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นิพนธ์ต้นฉบับ

การประเมินผลผลิตสุทธิขั้นปฐมภูมิของป่าปลูกโกงกางใบใหญ่โดยใช้มวลชีวภาพ และลักษณะทางชีพลักษณ์ของใบในพื้นที่ชายฝั่งบางปู จังหวัดสมุทรปราการ

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บทคัดย่อ

ความเป็นมาและวัตถุประสงค์: ผลผลิตซากพืชที่ร่วงหล่นเป็นองค์ประกอบที่สำคัญในการประมาณผลผลิตสุทธิขั้นปฐมภูมิ แต่มีการศึกษาไม่มากนักในป่าปลูกระดับไม้รุ่น การศึกษานี้มีวัตถุประสงค์เพื่อประมาณผลผลิตสุทธิขั้นปฐมภูมิ จากซากพืชที่ร่วงหล่นด้วยการศึกษาชีพลักษณ์ของใบไม้รุ่นโกงกางใบใหญ่ (*Rhizophora mucronata*) อายุ 3 ปี รวมถึงศึกษาการเพิ่มพูนมวลชีวภาพ ในป่าชายเลนปลูกบริเวณชายฝั่งบางปู จังหวัดสมุทรปราการ

วิธีการ: วางแปลงขนาด 5 × 5 ตารางเมตร จำนวน 4 แปลง เพื่อศึกษาโครงสร้างป่าและมวลชีวภาพโดยใช้สมการแอลโลเมตรีของไม้รุ่นโกงกางใบใหญ่ในการคำนวณ ศึกษาชีพลักษณ์ของใบโดยวิธี Tagging method เพื่อประมาณอัตราการร่วงของใบและปริมาณซากพืชที่ร่วงหล่นรายเดือน คำนวณผลผลิตซากพืชที่ร่วงหล่นจากผลรวมของซากพืชที่ร่วงหล่นรายเดือน ในช่วงเดือนสิงหาคม 2562 ถึงเดือนกรกฎาคม 2563 วิเคราะห์ความสัมพันธ์ระหว่างซากพืชที่ร่วงหล่นรายเดือนกับปัจจัยสิ่งแวดล้อม และผลผลิตสุทธิขั้นปฐมภูมิของไม้รุ่นที่มีชีวิตตลอดการศึกษา

ผลการศึกษา: อัตราการร่วงของใบมีค่ามากที่สุดในเดือนพฤษภาคมและมิถุนายน 2563 แต่ซากพืชที่ร่วงหล่นรายเดือนมีค่ามากที่สุดในเดือนพฤษภาคม 2563 ซากพืชที่ร่วงหล่นรายเดือนมีความสัมพันธ์เชิงบวกกับอุณหภูมิอากาศ ผลผลิตซากพืชที่ร่วงหล่นมีค่าเท่ากับ 0.89 ± 0.45 ตัน/เฮกแตร์/ปี ค่าเฉลี่ยมวลชีวภาพที่เพิ่มพูนมีค่าเท่ากับ 1.91 ± 0.35 ตัน/เฮกแตร์/ปี ป่าปลูกมีผลผลิตสุทธิขั้นปฐมภูมิอยู่ระหว่าง 2.32–3.45 ตัน/เฮกแตร์/ปี ซึ่งผลผลิตซากพืชที่ร่วงหล่นมีสัดส่วนที่ค่อนข้างสูงคิดเป็น 21.2–45.2% ของผลผลิตสุทธิขั้นปฐมภูมิ

สรุป: ชีพลักษณ์ใบของไม้รุ่นโกงกางใบใหญ่ ในป่าชายเลนมีความผันแปรตามช่วงเวลาและสัมพันธ์กับอุณหภูมิอากาศ สามารถใช้ในการประเมินผลผลิตซากพืชที่ร่วงหล่น และบ่งบอกถึงศักยภาพการกักเก็บคาร์บอนของไม้รุ่นในป่าปลูก

คำสำคัญ: มวลชีวภาพที่เพิ่มพูน; ผลผลิตซากพืชที่ร่วงหล่น; การกักเก็บคาร์บอน; ไม้รุ่น; แปลงปลูกป่าชายเลน

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ORIGINAL ARTICLE

Estimation of Net Primary Production of *Rhizophora mucronata* Plantation Using Biomass and Leaf Phenological Characteristics in a Coastal Area at Bangpu, Samut Prakarn Province

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ABSTRACT

Background and Objectives: Litter production is an important component for estimation of net primary productivity. However, there are few studies on the litter production of saplings in mangrove plantations. This research aimed to estimated leaf litter production by leaf phenological study of *Rhizophora mucronata* saplings (3-year-old), and the biomass increment was also observed in a mangrove plantation at Bangpu, Samut Prakarn Province.

