Comparison of litter production between natural and reforested mangrove areas in Central Philippines

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Abstract. Litter production in natural and reforested mangrove areas was measured for a one-year cycle, from July 2105 to June 2016, in three sites: Bais (Negros Oriental), Alcantara (Cebu Province), and Pangangan Island (Bohol Province). In Bais, total litter production was higher in natural mangrove forests with mean of 8.38 g m^{-2} day^{-1} (n = 12, SD = 3.75) than in reforested mangrove forests with mean of 3.45 g m^{-2} day^{-1} (n = 12, SD = 1.92). There was no significant correlation between monthly litter production and monthly rainfall (Pearson's r = 0.195; p = 0.544, n = 12). Based on quarterly data, leaf fall production was higher in natural mangrove forests than in reforested mangrove areas. Among the three sites, leaf fall production was higher in natural forest in Alcantara with mean of 7.43 g m^{-2} day^{-1} (n = 20, SD= 4.33) followed by Pangangan Island 7.06 g m^{-2} day^{-1} (n = 24, SD= 3.98) and Bais with the value of of 6.04 g m^{-2} day^{-1} (n = 24, SD = 1.89) whereas in reforested mangrove forests, the leaf fall production was observed to be higher in Pangangan Island with the value of 6.52 g m^{-2} day^{-1} (n = 24, SD = 2.78), followed by Alcantara with the value of 6.22 g m^{-2} day^{-1} (n = 20, SD = 3.29) and Bais with the value of 2.69 g m^{-2} day^{-1} (n = 32, SD =1.78). For the litter components, leaves were the main components, followed by fruits, twigs, flowers, and miscellaneous. This study showed that the natural mangrove forest has high production values of litter compared to the reforested mangrove area.

Key Words: mangrove, litter production, leaf fall production, litter components.

Introduction. Mangroves are tropical and subtropical marine plants that used to cover up to 75% of tropical coastlines. The most recent estimates suggest that mangroves presently occupy approximately 14 to 24 million ha of tropical and subtropical coastlines, which are mostly threatened by anthropogenic factors (Giri et al 2011). This ecosystem occurs mainly in sheltered areas such as estuaries, bays, and lagoons and is considered an open system due to its significant material exchanges with terrestrial, ocean, estuarine, and atmospheric environment (Lugo 2002).

Among tropical marine ecosystems, mangroves rank second in importance after coral reefs as regards of gross productivity (Wafar et al 1997; Duarte & Cebrián 1996). Because it is logistically and economically viable, litter production has been widely used to evaluate the productivity of mangroves (Putz & Chan 1986; Hegazy 1998; Silva et al 1998; Aké-Castilho et al 2006). Besides being used as an indicator of productivity, litter can also provide indirect evidence about plants phenology (Proctor 1983).

Litter can represent up to one third of mangrove primary production (Robertson & Daniel 1989) and may be remineralized by decomposition, accumulated in the sediment and/or exported to adjacent areas (Pool et al 1975). The export level of dissolved and particulate materials from the litter depends on geomorphology and tidal amplitude and tends to be larger in mangroves located in coastal areas dominated by tides or under strong river influence (Woodroffe 1992; Twilley et al 1997; Twilley & Day 1999).

In general, leaves are the main components of litter, accounting for more than 50% of the total production (Hossain & Hoque 2008). Although there are regional differences in its fall and variations in exchange with the ocean, the annual global production rate of this component is estimated at 92×1,012 g C, of which 25% accumulates in the sediment, 25% is recycled within the ecosystem, and 50% is exported to the coastal zone (Robertson & Daniel 1989).

Litter production of mangrove forests usually presents seasonal variation because it is influenced by several factors mainly related to the chemical and physical environment, for example: air temperature, solar radiation, rainfall, type of substrate, nutrient concentration, and freshwater availability (Clough 1992; Twilley & Day 1999). On a global scale, litter production varies between 1.0 and 20.3 t ha^{-1} $year^{-1}$, and in spite of regional and local variations, the values tend to decline with increase in latitude (Twilley & Day 1999; Mehlig 2001). Riverine forests are the most productive, followed by fringe and basin forests (Twilley & Day 1999).

The Talabong Marine and Wildlife Sanctuary mangroves cover approximately 250 ha (Calumpong 1994). Studies on mangrove productivity in the Philippines were first conducted by De Leon et al (1991) in a natural mangrove forest located in Bais Bay. No data were available for the reforested site, which is located in North Bais Bay. In Pangangan Island, Bohol, the mangrove forest covers roughly 158 ha (Cadiz & de Leon 1997). The planting of mangrove in Bohol, especially at Pangangan Island, started in 1986 by the Central Visayas Regional Project and the Department of Environment and Natural Resources (DENR) and has continued steadily ever since. Reforested mangrove areas in Cebu were established also in 1986 by the Central Visayas Regional Project in five municipalities – Ronda, Alcantara, Moalboal, Badian, and Alegria. The total area of mangrove cover was 152 ha (Cadiz & de Leon 1997). All the aforementioned sites have both natural and reforested mangrove forests (see details in Figure 1).

The main objective of this study is to compare litter production between natural and reforested mangrove forests. It is hoped that the findings of this study will help in better management in protecting and conserving mangrove forests in the Philippines.

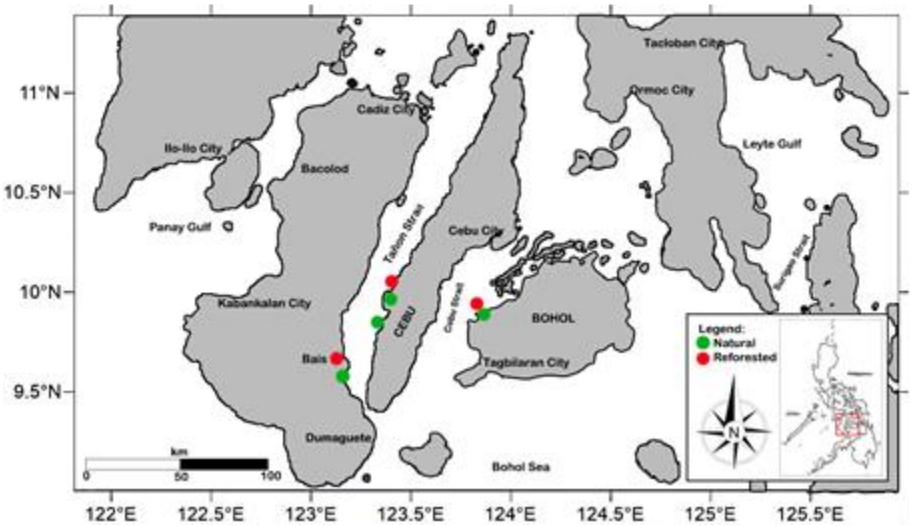


Figure 1. Map of the study sites.

