MANGROVE LITTER-FALL STUDIES AT THE AJKWA ESTUARY, IRIAN JAYA

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ABSTRACT

Litter traps were used to estimate litter-fall production in two mangrove communities in the Ajkwa estuary, part of the PT Freeport Indonesia project area. The two communities studied included *Bruguiera gymnorrhiza - Camptostemon schultzii – Rhizophora apiculata* (Site 1) and *B. cylindrica - R. apiculata* (Site 2). The period of study was from February 16, 1998 to October 27, 1998 for Site 1 and February 25, 1998 to December 12, 1998 for Site 2. Total annual litter-fall for Site 1 and Site 2 was estimated at 900.78 g/m²/yr and 744.35 g/m²/yr, respectively. For both communities, litter-fall consisted of leaves (61.5% of total litter production at Site 1 and 51.8% at Site 2), reproductive parts (20.5% at Site 1 and 11.1% at Site 2) and twigs (18.0% at Site 1 and 37.1% at Site 2). The monthly rate of total litter production at Site 1 displayed two peaks during the study period (a major peak in March and a minor one in October) while Site 2 showed only a single peak in February. Monthly rates of production for both leaf and twig litters at both sites peaked only once during the study period while rates of litter production from plant reproductive parts peaked twice. In both communities, the rate of twig litter production coincided with litter production from reproductive parts. During the sampling period, litter-fall rates varied substantially but were not significantly correlated with rainfall. However, the rate of twig litter production in both communities was significantly correlated with wind velocity.

Keywords : Ajkwa estuary, community, litter-fall, litter trap, mangrove, rate of litter-fall, reproductive parts, twig

Organic material covering forest floors, commonly referred to as litter, is primarily composed of dead plant parts (including leaves, twigs and reproductive parts). Litter production is defined as the weight of all dead material (of both plant and animal origin) deposited on a given unit area of soil surface within a specified time period (Chapman, 1986). Estimations of abundance and composition of litter-fall are important to the study of nutrient cycling (Proctor, 1984), primary production (Ovington, 1962) and the structure and function of the ecosystem (Kusmana *et al.*, 1998). Therefore, the study of quantitative aspects of litter-fall continues to be an important part of forest ecology (Proctor *et al.*, 1983). However, rates of forest litter production around the world vary widely due to differences in community structure, stand age, geographical situation (altitude), and seasonal climatic changes (Tanner, 1980).

Mangrove swamps are thought to be highly productive communities (Lugo & Snedaker, 1974) and are recognized as an important source of detritus to marine and estuarine ecosystems (Snedaker, 1978) supporting a variety of aquatic organism (Odum & Heald, 1972). Snedaker (1978) also reported that litter-fall produced in mangroves enters the estuarine system, where it forms the basis for a complex food web. Despite the likely importance of mangrove litter-fall to the aquatic ecosystem, little information exists regarding productivity in Indonesia.

The island of Papua contains one of the largest expanses of unmodified mangrove forests in the world. However, no recent data on the productivity of mangroves in this region have been published. The intention of this study was to provide baseline data on the input of organic matter from the mangrove communities into the surrounding coastal ecosystem; specifically to estimate monthly productivity and composition of litter-fall from mangroves in the Ajkwa river estuary within the PT Freeport Indonesia (PTFI) project area.

DESCRIPTION OF STUDY AREA

PT Freeport Indonesia (PTFI) Project Area

The Contract of Work (COW) signed between the Government of Indonesia (GOI) and PTFI in 1991, granted PTFI two working areas defined as:

(a). Contract of Work Mining Area (COW A). This area is approximately 100 km² and is the location of most mining activities. Activities include exploration, open-pit, and underground mining, ore processing (at the mill site) and mine overburden disposal.

(b). Contract of Work Project Area (COW B). This area of approximately 2,890 km² connects the mining area in the north of the Arafura Sea in the south. Supporting facilities and infrastructure including Tembagapura, Ridge Camp, Kuala Kencana, Amamapare Port, Timika Airport and other areas situated in the COW Project Area.

PTFI COW Area (Mining Area and Project Area) are in the Mimika Baru District of the Mimika Administrative Regency.

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Environment of Research Location

Climate

Figure 1 presents monthly rainfall and temperature data collected in the study area from January to December, 1998.