Methodology: Four plots of 5 × 5 m^2 were established for studying forest structure and evaluated biomass using the allometric equation developed for *Rhizophora* sapling. The leaf phenology was studied by using tagging method from August 2019 to July 2020. The leaf loss rate and monthly litterfall were estimated. Litter production was calculated by summing monthly litterfall. The correlation between monthly litterfall and environmental factors was analyzed. Finally, NPP was calculated by a summation of litter production and biomass increment which calculated biomass only living saplings through the study period.

Main results: The highest leaf loss rate was in May and June 2020, but the highest monthly litterfall was found in May 2020. Moreover, the monthly litterfall positively correlated with air temperature. The litter production was 0.89 ± 0.45 t/ha/yr, while, the average increment biomass was 1.91 ± 0.35 t/ha/yr. NPP in mangrove plantation ranged from 2.32–3.45 t/ha/yr which litter production was relatively high and accounted for 21.2–45.2% of NPP.

Conclusion: Leaf phenological of *R. mucronata* varied among period and related with temperature changes. It can be applied for an estimation of litterfall production and reflected a potential of a carbon storage in the sapling plantation.

Keywords: Biomass increment; litter production; carbon storage; sapling; mangrove plantation

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INTRODUCTION

Mangrove ecosystems, located at the land-sea interface in the tropics and subtropics, consist of diverse plant and animal communities and provide several ecosystem services such as nutrient cycling, regulation of climate cycles, stabilization of substrates (Field *et al.*, 1998). They are also recognized in terms of economic and ecological values due to their functions as a nursery and habitat for aquatic animals and sustain coastal ecosystems by preventing coastal erosion (Ronnback, 1999). In addition, mangrove forests are highlighted as an important carbon sink which is indicated by high net primary production (NPP) (Komiyama *et al.*, 2008; Poungparn *et al.*, 2020). Litter production is an important component of the NPP estimation. It was accounted for approximately 30 – 60 % of NPP (Amarasinghe and Balasubramaniam, 1992; Sukardjo and Yamada, 1992; Kamruzzaman *et al.*, 2017).

Litter production is the annual amount of plant litter falling onto a defined forest floor area. The litterfall in mangrove forest is consequently decomposed by microorganisms and fed benthic animals. The litter production indicated a potential of mangrove forests as a source of organic matter and nutrients that are exported from the forests to adjacent aquatic ecosystems (Srisunont *et al.*, 2017). Komiyama *et al.* (2008) reviewed that the litter production of mangrove forests varied in a range of 3.07–12.52 t/ha/yr depending on species, density and height of tree, location, and form of mangrove forests. It was notably that there are few studies on litter production in young mangrove plantation. While NPP estimation in the young plantations should not be ignored, according to high NPP in the mangrove forests mentioned earlier.

Litter trap method is commonly used for estimation of litter production in terrestrial forests (i.e., Chave *et al.*, 2010; Paudel *et al.*, 2015; Putra *et al.*, 2023). The litter traps are commonly square or circular in shape, which allows to calculate an area of the litter trap for an estimation of the litter production per unit area. Generally, a height of litter trap is set at 1.3 m from the ground which is the standard height for a tree diameter measurement (Feldpausch *et al.*, 2011). However, to apply this method for an estimation of litter production in the mangrove forest where is usually inundated by daily tide, the litter traps are raised above 1.3 m height to avoid submerged litter in the traps during a high tide (i.e., Poungparn *et al.*, 2012; Liu *et al.*, 2017). Nevertheless, the litter trap method is not applicable for estimation of litter production in a young plantation where most of the plants are saplings with an undeveloped or small canopy. Moreover, the height of sapling is not sufficient to place a litter trap away from the level of tidal inundation. Alternatively, a study of leaf phenology and biological events of leaf such as leaf emergence and fall occurring within a year (Kankong *et al.,* 2021; Spafford *et al.,* 2023), will allow one to estimate leaf litter production.

In last few decades, mangrove plantations have been restored in abandoned coastal areas in Thailand (Sremongkontip *et al.*, 2000), which *Rhizophora* species are widely used in mangrove restoration because they develop viviparous propagules more rapidly and efficiently than other mangrove species (Naktang *et al*., 2023). However, litter production and biomass increment for NPP estimation in the *Rhizophora* sapling plantation have rarely been reported. Bangpu is a coastal mangrove forest in Samut Prakarn Province that has a regular restoration project. Therefore, the present study aimed to estimate litter production by using a leaf phenological study in a 3-year-old *Rhizophara mucronata* plantation at Bangpu. Then, the estimated litter production is combined with the biomass increment for NPP calculation. It will beneficially provide a database of mangrove NPP.