Material and Method

Description of study sites. This study was conducted in Bais, Alcantara, and Pangangan Island, Philippines from July 2015 to June 2016. In the Philippines, the tropical climate is humid, and the seasons are not very pronounced; it is relatively dry from November to April and wet for the rest of the year.

Litter production. Mangrove productivity was determined by measuring litter production using 1×1 m litter traps. In each site, two traps were placed under each species with a minimum of six plots per site. These traps were tied to the prop roots or trunks of the mangrove tree, approximately 1 m above ground so that they would not be inundated by high tides (Calumpong & Cadiz 2012). The plots measuring 10x10 m were established based on English et al (1994).

Collection of litter fall was done 24 hours after the net was laid and on a quarterly duration during the period July 2015 to June 2016, except in Bais, where additional collections were done every fortnight per month for a period of one year. This was done to validate the 24-hour collections. For the fortnight collections, the rate of litter fall was calculated by dividing the dry weight of litter (g $DW{\cdot}m^{-2}$) by the number of days (14 days) between each collection date. The calculations were as follows:

$$\frac{\text{Dry Weight of Litter (g DW m}^{-2}\text{)}}{\text{Number of Days between Each Collection Date}} \quad \text{g DW m}^{-2}\ \text{day}^{-1}$$

T-test results showed significant difference ($t = -13.83$; p = 3.25*E-13) for fortnight and 24-hour data of litter production between natural and reforested areas. Thus, in comparing sites, only the 24-hour values for the specific quarter were used.

The materials collected were first sorted into the following fractions: leaves, flowers, fruit, wood (twigs), and miscellaneous (all plant materials <2 mm and occasional structures of other species) based on the method of Bernini & Rezende (2010). These were oven-dried until constant weight (80ºC/72 hours).

The production data were also transformed to t $ha^{-1}year^{-1}$ (Day et al 1987). The climatic data were obtained from the Philippine Atmospheric, Geophysical, and Astronomical Services Administrations (PAGASA) stations in Dumaguete City, Negros Oriental and in Dauis, Bohol.

Figure 2. Litter trap under *Avicennia marina* in Bais Natural Forest.

Statistical analyses. To determine significant differences in monthly litterfall production between natural and reforested areas, independent *T*-test and two-way ANOVA at α = 0.05 confidence level were performed using SPSS Statistic (version 21 for Windows). A post hoc test was applied to determine the months that caused the significant difference. Data on litterfall were normalized using log10 (× + 1) when analyzed using the two-way ANOVA. Equal variances assumed of Tukey's HSD were used as a post hoc test to compare litter production among sites using factorial ANOVA. Pearson's product-moment correlations were used to detect possible relationships between monthly litterfall production and diameter at breast height (DBH) per species as well as selected environment variables such as rainfall and organic matter in the soil.

Results

Litter production. Litterfall rate varied monthly between natural and reforested forests in Bais. Litter fall production in natural forests range from 4.43±1.51 to 13.59±7.11 g DW m^{-2} day^{-1} higher than in reforested areas, 2.39±1.38 to 4.49±3.37 g DW m^{-2} day^{-1}. Mean annual rates of litter fall for natural and reforested areas were estimated at 8.38±3.75 g DW m^{-2} day^{-1} and 3.45 ± 1.92 g DW m^{-2} day^{-1} respectively (Table 1).

Litterfall varied significantly between natural and reforested areas (F = 16.26, p = 0.00, n = 72). Rate of litterfall in natural mangrove forest peaked in August and April (13.59±7.11 and 10.30±1.09 g DW m^{-2} day^{-1}) and was lowest in January (4.43±1.51 g DW m^{-2} day^{-1}), whereas in reforested areas, it peaked in April (4.49±3.37 g DW m^{-2} day^{-1}) and was lowest in January (2.56±1.24 g DW m^{-2} day^{-1}) (see Table 1 for details).

Table 1

Mean monthly litterfall production (g DW m^{-2} day^{-1}) in Bais natural and reforested areas from July 2015 to June 2016

Months	*Bais*		*Average rainfall (mm)*
	Natural forest	Reforested areas	
July	10.53±6.36	2.39±1.38	3.9
August	13.59±7.11	3.77±2.66	2.8
September	5.67±3.06	4.26±1.79	5.3
October	8.75±2.52	4.46±2.18	2.5
November	7.97±1.62	3.66±1.59	0.8
December	6.22±1.05	2.89±1.52	0.3
January	4.43±1.51	2.56±1.24	0.6
February	6.23±1.37	2.81±0.93	0.6
March	8.15±2.01	3.58±1.09	0.0
April	10.30±1.09	4.49±3.37	0.0
May	6.89±2.30	2.69±1.57	0.3
June	7.09±6.67	3.21±1.67	0.0
Mean	8.38±3.75	3.45±1.92	-

The average monthly litter fall production and average rainfall showed no significant correlation (Pearson's r = 0. 195, p = 0.544, n = 72). The increases in litterfall rate in August and April in natural forest and in April in reforested areas could not be attributed to monthly rainfall values, which were low (2.8 and 0.0 mm). In November and December, average monthly rainfall decreased substantially, and average monthly rain peaked in the month of September (5.3 mm) (Figure 3).

Based on the quarterly data among the three sites, the rate of leaf fall varied significantly between natural and reforested mangrove forests (Factorial ANOVA, F(1,120) = 19.759, p = 0.000) and among the three sampling sites (Factorial ANOVA, F(2,120) = 16.539, p = 0.000) (Table 2).

