monsoon prevails (November-April). The mean annual precipitation is about 2,200 mm and the mean temperature 27.9°C. The tide is semi-diurnal and corresponds with the tide of Phuket Island which is located about 20 km west of the study site. The tidal range is about 2 m during spring tide but approaches 3 m during extreme spring tides.

The total area of mangrove forest is about 250 ha with an equal area of intertidal flats infront. It receives a freshwater input from an upland area which surrounds 3 sides of the forest. The seaward front is bordered by a sand bar with 2 tidal channels. The main channel which receives the drainage from about 3/4 of the forest area connects with a small canal from the upland area. The forest can be said to be under marine influence. Forest soil salinity is 31‰ and in the channel salinity is about 32‰, equal to the sea water salinity throughout the whole length of the channel at flood tide, and decreasing to 25‰ at the inner part during the ebb tide. The sediment is sandy mud with no accumulation of peat.

The mangrove was arbritarily divided into 2 zones corresponding to that described by MacNae (1968). *Rhizophora apiculata* and 3 other undergrowth species occupy the main part of the forest which is termed the *Rhizophora apiculata - Ceriops tagal* community. Further inland the dominant species are *Xylocarpus granatum* and *Rhizophora apiculata* designated the *Xylocarpus granatum* community. Figure 1 shows the relationship between each mangrove community and extent of tidal inundation. The *R. apiculata - C. tagal* community is generally flooded by all high tides. In this study, sites A, B, C were located within the *R. apiculata - X. granatum* community at different inundation levels, while site D was located in the *X. granatum* community which was flooded only by tidal levels higher than MHWN (Figure 2).

Methods

At each site (A, B, C & D) 10 x 1 m^2 litter traps with a 1.2 cm^2 nylon mesh were hung beneath trees at a height of 1.3 m above the ground in an area of about 100 m^2. The traps were collected at 10 day intervals or as indicated and the contents were separated into leaves of different species, twigs, fruits, and other reproductive parts. They were oven-dried at 105°C to constant weight.

For a litter accumulation study, 25 x 1 m^2 were cleared of litter at each site. The sample plots were marked by placing sticks at the 4 corners of each plot. Ground litter samples were treated in the same manner as litter collected from the traps. Sand and mud were removed before oven-drying. After 61 days, the same sampling plots were cleared to collect all litter in the plots and treated in the same manner.

The litter decomposition study was conducted using yellow and ready to fall leaves of *R. apiculata*. Each leaf was divided into halves. One half was kept for dry weight estimates and the other used in weight loss experiments. Twenty grams of half leaf samples was placed in a 10 x 20 cm bag with a mesh size of 1.2 cm. At sites A and D, twenty five bags were tied to mangrove roots on the forest floor. Five bags were collected after every 10 days during the first month and at 15 day intervals during the second month. The samples were rinsed and dried to constant weight at 105°C for dry weight estimates.

The litter export study was carried out by collecting floating material using a mesh size 1.2 cm placed across 1/3 of the width of the entrance to the main channel. Ten minute samples were taken at 2 hour intervals over each cycle during neap and spring tides. Samples were sorted out as leaves of various species, fruits, twigs and other miscellaneous parts. They were incubated at 105°C to constant dry weight. For suspended particulate matter, 1 l surface water samples were taken at 2 hour intervals over each cycle during neap and spring tides. The water was filtered through GFC precombusted filter paper. Samples were dried at 105°C and weighed for total suspended solids, then combusted at 550°C for 2 hrs for estimation of organic matter.

