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Spatial and seasonal variation of mangrove litter production in Bitung, Indonesia

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Abstract. This study aimed to figure out a spatial and seasonal variation of litterfall production and its correlation with environmental parameters. The area was distinguished into three zones based on species domination, landward (*Xylocarpus granatum*); middle zone (*Rhizophora apiculata*) and seaward (*Ceriops tagal*). Four square, 50x50 cm (1 mm nylon mesh) litter traps were hung randomly in each zone, and the litters were collected monthly. Secondary climate data were compiled from the NOAA and BMKG, while soil and water contents were acquired from TIO-RCO investigation. The number of litter production on Kema was in the moderate category compared to several studies. Spatially, total litter production on landward (6.90±3.67 $t.ha^{-1}.y^{-1}$) and seaward (6.66±3.08 $t.ha^{-1}.y^{-1}$) were not significantly different, but they had a significant difference to the middle zone (8.93±4.85 $t.ha^{-1}.y^{-1}$). Vegetative parts were highly dominant on litter composition. Total phosphate was highly correlated with spatial differences. Mangrove produced more litter during the dry season due to their higher metabolic adaptation to cope with the higher temperature and salinity. Even though there was no significant correlation between climate factors and total litter production. During season-transition periods, production of litterfall doubled than either dry/wet season followed by climatic parameter changes delivering physiological stresses.

Keywords: litter, mangrove, spatial, seasonal, variation

1. Introduction

Mangrove forests are one of the most productive ecosystems and richest tropical coastal ecosystems. Globally, mangroves have produced 11.1 MgC $ha^{-1}y^{-1}$ as net primary productivity (NPP) and stored 956 tC ha^{-1} of carbon stock [1, 2]. The importance of mangrove in carbon storage was focused by many studies [3-7]. Photosynthesis allows mangrove plants to capture and assimilate CO_2 at about 0.81 Mmol CO_2 ha^{-2} y^{-1} and convert them into biomass as the carbon stock [8]. Indonesia has been considered as the most productive mangrove area in the world since it has the most extensive area of mangroves. Indonesia is covered by 22.4% of global mangrove population and can potentially be used for global carbon estimation [9, 10].

Litter production assessment is one of the five ways used to estimate mangrove forest productivity [11]. Global mangrove productivity from litterfall was expected to be approximately 218 Tg C y^{-1} [12]. This number would be misleading since there was only one litterfall study mentioned on Indonesia's mangroves. A few studies dealing with mangrove litter had been done in Indonesia [13, 14]. Changes in weather and environmental condition would affect mangrove productivity.

Comprehensive studies on mangrove litter production in Indonesia are needed to increase the estimation accuracy.

Extensive coastal developments in North Sulawesi have triggered various threats on mangrove existence. However, lack of mangrove information was well-published from this area, only at Bunaken National Park [15]. Our study was focused in Bitung's mangroves. The surrounding areas would be fragile in the future since the national government has declared this area to be the northern gate of Indonesian trading port. It may deliver several impacts to the coastal ecosystems in the future. This study was aimed to calculate the litterfall in Bitung mangroves monthly. Besides that, we also provide a mangrove structure to discover its ecological importance.

2. Materials and Methods

2.1. Study site

Sites were located in a small area of mangroves in Kema, about 15 km from Bitung city. This sampling area was distinguished into three main zones such as seaward/SW (1.383086 N, 125.096578 E); middle/MZ (1.383777 N; 125.096197 E); and landward zones/LW (1.384421 N; 124.095913 E). Kema mangroves are laid on a semi-closed estuarine with a sandy loam substrate. Rhizophora apiculata is the dominant species of mangrove which has flowering periods in around June-August and fruiting periods from August to December. Bitung experienced a wet season from August to March during sampling periods [16].

Soil characteristics of each zone were analyzed on a previous study [17]. MZ and SW were significantly more acidic than the landward zone (table 1). Organic carbon in MZ was the highest and statistically different with SW. On the other hand, LW had no significant difference with those two sites. Moreover, nitrogen content in SW had significant differences with two other zones. None of the stations was different in terms of total P and C/N characteristics.