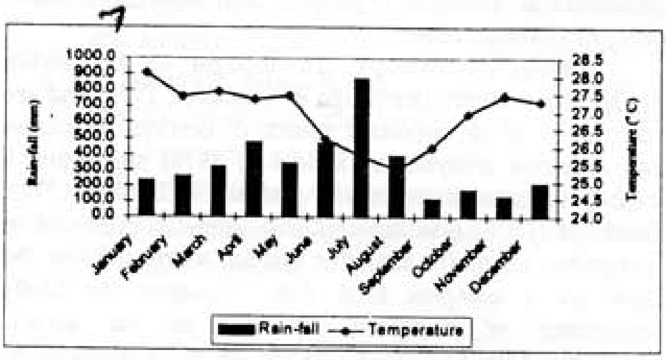

Figure 1. Total monthly rainfall and mean monthly temperatures, PTFI Project Area, January to December, 1998.

The total annual rainfall in the study area was approximately 3,980.1 mm. Total monthly rainfall ranged from 114.0 mm in September to 876.5 mm in July. The Schmidt and Ferguson System (1951) classifies this climate as Type A (no dry month throughout the year). The mean monthly air temperature in this area ranged from 25.4°C in August to 28.1°C in February and mean monthly humidity ranged from 80% to 91%. Average monthly wind velocity in this area ranged from 2.02 m/sec. in October and July, to 2.58 m/sec. in December.

Soil

The sites used for this study are situated within the Kajapah Land System and consist of inter-tidal swamps of mangrove and Nypa palm. Soils consist of recent fine alluvium (marine) or peat and are classified as Sulfaquents and Sulfihemists according to the classification of USDA Great Soil Group System. Sulfaquents are permanently saturated, unweathered soils that become strongly acidified upon aeration. The soil texture is peat.

Geology

According to the PT. Hatfindo Prima (1997), the regional geology of the PTFI consists of both older sedimentary rocks and recent sedimentary material. This material is composed of rocks from the Buru formation consisting mainly of calcareous mudstone, shale, limestone, conglomerate, and occasionally beds of lignite coal. The material ranges from unconsolidated to relatively consolidated. This geological unit is usually found in gently sloping hills, however, in cleared areas with steep slopes the material is unstable and susceptible to landslides. Fanglomerate and alluvial deposits are also found within the study area. Fanglomerate is a combination of conglomerate, sand and mud and is spread across the Timika lowlands and surrounding areas. The area stretching south to the coast is formed by alluvial and swamp deposits consisting of mud, sand, silt, peat and organic matter. This formation is largely unconsolidated with high permeability.

Vegetation

Preliminary research conducted by Ellison (1997), reported five mangrove communities in the Ajkwa estuary:

(a). Seaward pioneer community (*Avicennia – Sonneratia* association) - This community is located at lower elevations on accreting mud banks and inner bends of rivers. Community Species include *Avicennia marina*, *A. officinalis*, *A. eucalyptifolia* and *Sonneratia caseolaris*;

(b). *Rhizophora stylosa – Bruguiera gymnorrhiza* community – This community grows in the south of the main Ajkwa estuary and on outer bends of rivers. Additionally, *R. apiculata* and *R. mucronata* may also occur in this community;

(c). *Bruguiera – Rhizophora – Xylocarpus* community – This community is generally found at higher elevations on the inner bends of rivers. Within the study area, this community is located mainly in the north of the main Ajkwa estuary. Species identified in this community include *R. stylosa*, *R. mucronata*, *B. cylindrica*, *B. parviflora* and *X. mekongensis*;

(d). *Nypa fruticans* community – This community is found on accreting banks in northern mangrove areas; and

(e). Mixed mangrove forest community – This community grows in brackish water and consists of *R. apiculata*, *Heritiera littoralis*, *X. granatum*, *Pandanus* sp. and *N. fruticans*.

In general, the Ajkwa estuary is dominated by the *Bruguiera – Rhizophora – Xylocarpus* community, however, the *R. stylosa – B. gymnorrhiza* community dominates the composition of the Minajerwy estuary.