MATERIALS AND METHODS

Study site

The study site is a 3-year-old *Rhizophora mucronata* plantation with an area of approximately 4,808 m^2 with a planting spacing of 0.5 × 0.5 m^2 at the Bangpu Recreation Center in Samut Prakarn Province (13°31'N, 100°39'E) (Figure 1). This study site is a coastal fringe mangrove under a tropical monsoon climate. The climatic data from January 2013 to December 2018 were obtained from the Samut Prakarn (Bang pla) weather station, which is the nearest station to the study site. The rainfall is distinct between the dry (November to April) and the rainy (May to October) seasons. The mean rainfall in the rainy season was 1337 ± 332 mm, accounting for 81.7% of the mean annual rainfall. The mean temperature in the dry and rainy seasons were 28.05 ± 0.29 and 29.33 ± 0.21ºC, respectively. A mixed semidiurnal tide was investigated by Round (1988), with a relatively long inundation period of more than 16 h per day and the tides ranging from 0–1.5 m which were calculated from the tide table of the Hydrographic Department, Royal Thai Navy.

Sapling plots and data collections

The four plots of 5 × 5 m^2 were established in this plantation. We measured the stem diameter at 30 cm above the highest prop root ($D_{R0.3}$) and total height (H) of all saplings in August 2019 and July 2020.

Three saplings of *R. mucronata* with presenting of prop roots and having spread canopy in all four main directions, were selected for the leaf phenology study by using tagging method (Ochieng and Erftemeijer, 2002).

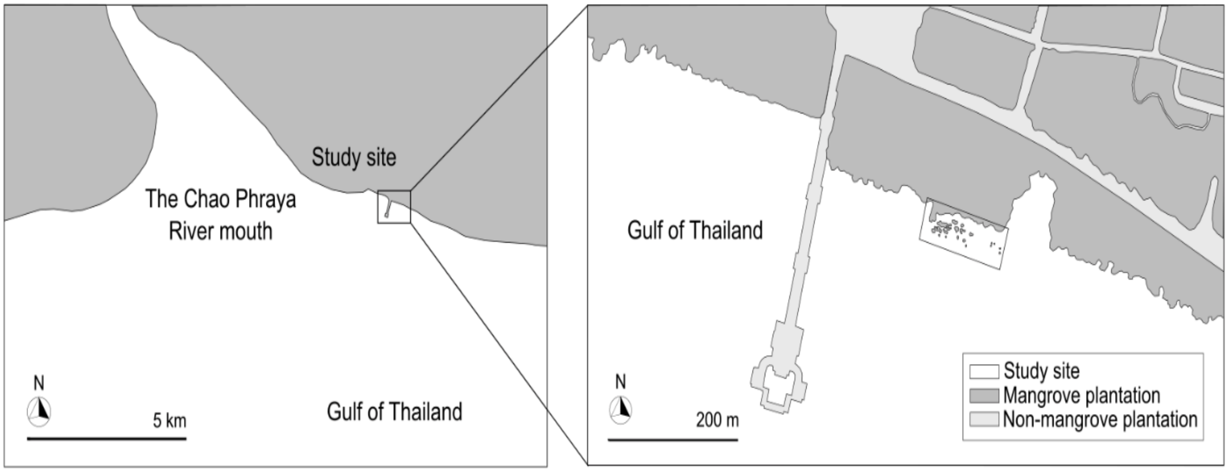

Figure 1 Mangrove plantation at the Bangpu Recreation Center in Samut Prakarn Province, ☐ *Rhizophora mucronata* sapling plantation

All shoots were tagged in number. All pairs of leaves that fully expanded were tagged from the lowest to the top of each shoot. We monthly examined the occurrence of the loss leaves on the tagged shoots for one year (August 2019 to July 2020), except March and April 2020 because of the lockdown period due to COVID-19. The sum of leaf losses in March and April was shown as the average per month. The new fully expanded leaves of each shoot were also continuously tagged. The dates that the leaves turned yellow were recorded to calculate the total number of day from the leaf emergence until it turned yellow.

We assumed that the dry weight of monthly leave loss represents the monthly litterfall in a defined area. To estimate the dry weight of monthly leave loss, we multiplied number of fallen leaves in each month to mean dry weight of a leaf. Various sizes of leave samples (n = 30) were collected from different height of shoots of *R. mucronata* saplings locating outside the plots. The leaf samples were oven-dried at 60 °C to a constant weight and then weighed dry.