RESULTS

Litter fall

Table 1 shows the amount of litter fall during June-August 1983 at sites A, B, C and D. The amount varied considerably at each site and among different sites. Total litter fall ranged from 0.82 to 3.61 $g/m^2/day$ with an average of 1.83 ± 0.73 $g/m^2/day$. Leaves were the major

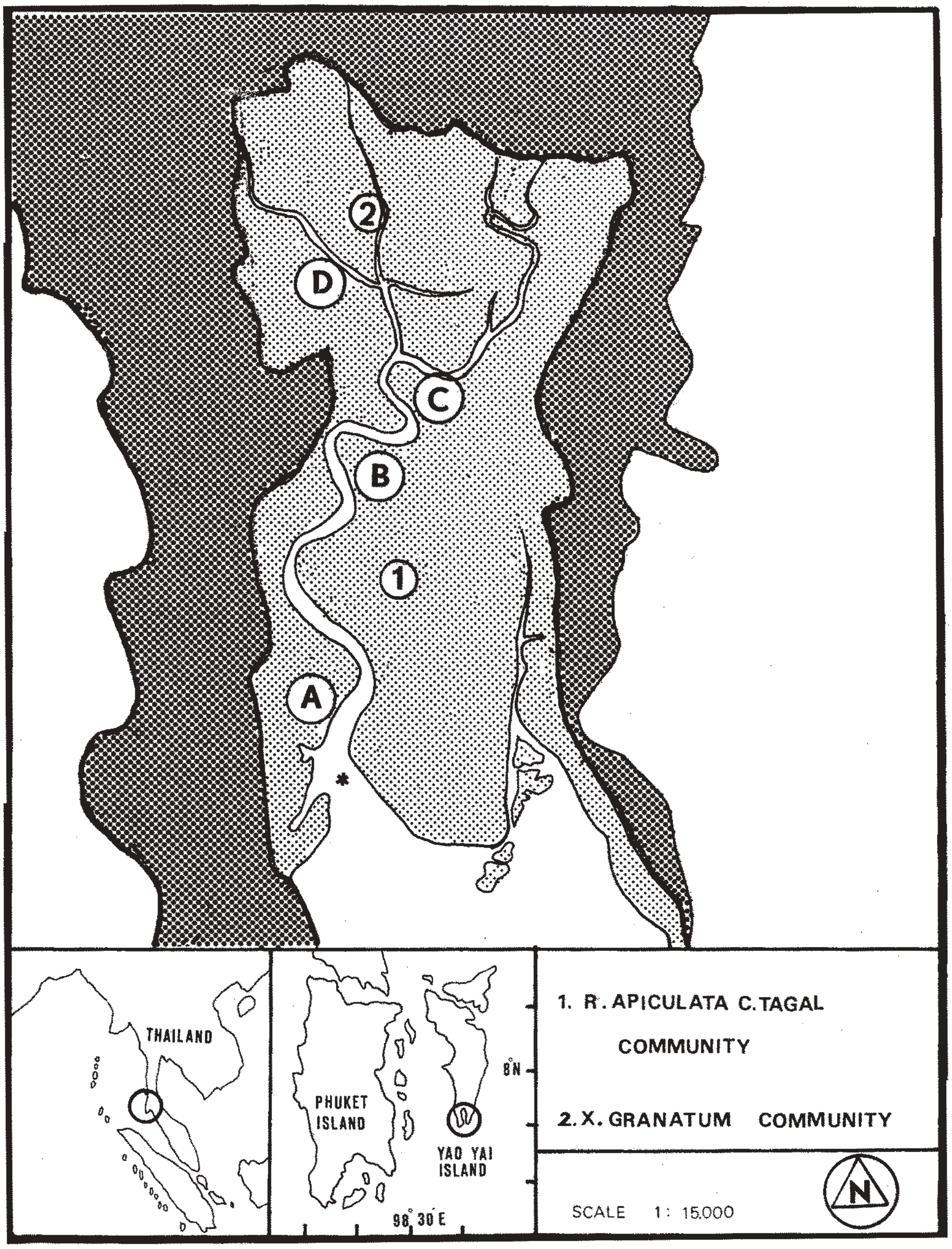

Figure 1 The mangrove forest on Yao Yai Island. Sites A, B, C and D are the locations of sampling sites.
* Location of sampling site for litter export.