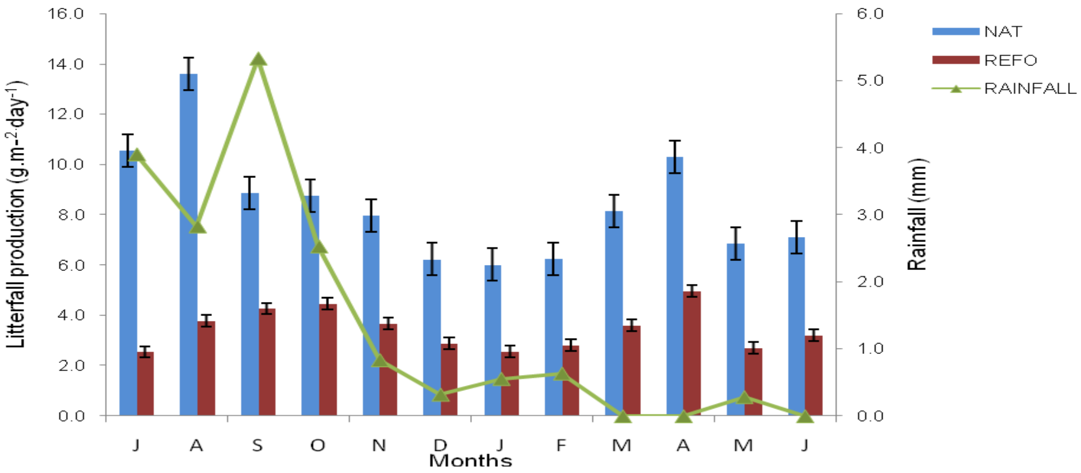


Figure 3. Mean monthly rate of litterfall (g DW m^{-2} day^{-1}) from July 2015 to June 2016 for Bais natural and reforested mangrove forests, with average monthly rainfall (mm). Legend: NAT – Bais natural; REFO – Bais reforested (data source of monthly rainfall: PAGASA station, Dumaguete City).

Table 2

Mean quarterly leaf fall production (g DW m^{-2} day^{-1}) in natural and reforested areas in Bais, Alcantara, and Pangangan Island

Month	*Bais*		*Alcantara*		*Pangangan Island*	
	Natural	*Reforested*	*Natural*	*Reforested*	*Natural*	*Reforested*
August	6.53±1.29	3.25±2.37	1.28±0.50	1.96±1.84	3.05±1.67	8.48±1.70
October	6.76±0.72	3.85±1.62	9.08±2.69	7.44±2.49	7.49±4.51	6.73±2.99
January	4.83±0.99	1.68±0.89	9.17±2.76	6.59±1.86	8.36±3.29	8.12±2.69
May	6.04±1.92	1.99±1.18	10.25±3.11	8.88±2.19	9.34±3.35	7.73±2.99
Mean	6.04±1.89	2.69±1.78	7.43±4.33	6.22±3.29	7.06±3.98	6.52±2.78

In Bais, leaf fall production in natural forest was 6.04±1.89 g DW m^{-2} day^{-1} higher than in the reforested areas, 2.69±1.78 g DW m^{-2} day^{-1}. Comparing the leaf fall production between the forests using the independent sample *T*-test, the results showed a highly significant difference (t = 7.09: p = 0.000, n = 58) (see Tables 2 & 3 for details).

Table 3

Independent *T*-test on the comparison of overall leaf production of natural and reforested forests in Bais, Alcantara, and Pangangan Island (SD = standard deviation)

Site	*Forest type*	*Mean*	*SD*	*T-test*	*p*
Bais	Natural	6.04	1.89	7.09	0.000*
	Reforested	2.69	1.78		
Alcantara	Natural	7.43	4.33	1.001	0.32
	Reforested	6.22	3.29		
Pangangan Island	Natural	7.06	3.98	0.55	0.59
	Reforested	6.52	2.78		

Figure 4 shows the leaf fall production in natural and reforested forests in Bais.

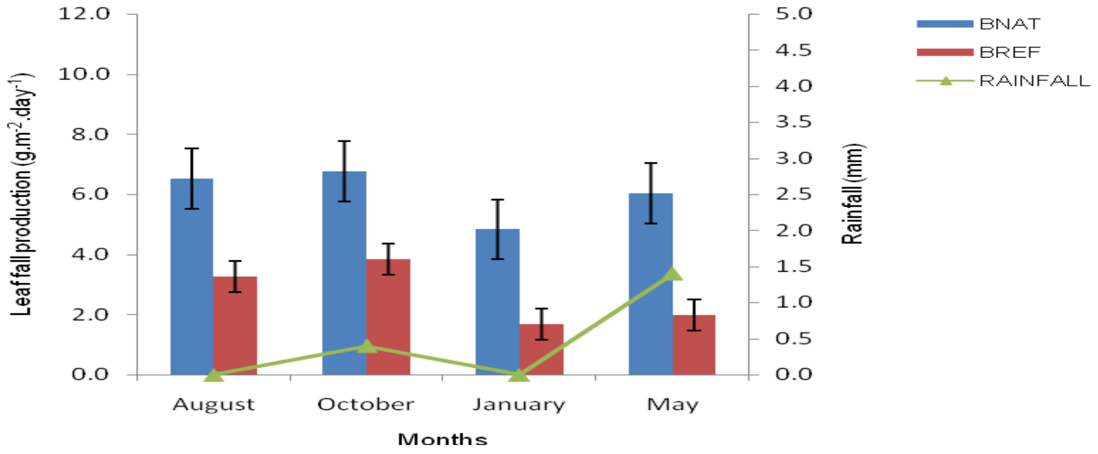


Figure 4. Mean quarterly leaf fall production (g DW m^{-2} day^{-1}) in Bais natural and reforested mangrove forests with average quarterly rainfall (mm). Legend: BNAT – Bais natural; BREF – Bais reforested (data source of quarterly rainfall: PAGASA station, Dumaguete City).

In Alcantara, leaf fall production in natural forest was 7.43±4.33 g DW m^{-2} day^{-1} higher than in the reforested areas, 6.22±3.29 g DW m^{-2} day^{-1}. Comparing the leaf fall production between forests using the independent sample *T*-test, the results showed no significant difference (t = 1.001: p= 0.32, n = 40) (see Table 3 for details).

Figure 5 shows the leaf fall production in natural and reforested forests in Alcantara.