METHODS

Location and Time Period of Research

This study was conducted at two sites (Site 1 and Site 2) within mangrove communities of the Ajkwa estuary in the PTFI COW area. In 1998, permanent plots were constructed at the 2 sites for estimating the abundance and production rate of litter-fall. Litter was collected from February 16, 1998 until October 27, 1998 at Site 1 and from February 25, 1998 until December 12, 1998 at Site 2.

Sample Plots

At each sample site, two sample plots of 100 m x 100 m were established in a prominent mangrove forest in the study area. Furthermore, in each community, two permanent plots were established which were completely divided into sub-plots of 20 x 20 m.

Measured Parameters

Parameters measured for this study included the diameters of trees greater than 10 cm as well as the production of litter from various tree components.

Data Collection Procedure

Tree diameters were measured 10 cm above the highest prop roots for *Rhizophora* spp. and 10 cm above the buttress or 1.3 m above ground level (diameter at breast height, DBH) for all other species.

Litter production was measured by collection in litter-fall traps as described by Newbould (1967). For this study, 13 litter traps (opening 0.50 m^2; depth-0.50 m), were suspended within each plot in the studied mangrove community. Traps were made from nylon mesh cloth (1 mm mesh size) and were suspended from tree branches above high tide. All materials accumulated in the traps were collected once per week during the sampling period.

Data Analysis

Estimates of litter-fall rates of various tree components (leaf, reproductive parts, twig) were calculated using standard statistical procedures (Sokal & Rohlf, 1986). To analyze the effect of rainfall on litter-fall, individual litter components (leaves, reproduction organs, stems) and total litter in each month were correlated with monthly total rainfall. As effects of rainfall may not be immediate, monthly mean rates of litter-fall were also correlated with monthly rainfall for previous months using time-lag correlation.

To explain the forest structure, density (N) and importance value index (IVI) of the trees were calculated using formula such as follows (Poole, 1974) :

(a). Density (N) = $\frac{\text{number of tree}}{\text{area of sample plot}}$

(b). Importance Value Index (IVI) = Relative Density + Relative Frequency + Relative Dominance

RESULTS AND DISCUSSION

Forest Composition and Structure

Mangrove forest species composition and structure of research Site 1 is presented in Table 1.

Table 1. Mangrove species composition and structure of Site 1.

No.	Plot	Species	N (No./ha)	BA (m^2/ha)	IVI (%)
1.	Plot 1	*Avicennia marina*	1	0.11	2.10
		Bruguiera cylindrica	1	0.03	1.87
		Bruguiera gymnorrhiza	235	17.31	145.34
		Camptostemon schultzii	91	7.03	74.90
		Rhizophora apiculata	47	8.85	70.69
		Rhizophora mucronata	5	0.25	
		Total	380	33.58	
2.	Plot 2	*Bruguiera gymnorrhiza*	242	16.53	160.17
		Camptostemon schultzii	83	7.00	79.87
		Rhizophora apiculata	42	5.46	57.42
		Xylocarpus australiasicus	3	0.06	2.55
		Total	370	29.06	

IVI = Importance Value Index
N = Density
BA = Basal Area

Based on data in Table 1, mangroves in Site 1 can be categorized as *B. gymnorrhiza – C. schultzii – R. apiculata* community. Seven species of mangrove trees were recorded within both sample plots. *B. gymnorrhiza, C. schlutzii* and *R. apiculata* were considered dominant species while the other four species were minor contributors to the mangrove community. In this community, *B. gymnorrhiza* was the most dominant species with an IVI of 145.34% and 160.17% for plots 1 and 2, respectively.

Forest species composition and structure of research Site 2 are presented in Table 2.

Table 2. Mangrove species composition and structure of Site 2.

No.	Plot	Species	N (No./ha)	BA (m^2/ha)	IVI (%)
1.	Plot 1	*Avicennia marina*	11	0.62	14.99
		Bruguiera cylindrica	322	11.20	134.30
		Bruguiera gymnorrhiza	1	0.04	1.48
		Ceriops tagal	1	0.01	1.37
		Diospyros maritima	6	0.14	5.12
		Rhizophora apiculata	188	9.47	103.20
		Rhizophora mucronata	5	0.13	6.03
		Xylocarpus australirsicus	1	0.01	1.37
		Xylocarpus granatum	34	1.25	32.13
		Total	569	22.87	
2.	Plot 2	*Avicennia marina*	1	0.12	1.93
		Bruguiera cylindrica	211	8.64	103.09
		Bruguiera gymnorrhiza	1	0.03	1.59
		Diospyros maritima	6	0.13	8.54
		Heritiera littoralis	7	0.09	8.18
		Rhizophora apiculata	311	16.98	152.44
		Xylocarpus granatum	26	0.42	24.62
		Total	563	26.41	