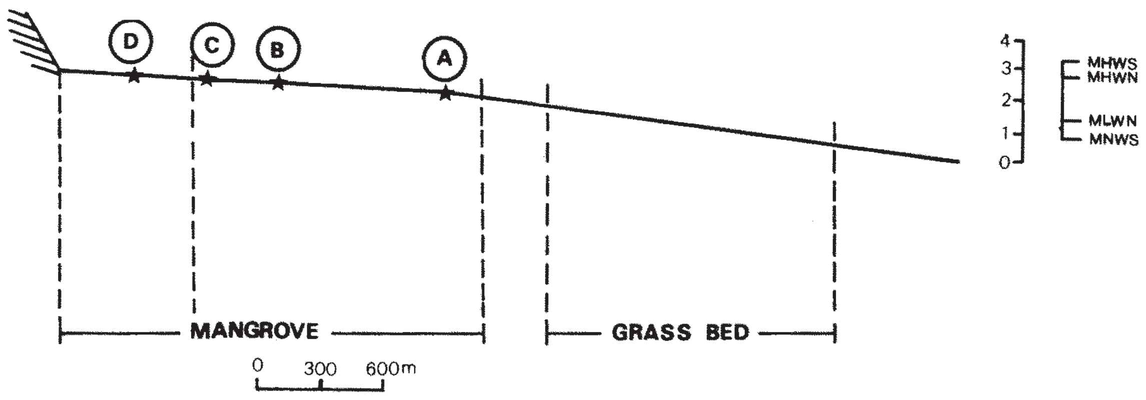

Figure 2 Shore profile though the mangrove community and adjacent sea grass bed in relation to tidal range. Sites A, B, C and D are locations of sampling sites.

Site	Total litter $g\ m^{-2}d^{-1}$	Leaf		Twig		Miscellaneous	
		$g\ m^{-2}d^{-1}$	% of total	$g\ m^{-2}d^{-1}$	% of total	$g\ m^{-2}d^{-1}$	% of total
A	1.91±1.29	1.39±0.86	72.7	0.11±0.18	5.6	0.41±0.42	21.7
B	1.59±1.67	1.27±1.10	82.3	0.15±0.24	7.6	0.17±0.37	10.1
C	1.60±1.41	1.33±1.41	81.4	0.12±0.22	9.0	0.15±0.35	9.6
D	1.98±1.98	1.18±1.98	59.3	0.28±0.95	14.1	0.53±0.72	26.6

Table 1 The amount of litter fall at different sites in the mangrove forest on Ko Yao Yai during June-August 1983. Values show both the amount of litter in different components and the percentage of each component to the total value.

component of the litter. Leaf litter ranged from 59.3% of total litter at site D to 82.3% at site B .On average, 76% of the total was leaf litter, while fruit and the miscellaneous fraction constituted 15.3% and 8.7% was twigs. *R. apiculata* leaves dominated the leaf litter fraction especially at site A-C (85-96%) but constituted only 65% of the leaf litter at site D. *R. apiculata* fruits also conferred a significant weight to the litter, especially at sites A and D (21% and 25% respectively).

Site	% of species composition of the leaf litter						
	Rhizophora apiculata	R.mucronata	Avicennia marina	Ceriops tagal	Xylocarpus granatum	Brugiera spp.	Lumnitzera littorea
A	98.7	-	-	1.3	-	-	-
B	90.5	-	-	0.3	1.6	5.2	2.5
C	86.9	-	-	7.3	-	5.8	-
D	65.0	2.6	19.9	4.5	4.2	3.9	0.3

Table 2 The percentage species composition of the leaf litter at different locations in the mangrove forest on Ko Yao Yai during June-August 1983.

Site	Total $g\ m^{-2}$	Leaf		Twig		Miscellaneous	
		$g\ m^{-2}$	% of total	$g\ m^{-2}$	% of total	$g\ m^{-2}$	% of total
Initial litter accumulation (g/m^2)							
A	48.13	20.70±11.28	43.00	23.99±29.26	46.90	3.52±7.30	7.30
B	81.87	27.47±19.81	33.60	28.10±25.20	34.30	26.32±37.60	32.00
C	115.84	27.38±22.38	23.60	57.76±63.53	49.90	20.14±24.41	17.38
D	30.98	9.20±9.11	29.70	17.73±24.90	57.00	4.05±9.04	13.10
Litter accumulation after 61 days ($g\ m^{-2}$)							
A	22.42	17.11±11.12	76.30	2.17±4.34	9.70	3.14±4.14	14.00
B	16.25	11.58±11.83	71.30	1.97±4.62	12.10	2.70±6.54	16.60
C	19.76	16.71±11.37	84.60	1.17±2.64	5.90	1.88±3.75	9.50
D	15.13	3.13±2.85	20.70	5.90±8.47	39.00	6.10±17.90	40.30