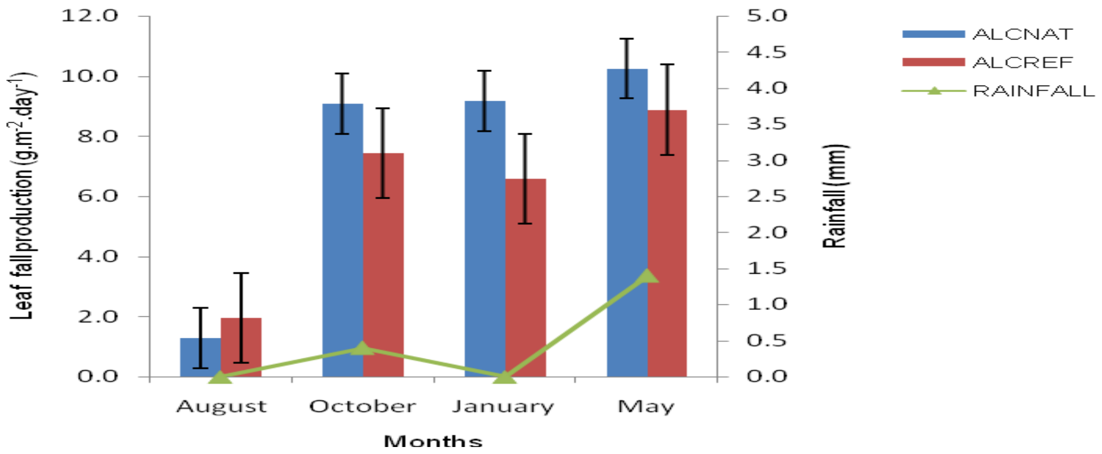


Figure 5. Mean quarterly leaf fall production (g DW m^{-2} day^{-1}) in Alcantara natural and reforested mangrove forests. Legend: ALCNAT – Alcantara natural; ALCREF – Alcantara reforested (data source of quarterly rainfall: PAGASA station, Dumaguete City).

In Pangangan Island, leaf fall production in natural forest was 7.06±3.99 g DW m^{-2} day^{-1} higher than in the reforested forest, 6.52±2.78 g DW m^{-2} day^{-1}. Comparing the forests using the independent sample *T*-test, the results showed no significant difference (t = 0.55, p = 0.59, n = 45) (Table 3 for details).

Figure 6 shows the leaf fall production in natural and reforested forests in Pangangan Island.

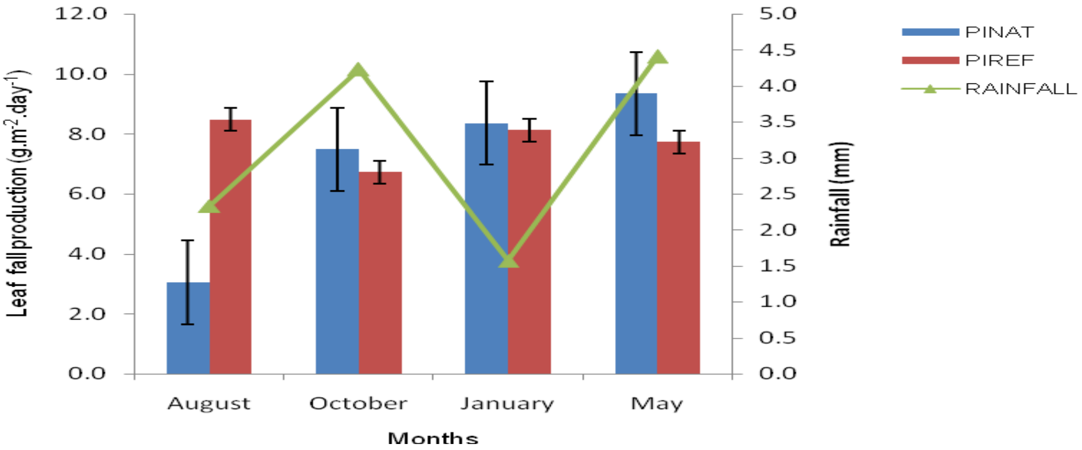


Figure 6. Mean quarterly leaf fall production (g DW m^{-2} day^{-1}) in Pangangan Island natural and reforested mangrove forests. Legend: PINAT – Pangangan Island natural forest; PIREF – Pangangan Island reforested (data source of quarterly rainfall: PAGASA station, Dauis, Bohol).

Among the sites, there was a significant difference between Bais and Pangangan Island (Tukey HSD, $p<0.05$) and Alcantara (Tukey HSD, $p<0.05$), respectively. There was no significant difference between Pangangan Island and Alcantara (Tukey HSD, $p>0.05$; see Table 3 for details).

Litter fall components. The phenology of mangrove trees in both natural and reforested mangrove forests was also assessed in three dominant species, namely, *A. marina*, *R. stylosa*, *and S. alba* where the three species were present on both natural and reforested areas. In the natural forest, flower fall peaked in May for *A. marina*, in June for *S. alba*, and in December for *R. stylosa*; whereas in reforested areas, flower fall peaked in March for *A. marina* and in December for *R. stylosa* (Figures 7, 8, 9). Fruit fall peaked in August for *A. marina* and *S. alba* and in September for *R. stylosa* in natural forest; whereas in the reforested areas, fruit fall peaked in March for *S. alba* (see Figure 9 for details). Leaf fall contributed 67% to 71% and 75% to 86% of total litterfall in natural and reforested areas, respectively.