The data of environmental factors (air temperature, rainfall, and wind speed) were retrieved from the Meteorological Department (Samut Prakarn Province) during August 2019 to July 2020.

Data analysis

Basal area and the mortality rate (Miura *et al.*, 2001) were calculated by using Eq. 1 and 2, respectively.

$$\text{Basal area} = \pi (D_{R0.3}/2)^2 \qquad \text{(Eq. 1)}$$

where $D_{R0.3}$ is stem diameter at 30 cm above the highest prop root (cm).

$$\text{Mortality rate} = (\ln(N_b/N_s)*100)/t \quad \text{(Eq. 2)}$$

where N_b is the number of initial planting (ca. 18000 stems/ha), N_s is the number of saplings that survived throughout the study, t is time (year).

The leaf loss rate was estimated by the method according to Kankong *et al.* (2021). The leaf longevity was calculated from total number of day from the leaf expansion to the leaf fall. Pearson's correlation coefficient (r) was used to assess the correlation between leaf loss rate and environmental factors. The correlation between monthly litterfall and environmental factors was also analyzed.

The aboveground biomass (W_{Top}) and root biomass (W_R) was calculated using the allometric equation developed for *Rhizophora* sapling (Eq.3 and 4) in southern Thailand (Umnouysin, 2011).

$$W_{TOP} = 0.2886\,(D_{R0.3}{}^2H)^{0.3990} \quad \text{(Eq. 3)}$$

$$W_R = 0.1632\,(D_{R0.3}{}^2H)^{0.5092} \quad \text{(Eq. 4)}$$

where H is total height (m).

The biomass increment during the study period was calculated from the biomass of living saplings (Clark *et al.*, 2001). For the litter production, we calculated by summing monthly litterfall from August 2019 to July 2020. Finally, NPP was calculated by a summation of biomass increment and litter production.

RESULTS AND DISCUSSION

Climatic factors

The annual rainfall was 1196 mm from August 2019 to July 2020. The highest monthly rainfall was 384 mm in September 2019, and the lowest rainfall was 0 mm in December 2019 and January 2020 (Figure 2). The rainfall during the rainy season was 1111 mm, accounting for 92.8% of the annual rainfall. The average air temperature was 29.2ºC from August 2019 to July 2020. The highest average air temperature was in May 2020 (31.1ºC), and the lowest average air temperature was in December 2019 (27.0ºC) as shown Figure 2. The maximum wind speed varied from 14–24 knot, the highest maximum wind speed was recorded in July 2020 (Figure 3)

Vegetation structure and sapling biomass

The initial planting density of the four plots was approximately calculated to 18000 stems/ha based on a planting distance of 0.5×0.5 m^2. The results showed that the average sapling density was 11000 ± 5033 stems/ha at the beginning of the study (August 2019) and decreased at the end of the study (July 2020) due to increasing mortality of saplings. Sapling mortality in the study site was due to strong wind and waves on the shoreline. When considering the growth of saplings that survived until the end of study, the average size of $D_{R0.3}$ and height increased in all plots (Table 1). But the total basal area of the stem decreased due to density reduction.

In August 2019, *R. mucronata* sapling in the four plots had the aboveground biomass in a range of 4.05–7.06 t/ha, the root biomass in a range of 2.87–4.50 t/ha, and total biomass ranged from 6.92–11.56 t/ha (Table 1). In July 2020, the decreased density of *R. mucronata* saplings resulted in the decreasing biomasses (Table 1). The biomass of *R. mucronata* saplings in this study was higher than that of a young *R. mucronata* plantation in Myanmar (Aye *et al.*, 2023); aboveground and belowground biomass was 0.69 and 0.37 t/ha, respectively. This was explained by the lower density of *R. mucronata* (50 stems/ha) in Myanmar. In addition, the climatic factors such as heavy rain and tropical cyclone frequency in Myanmar may result in different biomass from Bangpu.