Table 3 Litter accumulation of the forest floor at different sites. The values are obtained from 25 x 1 m^2 samples. Values show both the amount of litter in different components and the percentage of each component to the total value.

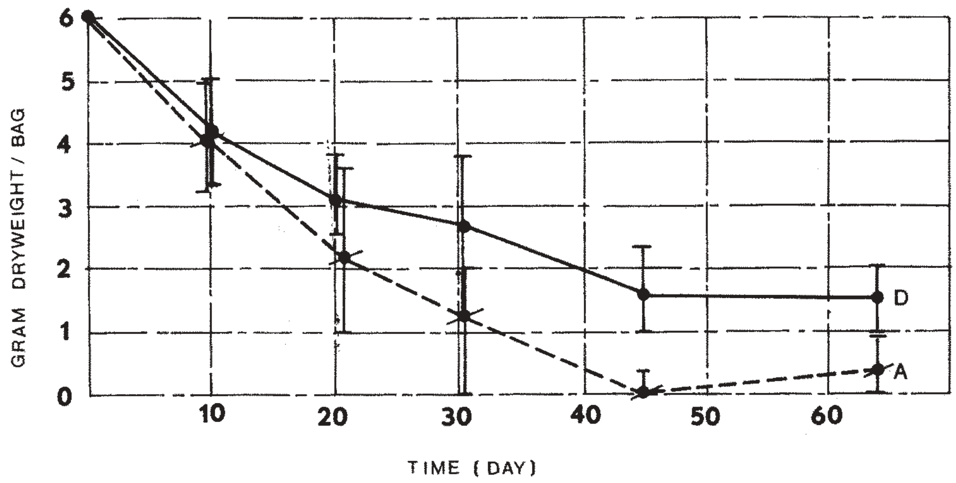

Figure 3 Decomposition of *R. apiculata* leaf litter at site A -------------- and site D ————————

Table 2 shows the percentage species composition of the leaf litter. *R. apiculata* leaves dominated at all sites and were most numerous at site A. Further inland, leaves of other species were found in litter traps and the number of species found was highest at site D which comprised various mangrove species including *Avicennia marina* (Chansang, 1984a)

Litter accumulation

Table 3 shows the litter accumulation data on the forest floor from 25 x 1 m^2 plots sampled at each site at the beginning of the study and after 61 days. The variation in accumulated litter among the sites was large. With the exception of site D, the total accumulation increased from site A to C.

Highest accumulation occurred at site C while site D registered the lowest values. Of considerable interest is the amount of leaf litter remaining on the forest floor. Site D, less frequently inundated by the tide, had the lowest leaf litter and lowest total accumulated litter. Leaf accumulation was lower at site A than at B and C. In contrast to the data obtained for litter fall, leaves constituted only 23.6 to 43% of the total litter on the floor. Twigs were the main component on the forest floor and comprised 57% of the litter at site D and 34.32% at site B. At sites A and C twigs comprised 49.6% and 49.9% of the accumulated litter. The fruit component ranged from 7.3% at site A to 32% at site B.

The amount of litter accumulated after 61 days of initial clearing at the 4 sites was lower than initially. With the exception of site D, the proportions of the various components of the accumulated litter collected after 61 days matched the litter fall rather than the initial standing crop of litter. The leaf component ranged from 71.3% at site B to 76.3% and 84.6% at sites A and C respectively. At site D, however, the leaf component was only 20.7% which was slightly lower than the standing crop compositon (29.7% of the total litter).