IVI = Importance Value Index
N = Density
BA = Basal Area

The data in Table 2 suggests that mangrove community in the Site 2 can be categorized as *Bruguiera cylindrica – Rhizophora apiculata* community. Total densities of trees in this community were estimated at 569 trees/ha (Plot 1) and 563 trees/ha (Plot 2). Basal areas were calculated at 22.87 m^2/ha (Plot 1) and 26.41 m^2/ha (Plot 2). A total of ten tree species were recorded in the sample plots. Among them, *B. cylindrica* and *R. apiculata* comprised more than 90% of the total stand density and basal area in this community.

The average diameter and height of trees in both plots were 15.87 cm (range = 9.6 cm to 87.9 cm) and 22.65 m (range = 4.88 m to 56.56 m), respectively. The mangrove community in Site 2 was comprised of more tree species than Site 1. Site 2 contained denser stands of trees with smaller diameters than Site 1. Mangroves in Site 1 are frequently subjected to tides providing a continuous supply of silts, clays and nutrients as well as aeration for optimal tree growth. Stands in this community produced trees with larger diameters than at Site 2 possibly a result of the tides functioning as an energy subsidy and stimulating net primary production of the intertidal wetlands (Odum, 1980). In terms of species richness, our results support Kusmana *et al.* (1998) who suggested that species richness in mangrove forest communities increases with distance inland from the coast due to decreasing salinity.

Compared to mangrove forests in other locations in Indonesia (Table 3), mangrove communities in the study area are similar to the mangrove forests in Simpang Ulim – Aceh (Al Rasyid, 1983), Halmahera - Maluku (Komiyama *et al.*, 1988a), Banyuasin - South Sumatra (Yamada & Sukardjo, 1980), Tanjung Kasam – Riau (Sukardjo, unpublished report).

Table 4 shows the density of trees with diameters greater than 10 cm as well as the species richness of trees in some virgin mangrove forests in Indonesia. Compared to mangrove forests in other regions, communities within the study area showed high species richness, similar to mangroves in Halmahera - Maluku. However, other studies of mangrove species in Irian Jaya have shown more species of mangroves than are found in our study area. For example, Prawiroatmodjo (unpublished report) recorded 14 species of mangroves in Teluk Bintuni - Irian Jaya. In terms of density, mangrove forests in the study area are most similar to mangrove communities in Halmahera – Maluku and Talidendang Besar – Riau.

Litter Production and Its Components

Table 5 shows estimated annual litter production in mangrove communities in the study area.

Annual litter production was estimated at 800.78 g/m^2/year from mangroves of Site 1 and 744.35 g/m^2/year from Site 2. At both sites, the leaves comprised more than 50% to the total litter. Monthly total litter production in both communities was highly variable (CV = 45 % to 79 %). It should also be noted that twig litter comprised a substantial proportion of total litter-fall production at Site 2.

Annual litter-fall production from Site 1 is higher than in Site 2. These results support the findings of Pool *et al.* (1975), Twilley *et al.* (1986) and Kusmana *et al.* (1998). Who reported that mangroves exposed to greater tidal activity and water turnover generally show higher litter-fall rates than mangroves in areas with stagnant water. Odum (1980) suggests that tides may function as an energy subsidy, stimulating production in intertidal wetlands. Tides have also been shown to provide silts and clays, as well as a supply of nutrients and aeration for optimal growth of mangroves (Wharton & Brinson, 1979).

Annual litter-fall rates in the study area lie within ranges previously reported for other mangrove populations. Litter-fall rates in both study sites were lower than for similar mangrove communities in Hinchinbrook Island - Australia (Duke *et al.*, 1981), Saleh River - South Sumatera (Soerianegara *et al.*, 1985), and Talidendang Besar - Riau (Kusmana *et al.*, 1998). However, rates were higher than for mangrove communities studied in Iriomote island - Okinawa (Kishimoto *et al.*, 1987). Differences in the abundance of mangrove litter-fall in these regions, may be attributable to differences in vegetation composition and structure (Othman, 1989), climatic factors (Proctor, 1984), the phase of forest growth and soil fertility (Schaik & Mirmanto, 1985) as well as tidal activity and hydrologic condition (Twilley *et al.*, 1986).