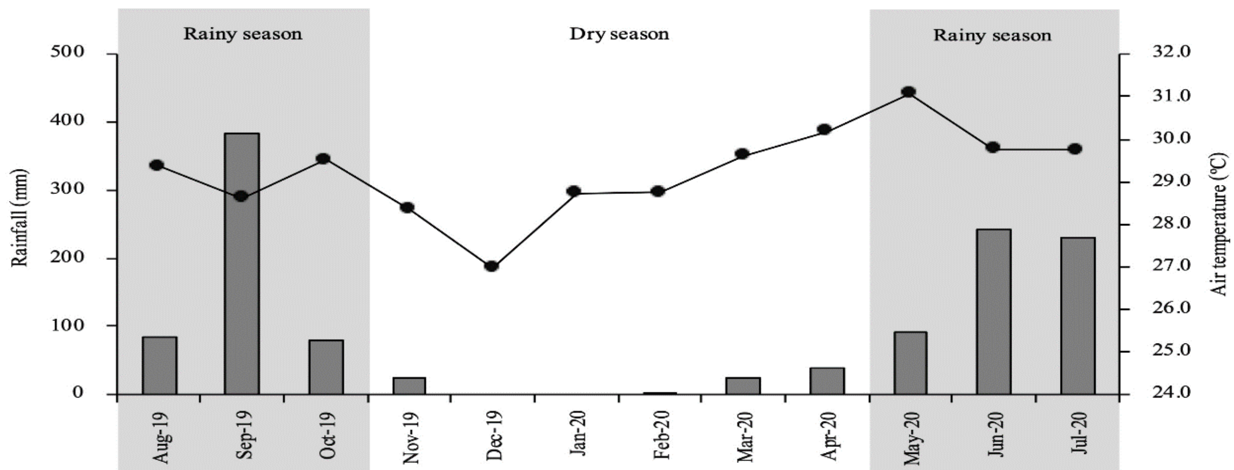

Figure 2 Monthly rainfall and average air temperature during August 2019 to July 2020 (Meteorological Department of Thailand)

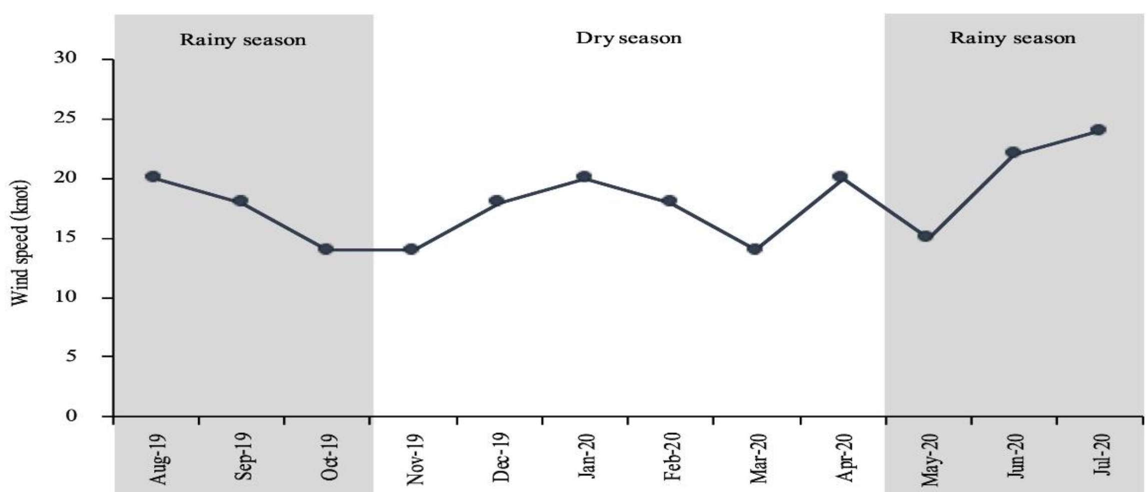

Figure 3 Wind speed during August 2019 to July 2020 (Meteorological Department of Thailand)

Table 1 The density, mortality rate, average $D_{R0.3}$ and height (H), total basal area (BA) aboveground biomass (AGB), root biomass (RB) and total biomass (TB) of *R. mucronata* saplings at Bangpu, recorded in August 2019 and July 2020

	plot	density (stem/ha)	mortality rate (%)	$D_{R0.3}$ (cm)	H (m)	BA (m^2/ha)	AGB (t/ha)	RB (t/ha)	TB (t/ha)
August 2019	1	16800	2.30	1.38 ± 0.49	1.35 ± 0.17	2.81	7.06	4.50	11.56
	2	7200	30.54	2.25 ± 0.23	1.65 ± 0.15	2.89	4.83	3.45	8.29
	3	6400	34.47	2.09 ± 0.56	1.65 ± 0.20	2.34	4.05	2.87	6.92
	4	13600	9.34	1.52 ± 0.41	1.40 ± 0.18	2.63	6.26	4.07	10.33
	average	11000 ± 5033	19.16 ± 15.75	1.81 ± 0.42	1.51 ± 0.16	2.67 ± 0.24	5.55 ± 1.36	3.73 ± 0.71	9.28 ± 2.07
July 2020	1	6400	25.85	2.29 ± 0.69	1.60 ± 0.29	2.86	4.32	3.14	7.46
	2	3600	40.24	3.08 ± 0.79	1.87 ± 0.22	2.84	3.27	2.56	5.83
	3	3600	40.24	3.17 ± 0.67	1.86 ± 0.32	2.95	3.33	2.62	5.95
	4	5200	31.04	2.14 ± 0.43	1.52 ± 0.12	1.94	3.24	2.28	5.53
	average	4700 ± 1361	34.34 ± 7.13	2.67 ± 0.53	1.71 ± 0.18	2.65 ± 0.47	3.54 ± 0.52	2.65 ± 0.36	6.19 ± 0.86