Decomposition of leaf litter

Figure 3 shows the results of weight loss from the litter bag experiment at sites A and D. One-third of weight loss occured within 10 days at both sites. Subsequently, weight loss was faster at site A. After 45 days, the leaf litter had totally degraded at site A while 25% still remained at site D, decreasing slightly further after 64 days. Leaf litter thus decomposed faster at site A than at site D.

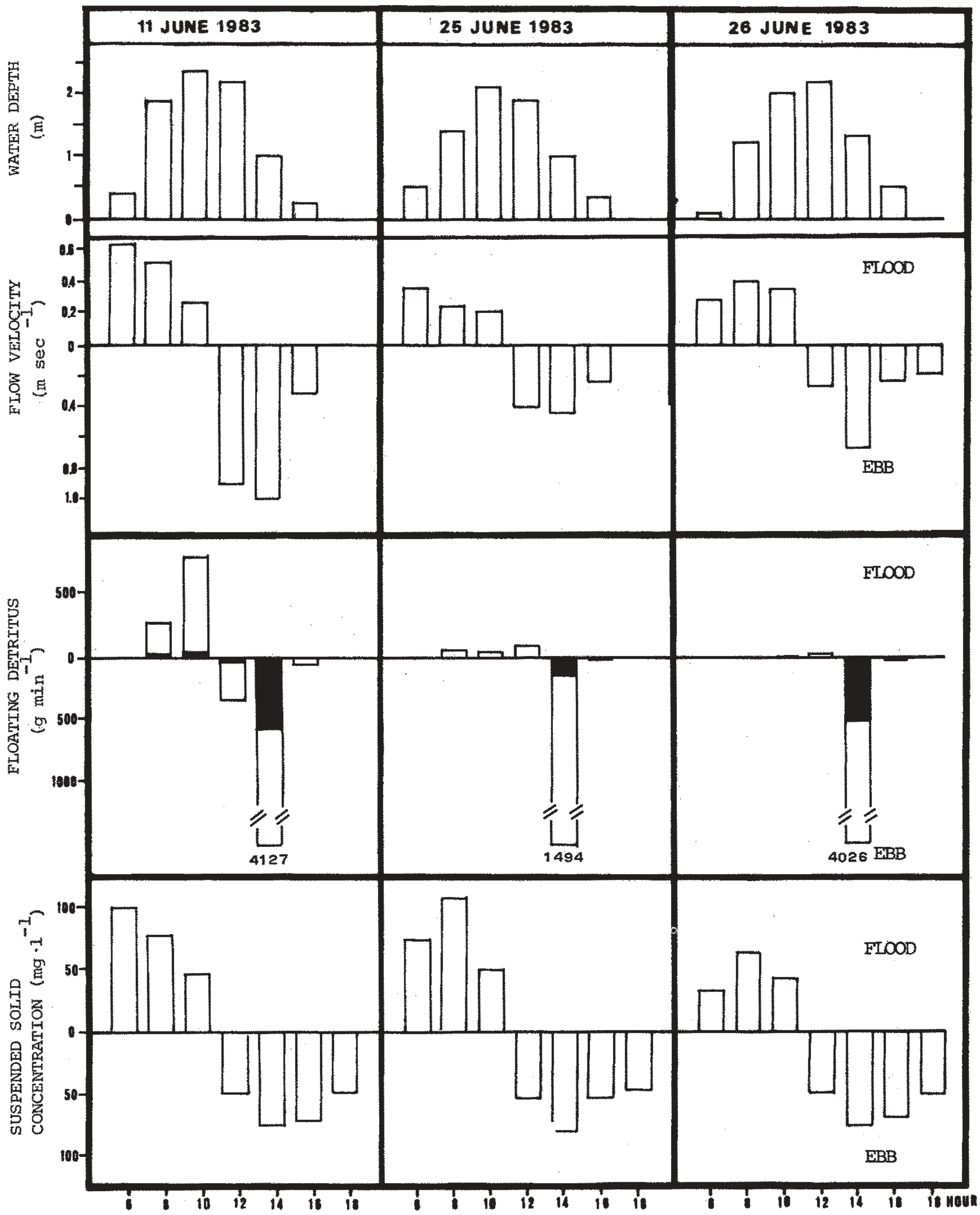

Figure 4 The process of litter transport at the entrance of the main channel over 3 spring tidal cycles.