Table 1. Soil properties in the three zones of Kema's mangrove [17].

Soil Properties	LW	MZ	SW
pH	6.02 ± 0.50^{b}	5.16 ± 0.78^{a}	5.04 ± 0.74^{a}
TOC	58.62 ± 9.34^{ab}	67.35 ± 16.18^{b}	45.31 ± 11.94^{a}
Total N	2.81 ± 0.39^{b}	2.81 ± 0.69^{b}	2.10 ± 0.56^{a}
Total P	0.41 ± 0.14^{a}	0.42 ± 0.06^{a}	0.45 ± 0.09^{a}
Eh	-23.20~93.70 (40.71)	-141.30~108.20 (12.90)	-122.20~108.20 (9.64)
C/N	21.11 ± 4.00^{a}	23.98 ± 2.04^{a}	22.03 ± 4.92^{a}

^{ab} Result of Post Hoc's Tukey test, different letter in the same row represented different mean value among sites which were P-value < 0.05.

2.2. Forest measurement

As many as four 10m x 10m quadratic plots were scattered in each zone. Plant measurement was established on two different plant classes such as sapling (dbh: < 4 cm) and tree (dbh: > 4 cm) [18]. The diameter of all plants was measured to determine mangrove density each class. Mangrove species were identified [19, 20].

2.3. Litter measurement

Four litter traps (0.5 x 0.5 x 0.20 m; 1 mm nylon mesh) were randomly hung diagonally between trees by nylon ropes. Those traps were at least 5 m apart and 2 m above ground [14]. All litter was collected monthly and sorted into three main parts; leaves, flowers, and fruits. The litter was oven-dried at 70°C for at least a week and weighed. The NPP of mangrove was calculated to estimate CO_2 sequestrated by the plant.

2.4. Statistical analysis
Non-metric MDS ordination was applied to figure out the mangrove stratification which was combined with a group cluster analysis in PRIMER 7.0 according to the species basal area. A Spearman rank analysis was used to analyze the correlation between the vegetation data (species abundance and basal area) and the environmental data. One-way ANOVA was performed to identify differences among sites of some parameters, e.g., tree and sapling density and diameter continued by Tukey-test. Litterfall data had been square root transformed before it was analyzed by two-way ANOVA to determine differences in litterfall production among zones over year.

3. Result and Discussion

3.1. Mangrove stratification
Kema mangroves represent a clear stratification which was divided into three zones. It was emphasized by non-metric MDS ordination through similarities of species basal area (figure 1). On the other hand, the variability of those vegetation data mostly had a significant correlation with soil contents (table 2). This proves that mangrove zoning had been influenced by species composition, tree size (represented by basal area) and soil contents.

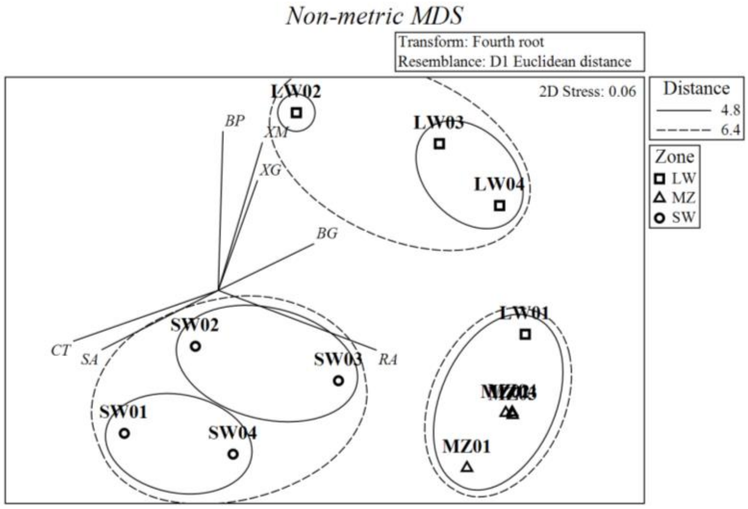

Figure 1. Ordination of MDS analysis on species abundance and basal area performing clear zoning in Kema's mangrove.