Rate of Total Litter-fall

Figure 2 shows monthly rates of total litter-fall of mangrove communities in the Site 1 and Site 2. Total monthly litter-fall during the sampling period ranged from 1.27 g/m^2/d to 4.07 g/m^2/d in Site 1 and 0.65 g/m^2/d to 6.35 g/m^2/d in Site 2.

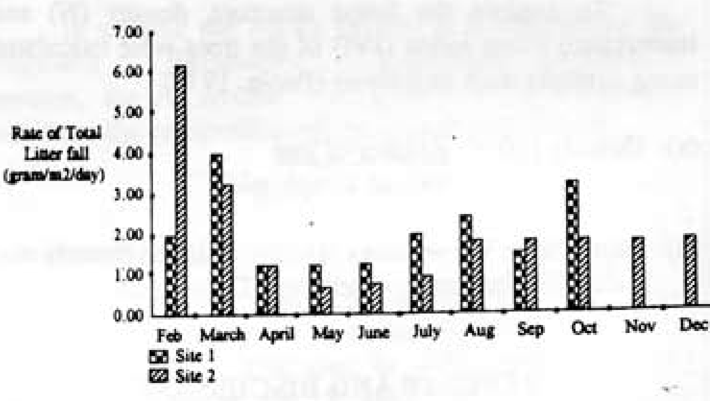

Figure 2. **Monthly rates of total litter-fall for mangrove communities in the research site in 1998.**

Table 3. Community types of some mangrove forests in Java and other islands in Indonesia.

No	Location	Community Type	Species Richness	Reference
A	**Java Island**			
1	Cilacap	*Aegiceres corniculatus - Ficus retusa*	14	Marsono (1989)
		Avicennia alba - Sonneratia alba		
		Rhizophora mucronata - Bruguiera cylindrica		
2	Ujung Karawang	*Avicennia marina - Aegiceras corniculatus*	9	Djaja *et al.* (1984)
3	Indramayu	*Avicennia marina - Avicennia alba*	9	Sukardjo (1980)
4	Pulau Rambut	*Rhizophora mucronata - Rhizophora stylosa*	13	Kartawinata & Waluyo (1977)
		Rhizophora mucronata		
		Scyphyphora hydrophyllacea - Lumnitzera racemosa		
5	Pulau Dua	*Rhizophora stylosa - Rhizophora apiculata*	12	Buadi (1979)
6	Baluran	*Rhizophora stylosa - Rhizophora apiculata*	16	Indiarto *et al.* (1987)
7	Grajagan	*Rhizophora apiculata - Avicennia* spp.	14	Sukardjo, unpublished report
8	Muara Angke	*Avicennia alba - Avicennia marina*	11	Kusmana (1983)
		Avicennia marina - Rhizophora mucronata		
B	**Other Indonesian Islands**			
1	Kangean Isles	*Rhizophora stylosa*	12	Soemodihardjo, unpublished report
		Rhizophora apiculata		
		Ceriops tagal		
2	Tanjung Apar (East Kalimantan)	*Rhizophora apiculata - Avicennia alba*	13	Sukardjo, unpublished report
		Avicennia officinalis - Avicennia alba		
		Ceriops tagal - Rhizophora apiculata		
3	Tanjung Kasam (Riau)	*Xylocarpus granatus - Lumnitzera racemosa*	12	Sukardjo, unpublished report
		Rhizophora apiculata - Xylocarpus granatus		
4	Way Sekampung (lampung)	*Avicennia* spp	14	Sukardjo (1979)
		Hibiscus tiliaceus - Pongamia pinnata		
5	Banyuasin (South Sumatera)	*Avicennia alba*	9	Yamada & Sukardjo (1980)
		Rhizophora apiculata		
		Bruguiera gymnorrhiza - Rhizophora apiculata		
6	Tanjung Bungin (South Sumatera)	*Rhizophora apiculata - Nypa fruticans*	9	Sukardjo *et al.* (1984)
		Nypa fruticans - Rhizophora apiculata		
7	Talidendang Besar (Riau)	*Bruguiera parviflora*	8	Kusmana & Watanabe (1991c)
		B. sexangula		
		B. sexangula - Nypa fruticans		
8	Gaung and Mandah Rivers (Riau)	*Rhizophora apiculata - R. mucronata*	7	Al Rasyid (1984)
		Bruguiera parviflora - B. sexangula		
		Aegiceras corniculatus - Nypa fruticans		
9	Central Sulawesi			Darnaedi & Budiman (1984)
	- Ranu	*Rhizophora apiculata - Ceriops tagal*	3	
	- Lapangga	*Rhizophora apiculata - Ceriops tagal*	8	
	- Matube	*Rhizophora mucronata*	3	
	- Morowali	*Rhizophora apiculata*	5	
10	Halmahera (Maluku)	*Sonneratia alba*	14	Komiyama *et al.* (1988)
		Bruguiera gymnorrhiza - Xylocarpus granatus		
		Rhizophora apiculata - Bruguiera gymnorrhiza		
		Nypa fruticans - Rhizophora stylosa		
11	Bone-bone (South Sulawesi)	*Sonneratia alba - Rhizophora apiculata*	20	Ahmad (1989)
		Rhizophora mucronata		
		Bruguiera gymnorrhiza		
12	Simpang Ulim (Aceh)	*Rhizophora apiculata - Bruguiera gymnorrhiza*	8	Al Rasyid (1983)