■ Leaf litter component.

Litter export

Figures 4 and 5 show the results of litter export during spring and neap tides. Most of the floating detritus was exported during the ebb flow of spring tides. The maximum export occurred during the first 2 hours of ebb flow when velocities reached a maximum. The export values varied according to the stages of the tide and flow velocities. From 3 cycles of spring tides, the maximum values of export rates varied from 1.5 kg/min to 4.1 kg/min. Twigs were the main component and leaf litter comprised between 9.3% to 14.4% of the total macrodetrital export. During neap tide, the volumes of water moving in and out of the tidal channel were significantly less as shown in terms of the depth of water at the entrance to the channel. Similarly, velocity was reduced. This, in turn, affected the movement of detrital particles both floating and suspended. Significantly less floating detritus was exported during neap tide. In addition, some was transported back into the channel during the flood tide. On average, the ratio of litter exported to litter returned during a neap tide was 1.5:1 as compared to the ratio during a spring tide which ranged from 3.5:1-437:1. Thus very little floating detritus was transported from the mangroves during neap tides and leaf litter constituted 11-39.2% of the total litter.

Transport of litter in the form of suspended solids was also studied. Higher concentrations of suspended solids were transported in and out of the mangrove channel during spring tides. The mean concentration at flood tide of 3 spring tidal cycles was 66.1$\pm$23.0 mg/l and 57.4$\pm$ 13.1 mg/l at ebb tide. However these values are not statistically different at $P < 0.05$ (LSD Test). During neap tides, the mean suspended solids concentrations at ebb and flood stages were 30.2$\pm$9.9 and 33.1$\pm$5.4 mg/l respectively. These values are also not statistically different. The lower concentrations of suspended solids at neap tide as compared with spring tide may reflect the intensity of tidal movement (i.e., a larger flood area and higher flow velocity which keeps the particulates in suspension.

The concentration of organic matter and inorganic matter in suspension varied significantly from one tidal cycle to the next. Over each cycle of neap tide, the concentrations of organic matter during ebb and flood were the same. The ratio of organic matter to total suspended solid was about 1:4.5.

DISCUSSION

Litter fall

The litter fall recorded from Ko Yao Yai forest during the 2 months of study is comparable to that recorded from a Phuket Island forest but lower than that recorded from other sites within SE Asia. In a Phuket Island forest, Christensen (1978), using a marking technique, recorded a value of 1.83 g/m^2/day from a small mangrove forest in the same vicinity with considerably lower tree density, basal area and tree height.

Significantly less litter fall has been recorded from Ko Yao Yai forest (which is an undisturbed mature forest: maximum tree height > 30 meters) than from forests of smaller tree size within the same region. Aksornkoae and Khemnark (1984) reported a litter fall of 2.55 gm dry wt/m^2/day from a mixed mangrove forest on the east coast of the Gulf of Thailand. Cng *et al.* (1980) reported a litter fall of 3.18 g/m^2/day from a mixed mangrove forest in Kedah, Malaysia. Sasekumar and Loi (1983) reported a total litter fall of 4.32 g dry wt/m^2/day in a *Rhizophora* forest in Selangor, Malaysia. This value is higher than the highest value of total litter fall reported in this study. Gong *et al.* (1984) reported that the litter production of *Rhizophora* in virgin forest was less than that of different age stands in a mangrove plantation at Matang. They interpreted this as the result of lower tree density in a virgin forest. The mature forest of this study has a still lower litter fall (1.83 gm/m^2/day) than that of Matang forest (2.09 gm/m^2/day).

In comparison with other regions, the litter fall value is within the range reported from south Florida, i.e., 0.84-1.78 gm dry wt/m^2/day (Lugo and Snedaker, 1975; Pool *et al.*, 1975; Teas, 1974; Heald, 1971) and that reported from Australia (1.14-1.31 gm/m^2.day) (Duke *et al.*, 1981).