The components of litterfall differed significantly (F = 545.07, p = 0.000, n = 216). The components of litter fall among species followed this order: natural mangrove forest, for the leaves: *S. alba* (2.53±0.76 g DW m^{-2} day^{-1}) > *R. stylosa* (2.02±0.6 g DW m^{-2} day^{-1}) > *A. marina* (1.75±0.43 g DW m^{-2} day^{-1}); for the fruits: *S. alba* (0.63±0.61 g DW m^{-2} day^{-1}) > *R. stylosa* (0.51±1.01 g DW m^{-2} day^{-1}) > *A. marina* (0.29±0.52 g DW m^{-2} day^{-1}); for the twigs: *S. alba* (0.40±0.31 g DW m^{-2} day^{-1}) > *A. marina* (0.23±0.20 g DW m^{-2} day^{-1}) > *R. stylosa* (0.23±0.11 g DW m^{-2} day^{-1}); for the flowers: *R. stylosa* (0.36±0.26 g DW m^{-2} day^{-1}) > *A. marina* (0.17±0.18 g DW m^{-2} day^{-1}) > *S. alba* (0.04±0.09 g DW m^{-2} day^{-1}) > miscellaneous: *A. marina* (0.14±0.35 g DW m^{-2} day^{-1}) > *S. alba* (0.12±0.19 g DW m^{-2} day^{-1}) > *R. stylosa* (0.008±0.003 g DW m^{-2} day^{-1}); and for the total litter fall: *S. alba* (3.70±1.24 g DW m^{-2} day^{-1}) > *R. stylosa* (3.5±1.39 g DW m^{-2} day^{-1}) > *A. marina* (2.59±1.13 g DW m^{-2} day^{-1}). In reforested mangrove area, for the leaves: *R. stylosa* (2.78±0.89 g DW m^{-2} day^{-1}) > *A. marina* (2.02±0.65 g DW m^{-2} day^{-1}) > *S. alba* (0.43±0.14 g DW m^{-2} day^{-1}); the fruits: *S. alba* (0.13±0.13 g DW m^{-2} day^{-1}) > *R. stylosa* (0.05±0.09 g DW m^{-2} day^{-1}) > *A. marina* (0.01±0.01 g DW m^{-2} day^{-1}); for the twigs: *A. marina* (0.23±0.11 g DW m^{-2} day^{-1}) > *R. stylosa* (0.06±0.09 g DW m^{-2} day^{-1}) > *S. alba* (0.07±0.04 g DW m^{-2} day^{-1}); for the flowers: *R. stylosa* (0.22±0.21 g DW m^{-2} day^{-1}) > *A. marina* (0.17±0.20 g DW m^{-2} day^{-1}) > *S. alba* (0.0 g DW m^{-2} day^{-1}); and miscellaneous: *A. marina* (0.06±0.06 g DW m^{-2} day^{-1}) > *R. stylosa* (0.008±0.03 g DW m^{-2} day^{-1}) > *S. alba* (0.005±0.02 g DW m^{-2} day^{-1}); and for the total litter fall: *R. stylosa* (3.23±0.85 g DW m^{-2} day^{-1}) > *A. marina*

(2.50±0.65 g DW m^{-2} day^{-1}) > *S. alba* (0.52±0.14 g DW m^{-2} day^{-1}) (see Table 4 for details).

Table 4

Component weights average (g DW m^{-2} day^{-1}) of annual litterfall of the three dominant mangroves species in Bais natural and reforested mangrove forests from July 2015 to June 2016

Species	*Leaves*	*Flowers*	*Fruits*	*Twig*	*Mixed*	*Total*
			Avicennia marina			
			Natural forest			
Mean±SD	1.75±0.43	0.17±0.18	0.29±0.52	0.23±0.20	0.14±0.35	2.59±1.13
Median	1.7	0.10	0.05	0.10	0.00	2.24
Min. & max.	1.00–2.30	0.00–0.50	0.00–1.60	0.00–1.60	0.00–1.20	1.56–5.80
			Reforested area			
Mean±SD	2.02±0.65	0.17±0.20	0.01±0.01	0.23±0.11	0.06±0.06	2.50±0.65
Median	1.96	0.1	0.00	0.24	0.05	2.40
Min. & max.	1.29–3.12	0.00–0.62	0.00–0.05	0.09–0.44	0.00–0.16	1.72–3.59
			Rhizophora stylosa			
			Natural forest			
Mean±SD	2.51±0.62	0.36±0.26	0.51±1.01	0.1±0.13	0.008±0.03	3.5±1.39
Median	2.45	0.35	0.1	0.005	0.0	3.05
Min. & max.	1.60–3.80	0.0–0.90	0.0–2.90	0.0–0.04	0.00–0.10	2.30–6.40
			Reforested area			
Mean±SD	2.78±0.89	0.22±0.21	0.05±0.09	0.06±0.09	0.008±0.03	3.23±0.85
Median	2.61	0.16	0.1	0.0	0.0	0.72
Min. & max.	1.21–4.33	0.0–0.59	0.0–0.32	0.0–0.30	0.0–0.28	1.76–4.45
			Sonneratia alba			
			Natural forest			
Mean±SD	2.53±0.76	0.04±0.09	0.63±0.61	0.40±0.31	0.12±0.19	3.70±1.24
Median	2.20	0.0	0.40	0.30	0.1	3.65
Min. & max.	1.70–3.90	0.0–1.80	0.0–1.10	0.0–0.30	0.0–0.70	2.20–6.32
			Reforested area			
Mean±SD	0.43±0.14	-	0.13±0.13	0.07±0.04	0.005±0.02	0.52±0.14
Median	0.45	-	0.008	0.008	0.0	0.56
Min. & max.	0.21–0.63	0.0–0.37	0.0–1.13	0.0–0.06	0.0–0.6	0.26–0.68

($p<0.05$), SD - standard deviation.

Figure 7 shows a comparison of litter fall components of *A. marina* in natural and reforested areas. Comparing litter fall components of natural and reforested area using two-way ANOVA, the results show a significant difference (F = 184.08, p = 0.000, n = 216). The results of post hoc test shows that litterfall components were significantly different.

Figure 8 shows a comparison of litter fall components of *R. stylosa* in natural and reforested areas. Comparing litter fall components of *R. stylosa* in natural and reforested areas using two-way ANOVA, the results show a significant difference (F = 218.82, p = 0.000, n = 72). The results of post hoc test show that litterfall components were significantly different.

Figure 9 shows a comparison of litter fall components of *S. alba* in natural and reforested areas. Comparing litterfall components of *S. alba* in natural and reforested areas using two-way ANOVA, the results show a significant difference (F = 218.82, p = 0.000, n = 72). The results of post hoc test show that litter fall components were significantly different.