Values for species richness pertain to tree species.

Table 4. Densities and species richness indices of trees with diameters greater than 10 cm for some virgin Indonesian mangrove forests.

No.	Location	Density (ind./ha)	Species richness	Reference
1.	Tanjung Bungin, South Sumatera	162 - 288	9	Sukardjo & Kartawinata, (1979)
2.	Banyuasin, South Sumatera	187 - 448	9	Yamada & Sukardjo, (1980)
3.	Gaung and Mandah Rivers, Riau	333	7	Al Rasyid, (1984)
4.	Tanjung Apar, East Kalimantan	80 - 528	13	Sukardjo, unpublished report
5.	Irian Jaya	144 - 255	14	Prawiroatmodjo, unpublished data
6.	Central Sulawesi	210 - 422	10	Darnaedi & Budiman, (1984)
7.	Halmahera, Maluku	206 - 586	14	Komiyama *et al.* (1988a)
8.	Talidendang Besar, Riau	364 - 592	8	Kusmana *et al.* (1992a)

Table 5. Estimated annual litter production of tree components in mangrove communities in the PTFI study area.

Site	Mangrove Community	Litter Components (g/m^2/year)			
		Leaf	Reproductive Part	Twig	Total
1	*Bruguiera gymnorrhiza -Comptostemon schultzii -Rhizophora apiculata* community	492.61 ± 95.47 (CV = 58.14 %)	164.28 ± 31.63 (CV = 57.76 %)	143.89 ± 68.35 (CV = 142.50 %)	800.78 ± 121.15 (CV = 45.39 %)
	%	61.5	20.5	18.0	100
2	*Bruguiera cylindrica -Rhizophora apiculata* community	385.66 ± 59.59 (CV = 51.25 %)	82.91 ± 31.24 (CV = 124.99 %)	275.78 ± 160.45 (CV = 192.96 %)	744.35 ± 195.42 (CV = 78.76 %)
	%	51.8	11.1	37.1	100

Value show average $(\bar{x})$ ± Se
CV = Coefficient of Variance

In Site 1, the monthly rate of total litter-fall was highest in March although a smaller peak was observed in October (Figure 2). However, in Site 2 the monthly rate of total litter-fall showed a single in February. There was no significant correlation between rainfall and rate of total litter-fall in both mangrove communities in the study area ($r < 0.05$, $n = 26$, $p > 0.05$). Our results support other tropical studies suggesting that maximum litter-fall coincides with both high and low periods of precipitation (Proctor *et al.*, 1983).

The difference in litter-fall rate between Site 1 and Site 2 may be the result of differences in vegetation composition and structure, tree physiological processes or tidal activity as reported by Othman (1989) and Twilley *et al.* (1986).