Litter fall at different sites on Ko Yao Yai reflects differences in dominance by different tree species. *R. mucronata,* for example, is a dominant species, whose leaves were not recorded from the litter as it predominantly occurs along the channel banks especially at site A (Chansang, 1984a).

Decomposition

The initial leaf weight loss due to decomposition during the first 10 days was about the same at all sites. This early phase is generally attributed to leaching (Heald, 1971; Camillier and Ribi, 1986). Due to the experimental design which excluded macrofaunal activity in the degradation of leaf litter, the differences in weight loss among sites A and D is attributed mainly to the difference in frequency of tidal inundation. This emphasizes the importance of inundation frequency in the decomposition processes of intertidal wetlands. It has also been found that *Rhizophora* leaves decomposed faster in mangrove forests than when left totally submerged in coastal waters (Poovachiranon and Chansang, 1982). Twilley *et al.* (1986) also attributed higher decomposition rates in wetter environments Florida mangrove forests to tidal inundation.

As discussed by Chansang (1984b), the quantity of leaf litter used and the experimental design affects the results obtained from weight loss studies. By comparing, however, the results of experiments conducted in similar ways, it can be seen that decomposition occurs faster in this forest than in the *Rhizophora* forests of South Florida (Lugo and Snedaker, 1975; Twilley *et al.*, 1986) and in the *Avicennia* forests of New South Wales, Australia (Goulter and Allaway, 1979) and New Zealand (Woodroffe, 1985). Decomposition appears to occur faster in the tropics than in temperate waters.

Litter accumulation

Twigs dominated the litter standing crop at all sites (Table 2). Fruits and flowers of *Rhizophora* dominated higher areas possibly due to seasonal factors as suggested by Ong *et al.* (1980). Interestingly the amount of litter accumulated at site D was less than at other sites both in terms of standing crop and accumulation after 61 days. Considering that of the four sites, site D was least frequently flooded, decreasing the chance of removal by the tide, and lowering the decomposition rate as shown in Figure 3, one would expect a higher standing crop of litter. In addition, site D standing crop litter contained a higher percentage of twigs (57%) than other sites (49%-34%). Recent investigations indicate the role of certain macrofauna in the assimilation of litter (Malley, 1978; Leh and Sasekumar, 1985; Poovachiranon *et al.*, 1986; Robertson, 1986). Sesarmid crabs which are commonly abundant in the landward zone of this region have been found to be important utilizers of mangrove litter (Malley, 1978). Leh and Sasekumar (1985) estimated that sesarmid crabs in the inner zone of the mangrove forest in Selangor, Malaysia consumed about 20-30% of the total litter. In this study, the density of a sesarmid *(Chiromanthes* spp.) was 4/m^2 at site D in comparison to 0.4 /m^2 at site A (Nateewathana and Tantickhdok, 1984). Poovachiranon (unpublished data) estimated that a *Chiromanthes* sp. consumed up to 15% of its body weight in leaf litter daily. Amphipods are also important mangrove detritivores. It was found that the amphipod, *Parhyale hawaiensis* consumed up to 170% of its body weight daily (Poovachiranon *et al.*, 1986). Due to their much larger size, however, the sesarmid crabs are more effective in degrading mangrove leaf litter, especially in the landward zone area. This observation is also confirmed by Robertson and Daniel (1989). In addition, it was also observed that intact leaves were incorporated into the sediment at sites B, C and D by *Thalassina anomala.*

As litter accumulation after 61 days was still less than the standing crop, an obviously longer period of accumulation than this is needed to reach a steady state. This also explain why the percentage composition of the litter was similar to that of the litter fall rather than the accumulated litter. While fruits may eventually germinate either at the same location or be removed by the tide and leaves are degraded rapidly, only the refractive component, i.e., twigs are left on the forest floor to become the major component of accumulated litter. We suggest that twigs comprise a significant organic mangrove component to be incorporated into the sediment.