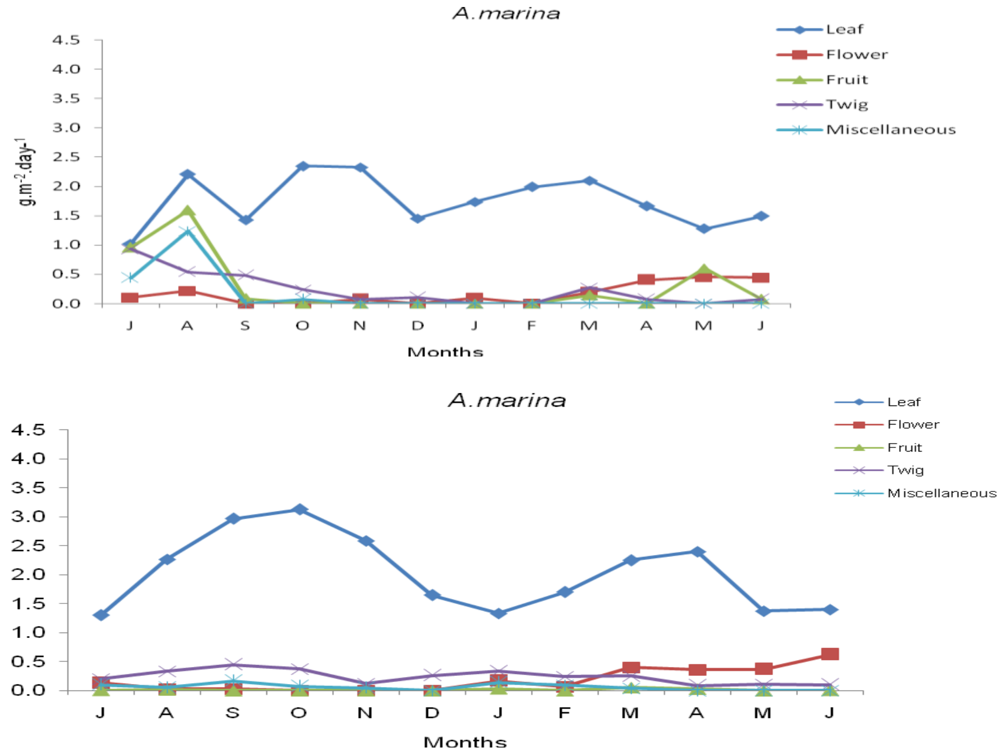


Figure 7. Litter production of *A. marina* (g DW m^{-2} day^{-1}) in Bais natural and reforested mangrove forests over the intervals sampled in July 2015 up to June 2016. Top: natural mangrove forest; bottom: reforested mangrove area.

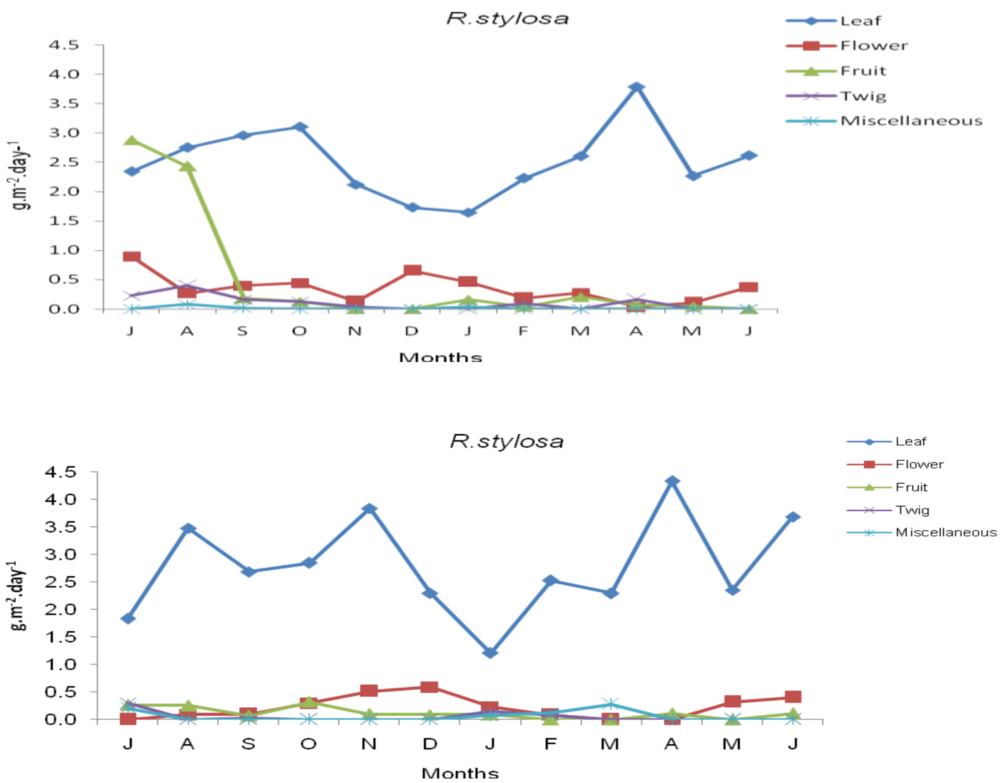
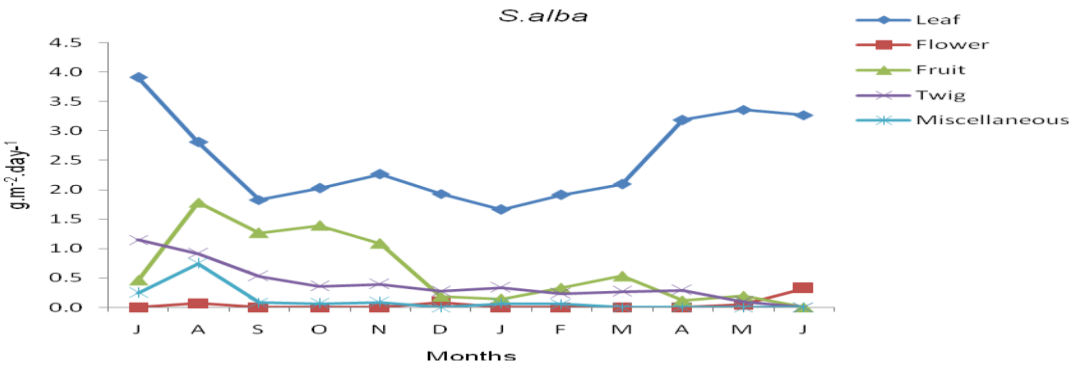


Figure 8. Litter production of *R. stylosa* (g DW m^{-2} day^{-1}) in Bais natural and reforested mangrove forests over the intervals sampled July 2015 up to June 2016. Top: Natural mangrove forest; bottom: reforested mangrove area.