Phenology of *R. mucronata* saplings

The samples of *R. mucronata* saplings for the leaf phenological study had $D_{R0.3}$ in a range of 2.33–2.95 cm and total height in a range of 1.61–1.98 m. The leaves started changing colour from green to yellow in approximately 171 ± 26 days and the leaves fell at 39 ± 20 days after that. Therefore, the leaf longevity of *R. mucronata* saplings was estimated at 210 ± 32 days, which is less than previous studies of *Rhizophora* trees reporting leaf longevity of approximately 300–600 days (Burrow, 2003; Sharma *et al.*, 2012; Wium-Andersen, 1981). It may be due to the difference in climatic factor (rainfall pattern), different stage of plant (saplings and trees), and biotic factor (insect herbivores).

The average leaf loss rate was 0.59 ± 0.11 %/day. The leaf loss rate was the highest in May and June 2020 (Figure 4) which was statistically significant difference during the study period (One-way ANOVA, P = 0.009). The leaf loss rate in the rainy and dry seasons was 0.58 ± 0.14 and 0.60 ± 0.07%/day, respectively. There was no statistically significant difference between the seasons (independent sample t-test, P = 0.728). Moreover, the leaf loss rate was not related to environmental factors (Pearson correlation, r = – 0.279, P = 0.406 for rainfall; r = 0.349, P = 0.292 for air temperature, and r = 0.185, P = 0.586 for wind speed).

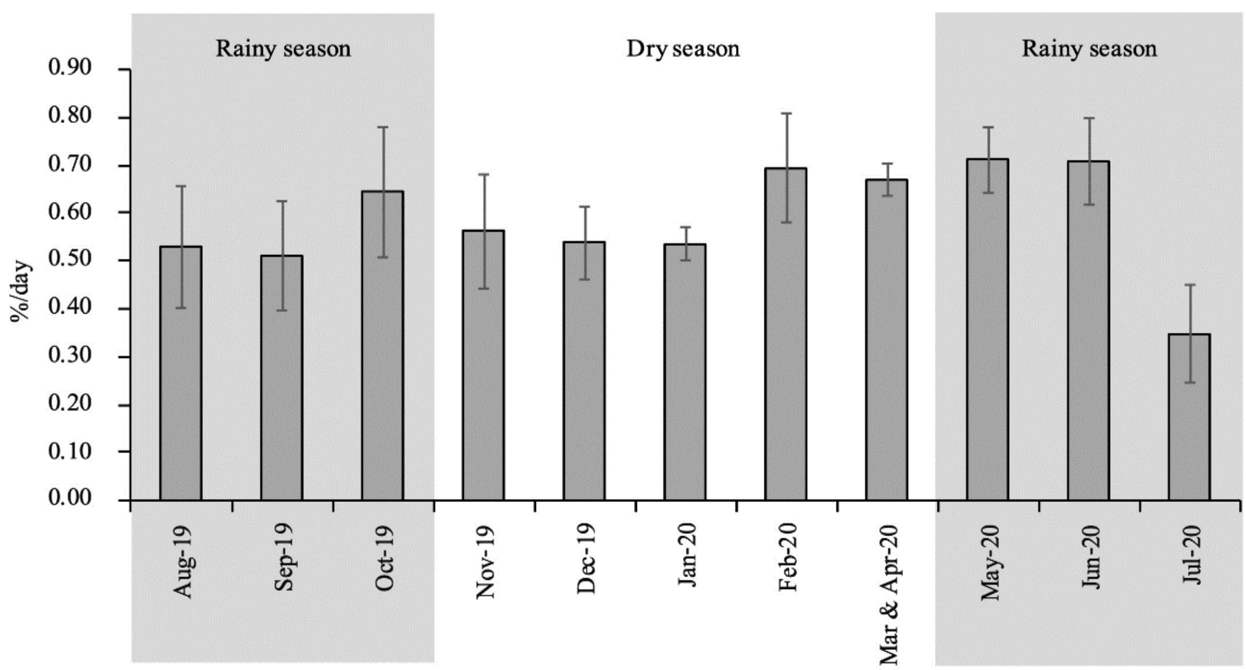

Figure 4 Average of monthly leaf loss rate of *R. mucronata* saplings during August 2019 to July 2020