Rate of Leaf Litter Production

The monthly rates ranged from 0.59 $g/m^2/d$ (May) to 3.14 $g/m^2/d$ (October) and 0.34 $g/m^2/d$ (May) to 1.85 $g/m^2/d$ (December) in the mangrove communities in Site 1 and Site 2, respectively (Figure 3). Both communities showed a general increase in monthly leaf production through the end of sample collection.

As with previous studies conducted on litter-fall (Table 1), leaves were the major component of litter; therefore, the observed pattern of litter-fall production is attributable primarily to leaf litter. Monthly rates of leaf litter production varied widely throughout the collection period (CV > 50%) and no significant correlation existed between rainfall and rate of leaf litter-fall in both mangrove communities in the study area ($r < 0.60$, $n = 26$, $p > 0.05$). This result suggests that maximum leaf litter production coinciding with periods of high rainfall is not common in the tropics, although peaks in leaf-fall production have been shown to coincide with either low or high rainfall (Proctor *et al.*, 1983).

Although the density of mangroves in Site 1 is lower than in Site 2, Site 1 produces higher amounts of leaf litter. Possible reasons for this discrepancy are: (1) mangrove community in Site 1 consists of trees with larger diameters than Site 2; (2) the mangrove community in Site 1 may produce more new leaves as an adaptation to high salinity conditions due to frequent inundation from tidal action; and (3) the exposure to tides at Site 1 possibly produces more optimal growth conditions.

Compared to other similar mangrove communities, the annual rate of leaf litter production in the PTFI study area is less than for mangroves in Talidendang Besar – Riau (Kusmana *et al.*, 1998). However, the rate is higher than for mangrove communities in Hinchinbrook island – Australia (Duke *et al.*, 1981) and Iriomate island – Okinawa (Kishimoto *et al.*, 1987). These differences may be attributable to differences in vegetation composition, climatic factors, tidal activity and hydrologic condition (Lugo & Snedaker, 1974 ; Twilley *et al.*, 1986).

Rate of Reproductive Parts Litter

The monthly rate of litter production from plant reproductive parts ranged from 0.13 $g/m^2/d$ (June) to 0.71 $g/m^2/d$ (August) for Site 1 and from 0.15 $g/m^2/d$ (June) to 0.99 $g/m^2/d$ (February) for Site 2 (Figure 3).

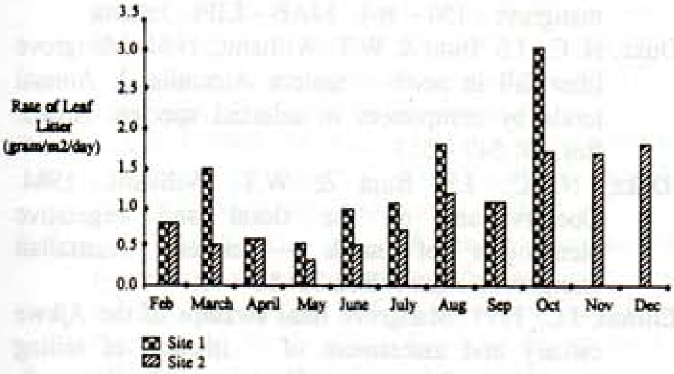

Figure 3. The rate pattern of leaf litter of mangrove community in the research site in 1998.

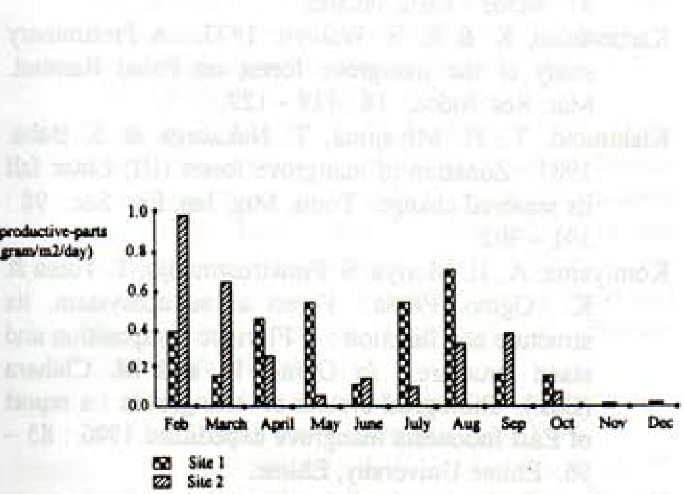

Figure 4. The rate pattern of reproductive-parts litter of mangrove community in the research site in 1998.