Table 2. Pearson correlation rank among similarities of vegetation data, i.e., species abundance (SA), basal area (BA) to soil chemistry parameters (pH, OC, TKN, TP, Eh and C/N ratio).

Production	pH	OC	TKN	TP	EH	CN
SA	0.379**	0.457**	0.434**	0.263*	0.299*	0.299*
BA	0.419**	0.461**	0.409	0.119	0.412**	0.412**

* Correlation is significant at the 0.05 level (2-tailed)
** Correlation is significant at the 0.01 level (2-tailed)

Mangroves are stratified into several zones due to the variability of soil and water in landward and seaward areas [21]. However, shoreline geomorphology, elevation, and water pool also contribute to mangrove stratification [22-24]. Those variables influence the salinity gradient which is impacted by species distribution [25]. Each species has different tolerances to salt concentration [26]. Our study found that the LW zone is dominated by *Xylocarpus mollucensis* both tree and sapling level (tabel 3). *Xylocarpus* species was frequently found in the landward zone with less salinity [27]. Estuarine typical of Kema mangrove allows *Rhizophora apiculata* to be widely distributed in all zones, though it is dominant only in MZ. *Ceriops tagal* has the highest domination in the seaward site due to its higher salinity tolerant and harder substrate [28]. Salinity, pH, and organic carbon were three essential soil parameters for species dispersal on this study. Porewater salinity and soil pH decreased significantly from seaward to landward [29].

Table 3. Species composition; average of the tree (TD, ind/ha) and sapling density (SPD, ind/ha); diameter (DBH, cm) and important value index (IVI, %) of mangrove community in Kema.

Sites	Species	TD	SPD	DBH_{max}	DBH_{mean}	IVI_{tree}	$IVI_{sapling}$
LW	R. apiculata	1,000	0.00	13.36	8.96	97.29	0.00
	B. gymnorrhiza	533	0.00	7.64	5.25	44.04	0.00
	B. parviflora	433	0.00	10.18	6.27	42.84	0.00
	X. granatum	134	0.00	4.45	4.45	15.25	0.00
	X. moluccensis	1,500	1067	11.45	5.60	100.58	300.00
	Total	3,600[a]	1067	13.36	6.11	300.00	300.00
MZ	R. apiculata	4,767	267	14.32	7.59	244.74	79.68
	B. gymnorrhiza	567	800	9.86	4.77	55.26	174.43
	B. parviflora	0.00	133	-	-	0.00	45.90
	Total	5,334[b]	1200[a]	14.32	6.18	300.00	300.00
SW	R. apiculata	133	267	4.77	4.77	46.44	45.78
	S. alba	300	0.00	15.27	9.05	121.66	0.00
	C. tagal	534	2267	4.77	4.45	131.90	59.26
	B. gymnorrhiza	0.00	1067	0.00	0.00	0.00	160.78
	B. parviflora	0.00	133	0.00	0.00	0.00	34.17
	Total	967[c]	3734[a]	15.27	3.66	300.00	300.00

[ab] Result of Post Hoc's Tukey test, different letter in the same column represented different mean value among sites which were P-value < 0.05.

The highest soil organic content affects the forest structure in MZ, which has the densest mangrove stand among all sites (table 2). The tree density of mangroves in MZ was at 5333 tree/ha, followed by LW site at 3600 tree/ha and SW site at 967 tree/ha. The density in LW and MZ are categorized in a dense stand, while SW's mangroves are in a rare category. The mean of the tree density in Kema (3300 tree/ha) is higher than Wondama-Papua [30], Biak-Papua [31], Makassar-South Sulawesi [32] and Bintan-Riau island [8].