The results of this study are consistent with Wium-Anderson (1981) which studied in a *R. mucronata* forest on Phuket Island, southern Thailand. They reported that the leaf loss was not different between the seasons and not related to climatic conditions, although the highest leaf loss was found in February of a dry season. Nevertheless, the leaf loss rate in our study was the highest in May and June of the rainy season. This may be affected by the strong wind during the early rainy season (Figure 3). Moreover, Wang'ondu *et al.* (2013) reported the highest number of leaf loss in October in Gazi bay, Kenya, which positively correlated with air temperature but negatively correlated with the relative humidity. The different patterns of leaf loss may be induced by the difference in local environmental factors and characters of mangrove forests, even though these forests are in the tropical monsoon climate. Locating the south of Thailand on the Andaman coast, Phuket Island is directly influenced by the southwest monsoon during May to October leading to higher annual rainfall than that of Bangpu located in central Thailand. While the mangrove forest at the Gazi Bay in Kenya is influenced by two seasonal monsoons, namely the southeast monsoon and northeast monsoon, with two peaks of rainy season (April to July and October to December).

The leaf loss pattern of *R. mucronata* in our study was also different from those of other mangrove species in the family Rhizophoraceae in subtropical mangrove on Okinawa Island of Japan including *Kandelia obovata* (Kamruzzaman *et al.*, 2012) and *K. candel* (Gwada *et al.*, 2000). Kamruzzaman *et al.* (2012) reported the highest leaf loss in July according to typhoon season, while Gwada *et al.* (2000) found that the highest leaf loss was in October and it did not relate to environmental factors (temperature, relative humidity, and day length). Therefore, both mangrove tree species and local environmental factors influence on the patterns of leaf phenology.

Litter production of *R. mucronata* sapling plantation

The average dry weight per leaf of *R. mucronata* sapling was 1.06 ± 0.28 g. Based on this value, the number of fallen leaves in each month was converted to the monthly litterfall. The monthly litterfall was the highest in May 2020 with an average of 21.86 ± 17.14 g/stem/month. While it had the lowest value of 5.12 ± 2.77 g/stem/month in November 2019 (Figure 5). Moreover, the litterfall in the rainy and dry seasons was not statistically different (independent sample t-test, $P = 0.751$) with the average value of 15.86 ± 5.68 and 14.67 ± 6.37 g/stem/month, respectively.

The leaf litterfall was positively correlated with mean air temperature (Pearson correlation, r = 0.646, *P* = 0.032). It is consistent with Rani *et al*. (2016) which found that the litterfall positively correlated with temperature because it might be due to a response to water stress under high temperature condition. High temperature induced leaf senescence via accelerated transpiration rate and increased the salt content in leaves that led to increasing litterfall (Mchenga *et al.*, 2017). But we found no correlation between the leaf litterfall and rainfall (Pearson correlation, r = – 0.114, *P* = 0.739) and maximum wind speed (Pearson correlation, r = - 0.015, *P* = 0.966). Litter production was calculated as 0.89 t/ha/yr (Table 2). However, this study observed the litter production of saplings (1.35–1.87 m in height), thus, the litter production was lower than other studies reporting the litter production of mangrove trees. At a Tanzanian mangrove forest, *R. mucronata* zone with tree canopy height of 6–12 m had the annual litter production rate was 2.8 t/ha/yr and it increased with rising air temperature and wind speed (Mchenga *et al.*, 2017). While the study of leaf litter production of *K. obovata* (average tree height of 4.27 m and average diameter of 5.09 cm) in Japan showed the average leaf litter production of 5.31 t/ha/yr and positive correlations between litter production and day length, air temperature and relative humidity (Kamruzzaman *et al.*, 2012). Therefore, size, species, and local environmental factors are considered to be the cause of different litter production in mangrove forests.