By comparing the standing crop of litter on the forest floor in this forest with that of other mangroves, Ko Yao Yai can be shown to be lower in litter standing crop than forests at Kedah, Malaysia (74-145.2 g/m^2) (Ong *et al.*, 1980) and Matang, Malaysia 147 g/m^2 (Gong *et al.*, 1984). These forests are in the same geographical region. The accumulation of litter in Ko Yao Yai is higher than in Australia (6 g/m^2) (Robertson and Daniel, 1989), and much less than in Florida (559 g/m^2) (Lugo and Snedaker, 1975).

In calculating litter turnover rates by using the formula $1/k=X_{ss}/L$ where L is litter production, X_{ss} is the steady state accumulation of surface litter on the forest floor and 1/k is the residence time (Twilley *et al*, 1986); the residence time of leaf litter at sites A, B, C and D were calculated to be 14.4, 21.1, 20.1 and 7.8 days respectively. At site D, the turnover rate was highest. This finding seems to contradict the results of the decomposition experiment, in that decomposition occurred faster at site A. This emphasizes the significance role played by biological processes in leaf litter removal from the standing crop in the upper zone of mangrove forests in Southeast Asia, as discussed earlier.

The values of litter turnover rates in this forest are comparable to those calculated from forest data in Kedah, Malaysia (Ong *et al.*, 1980). They are , however, much higher than those values compiled by Twilley *et al.* (1986). This difference may be due to the influence of hydrology on litter degradation.

Litter export

The tide is an important factor controlling the export of floating detrital particles. Most of the floating particles were exported during the ebb flow of spring tides. The excessively large quantities of twigs exported may be due to tree cutting. It was observed during the study that about one third of the forest had been cut down by villagers. Only branches were used, leaves, twigs and tree trunks being left in the forest. While leaves were decomposed, twigs which were more refractive, were transported out during spring tide. Assuming that the main channel drained about 3/4 of the forest, it has been calculated that leaf litter export as floating particles is about 15% of daily leaf fall during a spring tide and about 0.5% during a neap tide. It is concluded that most of the leaf litter is decomposed within the forest. Of this, some would be exported as suspended particles and dissolved organic matter and a certain percentage, especially in the landward zone would be incorporated into the food chain and sediment. On average, this forest exported about 7.7% of this daily litter fall as floating detritus. The percentage export value reported in this paper is the same as that recorded from a small mangrove forest in the vicinity (Poovachiranon and Chansang, 1982). This value is considerably higher than that obtained in a mangrove forest in New Zealand. Woodroffe (1985) estimated that only 2% was exported as floating macrodetritus from Tuft Crafter mangroves in New Zealand.

This study does not resolve whether or not there is the net export of suspended particulate organic matter from this mangrove forest into the estuary. It can only be concluded that more spended particulate matter is exported during ring tides than neap tides. Further studies on e transport of suspended organic matter and ssolved organic matter in and out of the forest, d mineralization processes within the forest, e needed for a more complete understanding of angrove litter dynamics.

We agree with Twilley (1985) that the tide is important factor in the productivity of different types of forests. However, the classification mangrove forest types as riverine, fringe, or sin in the tropical regions of North and Central nerica (Lugo and Snedaker, 1974) seems to be ther restricted and may not be applicable to angrove forests in other parts of the world. or example, within the vicinity of Phuket Island, the mangrove forest studied by Christensen 978) can be classified as fringe and the forest this study and the one reported upon by hansang and Poovachiranon (1982) may be scribed as basin. However, these forest are all nder the same tidal influences so that their ysiognomy is the same. Thus the concept of assifying estuarine areas according to tidal nge (Nichols and Biggs, 1984) might be more propriate in considering the interaction between mangrove forests and estuarine areas in different geographical regions. Using this definition the mangrove forest in this study and the Hinchinbrook mangrove forest (Boto and Bunt, 1981) would be under mesotidal range while the mangrove forests along the Florida coast would be of microtidal range. Considered together with coastline geomorphology such tidal parameters may provide a better understanding of mangrove litter dynamics and the importance of the mangrove to the adjacent estuary.

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