Litter production from plant reproductive parts peaked in March at Site 1 and February at Site 2. Smaller peaks were observed in August at Site 1 and in September at Site 2. Production between February and October from mangrove reproductive parts showed the same general trend as leaf litter production. Our data support the findings of Duke *et al.* (1984) who reported a relationship between leaf litter and litter production from plant reproductive parts for mangroves in north-eastern of Australia. Other research on mangroves has suggested that the relationship between leaf litter and litter from plant reproductive parts may be influenced by the phenological cycles of mangroves (Duke *et al.*, 1984).

Production of litter from reproductive parts in the study area varied considerably between months (CV = 58% to 125%). However, no significant correlation ($r < 0.40$, $n = 26$, $p > 0.05$) existed between the rate of production of litter from reproductive parts and rainfall.

Compared to similar mangrove communities in other regions, the rate of production of litter from mangrove reproductive parts in the study area is less than from mangrove communities in Hinchinbrook Island, Australia (Duke *et al.*, 1981). This difference in production is possibly the result of differences in forest structure, climate or habitat condition.

Rate of Twig Litter Production

Twig litter rates for mangroves in the study area ranged from 0.12 $g/m^2/d$ (September) to 1.73 $g/m^2/d$ (March) at Site 1 and from 0.00 $g/m^2/d$ (October and December) to 4.49 $g/m^2/d$ (February) at Site 2. Monthly production of twig litter peaked in March at Site 1 and in February at Site 2 (Figure 3).

Monthly production of twig litter showed a similar trend to litter production from reproductive parts suggesting that flower-fall may stimulate the shedding of twigs possibly due to decreasing physiological function of the twig after living flower buds are shed. This supports the results of Lopez-Partillo & Ezcurra (1985) and Kusmana *et al.* (1998), who reported marked seasonal patterns of woody litter production in mangrove forests in Tabasco, Mexico and Talidendang Besar-Riau, respectively.

During the litter collection period, the rate of twig litter production varied considerably (CV = 143% to 193%). Production rates were significantly correlated ($r = 0.70$, $n = 26$, $p = 0.05$) to wind velocity, but not to rainfall ($r < 0.30$, $n = 26$, $p > 0.05$). Higher wind velocity may be responsible for higher rates of twig litter production at Site 2 than Site 1 due mangroves at site 2 grow in the rather higher ground level and hence its frequently subjected to strong wind.

The mangrove communities examined for this study have much higher twig litter rates than do other studied mangrove forests around the world. This may be attributable to differences in vegetation composition and structure, phenological processes in relation to habitat condition, or climatic factors (wind velocity).

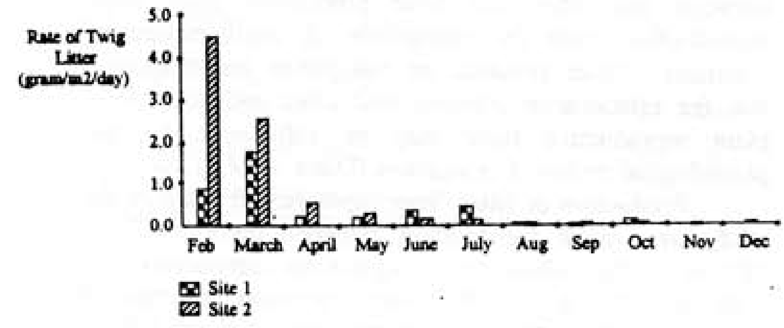

Figure 5. The rate pattern of twig litter of mangrove community in the research site in 1998.

CONCLUSION

The total annual litterfall for site 1 and site 2 was estimated at 800.78 $g/m^2/yr$ and 744.35 $g/m^2/yr$, respectively. The monthly rate of total litter production at site 1 displayed two peaks during the study period (a major peak in March and a minor one in October) while Site 2 showed only a single peak in February. Monthly rates of production for both leaf and twig litters at both sites peaked only one during the study period while rates of litter production from plant reproductive parts peaked twice. During the sampling period, litter-fall rates varied substantially but were not significantly correlated with rainfall.

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