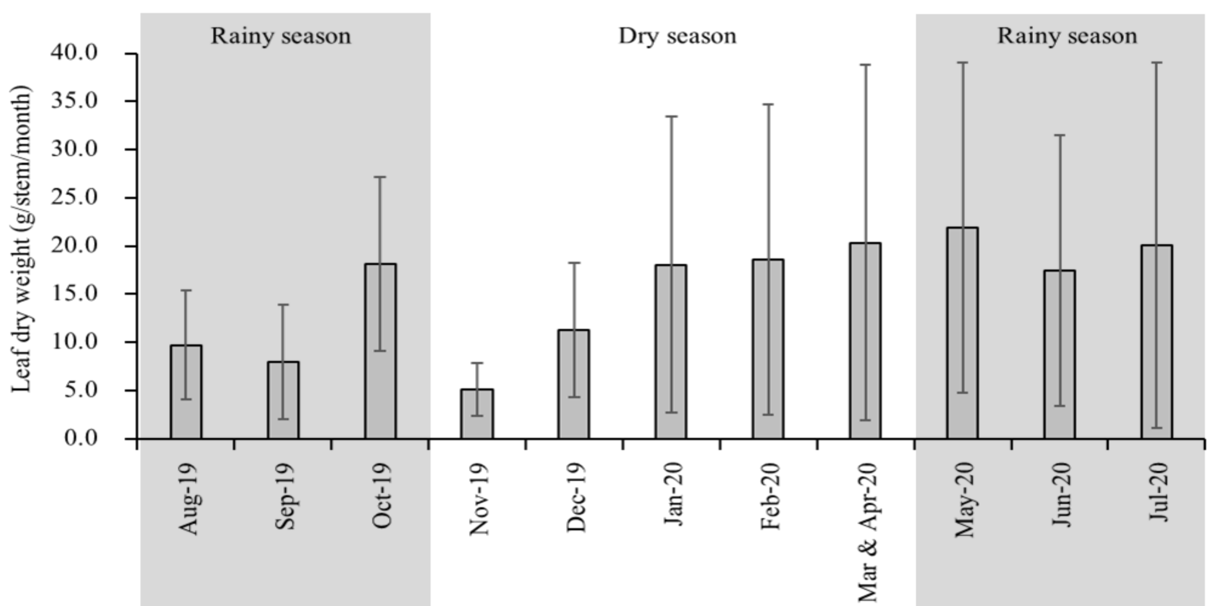

Figure 5 Monthly litterfall (mean ± SD) of *R. mucronata* saplings during August 2019 to July 2020

Biomass increment and NPP of *R. mucronata* sapling plantation

The biomass increment ranged from 1.62–2.41 t/ha/yr and the litter production ranged from 0.64–1.56 t/ha/yr (Table 2). The NPP was estimated in a range of 2.32–3.45 t/ha/yr with an average value of 2.80 t/ha/yr (Table 2). Our estimated NPP was relatively low in a comparison to the study of *R. mucronata* in Sri Lanka (3.88–12.86 t/ha/yr, Amarasinghe and Balasubramaniam, 1992) and Indonesia (20.80–25.00 t/ha/yr, Sukardjo and Yamada, 1992). The magnitude of NPP depends on both biomass increment and litter production (Komiyama *et al.*, 2008). The proportion of biomass increment was slightly higher in this sapling plantation compared to the *R. mucronata* trees (Amarasinghe and Balasubramaniam, 1992; Sukardjo and Yamada, 1992). The litterfall production in this study was lower than that of those studies mentioned above, but the proportion of litter production (21.2–45.2% of the NPP) was similarly accounted for 30–40% of NPP. Although the mangrove plantation along the coast of Samut Prakarn Province is still in a stage of saplings (3-year-old), it tended to be a high carbon stock due to high NPP. It suggests a benefit of a mangrove plantation by mean of increasing capacity of carbon storage in the coastal areas.

Table 2 Biomass increment, litter production, and NPP of *R. mucronata* sapling at Bangpu during August 2019 to July 2020

plot	Biomass increment (t/ha/yr)	Litter production (t/ha/yr)	NPP (t/ha/yr)
1	2.41	0.65	3.06
2	1.62	0.70	2.32
3	1.89	1.56	3.45
4	1.73	0.64	2.37
Average ± SD	1.91 ± 0.35	0.89 ± 0.45	2.80 ± 0.55

CONCLUSIONS

The leaf phenology of *R. mucronata* saplings in a coastal plantation at Bangpu was not significantly different between the seasons, although the variation in monthly rates of leaf loss was occurred. The leaf loss rate was the highest in May and June 2020 during the rainy season due to high wind speed. Based on the monthly fallen leaves, we calculated the litter production. The litter production and biomass increment were lower than those of studies in other mangrove forests due to the differences in size, species, and local environment.

Also, the differences in litter production and biomass increment may be attributed to the limitation of data collection during the lockdown period due to COVID-19. This study demonstrated that the leaf phenological study of mangrove sapling was applicable for an estimation of litterfall production which is an essential component in NPP estimation. The coastal mangrove forest in Samut Prakarn Province continued to accumulate carbon. The high NPP indicates that *R. mucronata* saplings are still growing and may have carbon storage capacity. Lastly, to further improve understanding of NPP in young mangrove plantations, future research might also look at other environmental factors such as salinity, inundation period, and soil nutrients. It may also be studied in other mangrove species, especially that use for restoring mangroves.

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