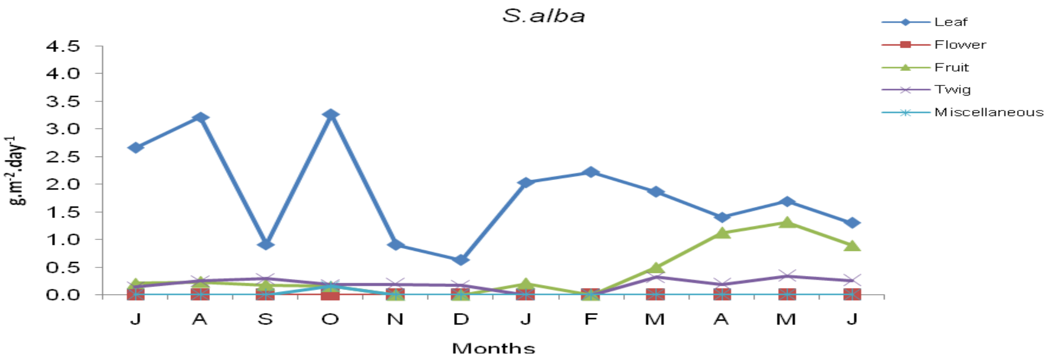


Figure 9. Litter production of *S. alba* (g DW m^{-2} day^{-1}) in Bais natural and reforested mangrove forests over the intervals sampled in July 2015 up to June 2016. Top: natural mangrove forest; bottom: reforested mangrove area.

Summary of average DBH of *A. marina*, *R. stylosa*, and *S. alba* is given in Table 5. Both *A. marina* and *R. stylosa* showed no significant difference of DBH and litter production (r = 0.016, p = 0.924; r = 0.024, p = 0.897). Both *A. marina* and *R. stylosa* has smaller sizes of DBH ranging from 11.51±3.57 cm to 12.21±3.32 cm. Contrarily, there is a significant difference of DBH and litter production of *S. alba* (r = 0.369, p = 0.032), which has bigger size of DBH of 34.22±14.06 cm.

Table 5

Correlation of species, DBH, and litter production in three dominant species study sites

Species	*Average DBH (cm)*	*Average litter production (g DW m^{-2} day^{-1})*	*r*	*p*
Avicennia marina	12.21±3.32	4.10±1.79	0.016	0.924
Rhizophora stylosa	11.55±3.57	4.84±1.13	0.024	0.897
Sonneratia alba	34.22±14.06	4.75±1.49	0.369	0.032*

Correlation of species density and litter production is given in Table 6. The positive correlation of species density and litter production was observed in Bais natural and reforested areas and in Pangangan Island natural forest, with species density per plot ranging from 21.37±4.47 to 27.16±3.19 and 29.00±1.41, respectively. In Alcantara, there was no significant difference of species density and litter production, as both natural and reforested forests has a similar species density of 23.40±2.19 to 23.80±1.30.

Table 6

Correlation of species density and litter production of the study sites

Sites	Average density	Average litter production (*g DW m^{-2} day^{-1}*)	*r*	*p*
Bais natural	27.16±3.19	8.38±2.21	−0.828	0.042*
Bais reforested	21.37±4.47	3.44±1.36	0.815	0.014*
Alcantara natural	23.40±2.19	9.74±3.12	−0.431	0.469
Alcantara reforested	23. 80±1.30	7.67±2.75	0.431	0.469
Pangangan I. natural	29.00±1.41	8.28±3.13	0.910	0.012*
Panganga I. reforested	22.00±1.54	6.59±1.69	0.203	0.700

A significant positive correlation of OM content and litter production was observed in Bais (*r* = 0.725, p = 0.003, n = 14) and Alcantara (*r* = −0.775, p = 0.008, n = 10), whereas in Pangangan Island, the results showed no significant correlation of OM content and litter production between the forests (*r* = 0.206, p = 0.520, n = 12). The Pearsons' correlation of OM content and litter production of the three study sites are given in Table 7.

Table 7

Correlation of OM content and litter production in the three study sites

Sites	*Average OM content*	*Average litter production (g DW m^{-2} day^{-1})*	*R*	*p*
Bais natural Bais reforested	56.92±16.44	5.56±3.05	0.725	0.003*
Alcantara natural Alcantara reforested	63.03±6.73	8.70±2.97	−0.775	0.008*
Pangangan I. natural Pangangan I reforested	71.28±8.38	7.43±2.55	0.206	0.520

Discussion

Litter production. The annual litter production estimated for the mangrove forests in Bais is higher compared to the annual litter production of the mangrove forests in several locations around the world as presented in Table 8 (Bernini & Rezende 2010). In Bais, higher litter production was recorded in natural forest compared to reforested area.

According to Hossain & Haque (2008), mixed stands produce more litter compared to mono-specific stands. This trend was observed in Bais natural forest, which consisted of mixed stands; the litter fall productivity was higher (30.58 t ha^{-1} $year^{-1}$). These are comparable with the forests in Brazil, which consist of mixed stands of *Avicennia germinans*, *Laguncularia racemosa*, and *Rhizophora mangle* and the litter fall productivity was 20.3 t ha^{-1} $year^{-1}$ (Mehlig 2001). Meanwhile, reforested area has lower litter production (12.59 t ha^{-1} $year^{-1}$) compared to forest of a monostand of *A. marina* in Arabia (17 t ha^{-1} $year^{-1}$) (Hegazy 1998) and a monostand of *A. marina* in Australia (15 t ha^{-1} $year^{-1}$) (Bunt 1995).

The rate of litter production showed significant positive correlation with stand density in Bais natural and reforested areas (*r* = 0.042, p = 0.014; *r* = 0.815, p = 0.014) and also in Pangangan Island natural forest (*r* = 0.910, p = 0.012). A significant negative correlation was observed in Alcantara natural and reforested forests (*r* = −0.431, p = 0.469; *r* = 0.431, p = 0.469). This corresponds to the study of Mahmood & Saberi (2005), which reported that a mangrove stand density of 2,180 stems per hectare at

Kuala Selangor, Malaysia produces almost twice the amount of litter compared to a mangrove stand with a density of 166 stems per hectare.