The high density of tree stand is implied by the small size of the trunk diameter. Averagely, trunk diameters in our study ranged from 3.66 cm to 6.18 cm. This range is considered to be smaller stand mangroves compared to some studies. Papuan pristine mangroves have an average trunk size of 19.77 cm which is much higher than this study [30]. Other Sulawesi mangroves also have bigger trunk size averages than Kema, such as 11.71 cm in Makassar [32] and 17.03 cm in Kendari city [33].

3.2. Litter production

Kema mangroves produce a moderate level of litterfall over time and sites (figure 2). Litter production in *Rhizophora*-dominated zones, MZ and LW (as co-dominant species), were 8.93±4.85 $t.ha^{-1}.y^{-1}$ and 6.90±3.67 $t.ha^{-1}.y^{-1}$ which are lower than other studies [13]. However, the product was higher than Sri Lankan mangroves [34]. *Ceriop*s-dominated zone, SW, had the lowest production at 6.66±3.08 $t.ha^{-1}.y^{-1}$. Smaller stand morphology, single leaf size and weight of *Ceriops tagal* were three factors that delivered lower production on SW. Other studies also found less production of *Ceriops* forest [35, 36].

Litter production in the wet season (August-March) is higher on average than in the dry season (April – June). This trend can also be found in several other studies [37-40]. In contrast, several studies found that the peak of litterfall period is during the rainy season [41, 42]. The production is constant during each peak of the season, while it increases following weather transition. Environmental stresses such as climatic, soil and water factors, can trigger litter fall increases as an adaptation process of the cellular metabolism [26]. In this study, only phosphorous soil content had a significant correlation to total litter production which is also noted in another study [43].

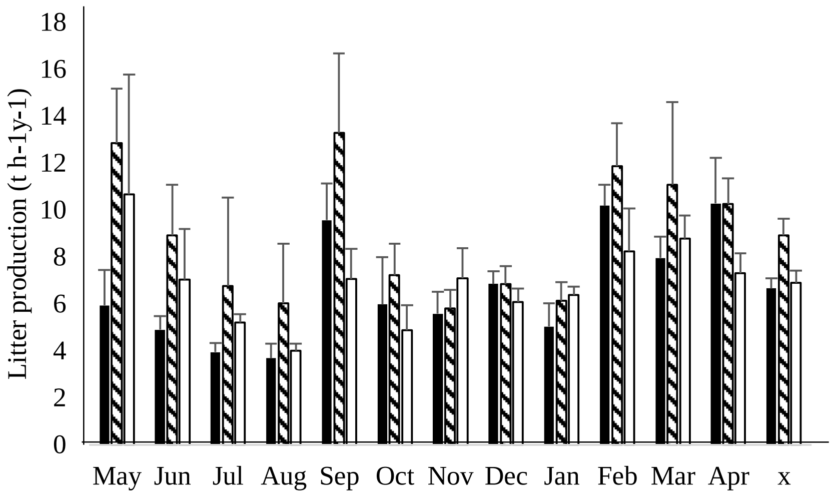

Figure 2. Monthly litter production (t $h^{-1}.y^{-1}$) of mangrove in Kema. x=average of annual litter production. LW (■); MZ (▧); SW (□).

During the dry season, higher temperatures elevate the cellular metabolism rate and trigger more litter production to cope with the higher salt concentration. Salt is accumulated through senescent leaves and shortly falls into the forest floor [26]. Beside tidal inundation, the freshwater input may affect the salinity. Litter production is also controlled by a nutrient concentration which is regulated by rainfall and riverine input [40]. It is not only to support mangrove productivity but also to bring nutrient, dissolved gases and suspended materials for salinity regulation [44].

4. Conclusion

Kema mangroves delivered moderate litter production over the year and tended to be constant during the season peak and soar along transition periods. Spatial variation of litter production is proven to be significant and relate to soil phosphate content and salinity. Mangrove species composition also bring a variation of fallen litter which is stratified following the environmental parameters.

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