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Phenology and litterfall production of mangrove *Rhizophora stylosa* Griff. in the subtropical region, Okinawa Island, Japan

Sahadev Sharma[1], A.T.M. Rafiqul Hoque[1], Kangkuso Analuddin[2] and Akio Hagihara[3]
[1]*Graduate School of Engineering and Science*, *University of the Ryukyus*, *Japan*/ [2]*Department of Biology*, *Heluoleo University*, *Kendari*, *Indonesia*/ [3]*Faculty of Science*, *University of the Ryukyus*, *Japan*

***Abstract*—Mangrove forests in Japan are at their northern limits, and are distributed from the Yaeyama Islands in the subtropical zone to the southern part of Kyushu Island in the warm-temperate zone, and therefore they are poor in species. Phenological traits of a subtropical Rhizophoraceae mangrove, *Rhizophora stylosa* Griff., are measured during the period of April 2008 to March 2010. The litterfall traps were emptied monthly and the litterfall was sorted into leaves, stipules, branchs, flower buds, fruits, fruits expanded and hypocotyles. Mean annual total litterfalls of the 1st year and 2nd year were respectively estimated as 931.7±16.6 and 1321.9±31.2 (SE) g m^{-2} yr^{-1}, of which the leaf litterfall comprised 65.2 (1st year) and 49.7% (2nd year). All litterfalls showed a seasonal pattern: the highest peak occurred during summer and the lowest during winter. The reproductive cycle of *R. stylosa* was seasonal. In general, the species presented flowering peaks from May to September when temperature was high.**

INTRODUCTION

The reproductive biology of mangroves has often been regraded with interest owing to the unusual breeding mechanisms, including vivipary, exhibited by many of these plants [1]. In fact, the focus of research on mangrove reproductive biology has almost exclusively been on the fruit dispersal stage [2]. Surprisingly little is known on the processes and success rate of propagule production.

Mangroves are unique trees that are found almost exclusively in the tropics and subtropics. *Rhizophora* are considered the most important of all mangrove genera across the Pacific tropical and subtropical region. The litterfall is a main component of net primary production [3], reflects phenological events [4], [5] and is also an important part of energy and nutrient fluxes in mangrove ecosystems [6]. Phenological data are essential to know the tree ability to adapt growth and propagation strategies to ambient climatic conditions. This kind of knowledge is most valuable if available across a broad geographic scale. However, little is known about *R. stylosa* phenology in Okinawa Island near the northern limit of mangrove distribution; information is available for *Kandelia obovata* and *Bruguiera gymnorrhiza* [7], [8].

As mangroves in Okinawa thrive in a distinct seasonal climate, they have to cope with substantial seasonal changes in environmental factors. In general, *R. stylosa* focused on this study shows a conspicuous seasonality regarding phenophase peaks. The aim of this study is to investigate the vegetative and reproductive biology, and the litterfall production of mangrove *R. stylosa* growing in the subtropical region. The general trends that regulate the vegetative and reproductive production in the mangrove system are discussed.

MATERIALS AND METHODS

Study site

The study was conducted in a mangrove forest (26°11′N and 127°40′E) of Manko Wetland, Okinawa Island, Japan (Fig. 1), from April 2008 to March 2010.

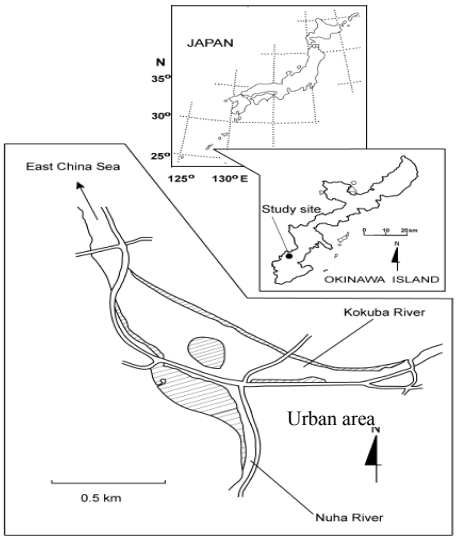

Fig. 1. Location of the study area. The hatched zone indicates the mangrove area.

This wetland is an important area for migratory birds and has been registered as the RAMSAR site since 1999. The mangrove *Kandelia obovata* (S., L.) Yong is the dominant species in the study site. A few patches of *Rhizophora stylosa* Griff., *Bruguiera gymnorhiza* (L.) Lamk. and *Excoecaria agallocha* L. are also observed.