Table 8

Rate of litter production by different mangrove species

Location	*Species*	*Dry weight ($g/m^2/day$)*	*Reference*
Bais natural forest	Mixed species	8.38	Present study
Bais reforested forest	Mono species	3.45	Present study
Hinchinbrook Island, Australia	*Rhizophora* spp. *C. tagal* *B. gymnorrhiza* *B. parviflora* *Avicennia* spp. *S. alba*	2.99 1.97 2.19 2.74 2.19 2.16	Duke et al 1981
Sungai Merbok, Malaysia	*R. apiculata* *R. mucronata* *B. gymnorrhiza*	2.76	Ong et al 1995
Western Port Bay, Australia	*Avicennia* spp.	0.55	Clough & Attiwill 1982
Kuala Selangor, Malaysia	*Avicennia* spp. *S. alba* *Rhizophora* spp.	4.22 3.84 4.32	Sasekumar & Loi 1983
Matang Mangrove, Malaysia	*R. apiculata (planted)* *R. apiculata* *R. mucronata* *Bruguiera* spp.	1.91 0 3.12, 2.09	Gong et al 1984
Southwest Florida	*Avicennia* spp. *Rhizophora* spp.	1.22 2.22	Twilley et al 1986
Ohura Bay, Okinawa	Mixed mangrove	2.11–2.94	Hardiwinoto et al 1989
Transkei estuaries, South Africa	Mixed mangrove	1.25	Steinke & Ward 1990
Okinawa, Japan	Mixed mangrove	3.55	Mfilinge et al 2005

The present study shows that OM content has a positive correlation with litter production (Table 7). According to Twilley & Day (1999), a variety of factors may influence the productivity of mangrove forests. Most factors associated with changes in the physical or chemical environment include solar radiation, temperature, tides, nutrient concentration, and pH. In addition, the individual plant species present in the area can also affect patterns of productivity because some plants have growth rates that are intrinsically higher than others (Twilley & Day 1999).

As regards sizes of DBH of trees present in the study sites, the findings show that there is a positive correlation between DBH per species and litter production (Table 5). Among the three species observed during the course of the study, *Sonneratia alba* showed significant positive correlation (r = 0.369, p = 0.032) with average DBH of 34.22±14.06. On the contrary, *A. marina* and *R. stylosa* showed no correlation between DBH and litter production (r = 0.016, p = 0.924; r = 0.024, p = 0.897), with the average DBH ranging from 12.21±3.32 and 11.51±3.57 (Table 5).

The result of the present study showed no correlation between total monthly litter fall production and monthly rainfall. The findings are similar to results obtained by Ramos de Silva et al (2006) who studied *R. mangle* forest in Rio Grande do Norte, Brazil, and found no correlation between litter fall and rainfall. Similarly to our results Lopez-Portilho & Ezcurra (1985) showed no correlation between rainfall and litter production of *A. marina*. This fact indicates that productivity can be influenced by other factors such as nutrient availability (Twilley 1995) which is located along gradient of flooding and geomorphologic peculiar environment, where the species occur (Lopez-Portilho & Ezcurra, 1985), along physiological characteristics of species (Twilley et al 1997).

Higher rate of litter production in mangroves is usually observed during the dry season (Aksornkoae & Khemnark 1984; Bunt 1995). Lugo & Snedaker (1975) observed that soil and water salinity and higher rate of evapotranspiration facilitate the shedding of leaves in an energetically cheaper way.

Results from quarterly data among the three study sites show that leaf fall production is higher in natural forest than reforested area. The leaf fall production rate seems to vary with stand age. These findings are comparable with the study done by Gong et al (1984), which showed that the rate of litter production in different ages (5–25 years old) of *R. apiculata* stands in Matang Mangrove Reserve was different with stand ages. The annual litter fall (11.40 t ha^{-1} $year^{-1}$) was higher in 25-year-old stands followed by younger-aged stands.

Litterfall components. Individual species may differ in the conditions that produce heavy litter. Moreover, productivity may also vary from habitat to habitat, and habitat-specific stresses like aridity and nutrient conditions. For instance, the offset trend for *R. stylosa* is mainly attributed to its reproductive season. Its flowering season culminates in December, while fruits of propagules start to fall off in August and the rest of the months, which constitute a significant component of the litter that reached up to 71.92% of the total litter.

In this study, the rate of different litter components varies between natural and reforested areas. The different pattern of litterfall components between natural and reforested areas described in this study is an indication that there was a variation in mangrove stand age. The litter fall components in natural forest are higher than reforested area. The proportion of various litter components varied with the age of the stands. The present study showed that the proportion of leaves of natural forest was 69.25% and that of reforested area was 80.69%, respectively.

The proportion of litter components also varies with species. In natural forest, the proportion of leaves among species followed the following order: *R. stylosa* (71.92%), *S. alba* (68.07%), and *A. marina* (67.77%); whereas in reforested area, the proportion of leaves among species followed the following order: *R. stylosa* (86%), *A. marina* (80.72%), and *S. alba* (75.12%). This value was comparable with a study by Wafar et al (1997) on four different species, namely, *R. apiculata*, *R. mucronata*, *S. alba*, and *A. officinalis* in Mandovi-Zuari, Central West Coast of India, which showed that the percentage contribution of litter components varied among species and the percent contribution of leaves, flowers, fruit, and miscellaneous varied from 43% to 68%, 3% to 8%, 10% to 19%, and 10% to 39%, respectively.

The proportions of fruits or propagules in natural and reforested forests were 14.22% and 6.81%, respectively. These values are comparable to the study by Clough et al (2000) showing that the proportion of propagules represented less than 1% of the total litter fall in 6- to 12-year-old stands, but it was 26% and 38% in 21- and 36-year-old stands, respectively.

The contribution of flower to the total litterfall was 5.91% in natural forest and 4.66% in reforested forest. Flower proportion is much higher (5.8%) in older stands and 6.1% in stands of 21- and 36-year-old stands, respectively. The rate of litter production usually increased with the increasing age of stands but the rate almost remained constant after a certain age (Clough et al 2000).

Conclusions. Based on the findings, average annual litter production in Bais natural mangrove forest showed significantly higher litter production compared with reforested areas ($F = 16.29$; $p = 0.00$, $n = 72$). Litter fall production in natural forests ranged from 4.43±1.51 to 13.59±7.11 g DW m^{-2} day^{-1} and in the reforested area ranged from 2.39± 1.38 to 4.49±3.37 g DW m^{-2} day^{-1}. Mean annual rates of litter fall for natural and reforested areas were estimated at 8.38±3.75 and 3.45±1.92 g DW m^{-2} day^{-1}, respectively. Leaf fall production in natural and reforested areas in sites studied differed significantly among the three study sites (Factorial ANOVA, $F(2,120) = 16.539$, p =

0.000). The components of litterfall differed significantly ($F = 545.07$, $p = 0.000$, $n = 216$), and leaf fraction was the main component of litter (69.25% to 80.69%), followed by fruits (6.81% to 14.22%), twigs (2.94% to 10.90%), flowers (4.66% to 5.91%) and miscellaneous (0.33% to 5.65%).

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