The warmth index [9] based on the data of 2000 – 2009 obtained from the Okinawa Meteorological Observatory, Naha, Okinawa, was 219.8°C month, indicating that this area belongs to the subtropical region. Monthly mean minimum temperature is 16℃ in January and monthly mean maximum temperature is 29.4℃ in July during the study period. Mean annual rainfall is 1417.5 mm yr^{-1} during the study period.

Litter collection

Five plots (4 m x 4 m each) were established for a *R. stylosa* stand. All individuals in the subplots were counted and numbered. Litterfall was measured using litter traps. One litterfall trap with an opening of 0.19635 m^2 was placed at 1 m above the soil surface in each of 5 plots. The litterfall traps were emptied monthly from April 2008 to

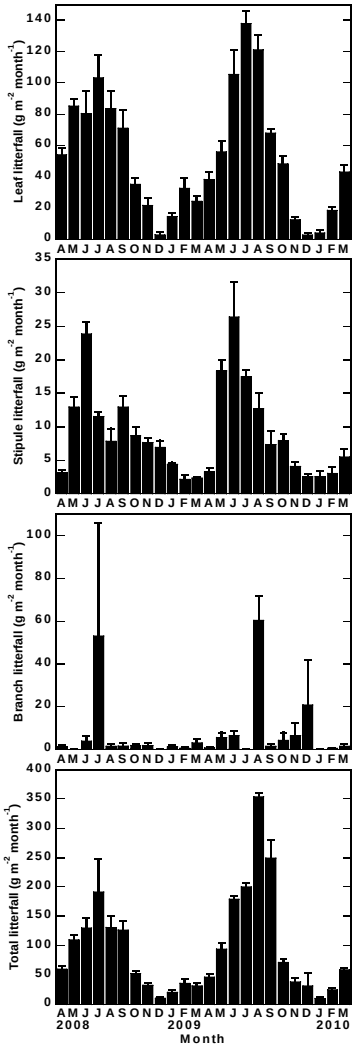

Fig. 2. Seasonal trends in monthly mean litterfall. Vertical bar stands for the standard error of the mean.

March 2010 and the litterfall was sorted into leaves, stipules, branches, flower buds, flowers, fruits, fruits extended and hypocotyles. The sorted litterfalls were dried to a constant mass at 80°C over a 48 h period, and then weighed.

Table 1. Annual litterfall of the 1st year (Apr. 2008 – Mar. 2009) and the 2nd year (Apr. 2009 – Mar. 2010).

Litterfall	1st year	2nd year
Leaf	610.05± 9.54	657.26±13.17
Stipule	104.33± 1.76	111.06± 2.24
Branch	68.52± 4.31	107.10± 4.96
Flower bud	8.82± 0.29	12.34± 0.37
Flower	31.96± 1.21	43.27± 1.42
Fruit	49.97± 1.08	114.08± 3.26
Fruit expended	15.56± 0.85	29.44± 1.68
Hypocotyl	46.51± 2.80	247.38±14.14
Total	935.73±16.68	1321.9±31.20

Mean value (g m^{-2} yr^{-1}) is shown with its SE.

RESULTS AND DISCUSSION

Vegetative phenology

As depicted in Fig. 2, leaf litterfall showed a seasonal pattern: the highest peak occurred in July and the lowest peak occurred during the December. According to [10], the leaf litterfall of *Avicennia marina* (Forsk.) Vierh. increased with increasing air temperature. In the subtropical region, leaf fall and leaf production are low during the winter season [11], [12].

Stipule litterfall was the highest in July, while the lowest during winter (Fig. 2). It is obvious from Fig. 2 that new leaves were formed or expanded at different rates throughtout the year, whereas shedding of old leaves took place at more even rates. *Rhizophora mangle* L., studied in subtropical Florida by [11], is a continuously growing species but shows a unimodal growth with a very high rate of leaf replacement in the warm and humid summer.

Although branch litterfall did not show any clear seasonal pattern (Fig. 2), it showed the highest peak during summer. According to past studies, the highest branch litterfall of *K. obovata* in Okinawa Island resulted from the typhoon [13] and the branch litterfall of *A. marina* depended on the storm [14].

Total litterfall showed a seasonal trend with the highest litterfall in summer and the lowest in winter (Fig. 2). Mean annual total litterfalls of the 1st year and the 2nd year were estimated as 935.7±16.7 and 1321.9±31.2 (SE) g m^{-2} yr^{-1} (Table 1), of which leaf litterfall comparised the largest component, i.e. 65.2 and 49.7% respectively in the 1st year and the 2nd year. The mean annual litterfall recorded in this study was within the range of values for *Rhizophora* spp. in Australia and Vietnam [15], [16].

Reproductive phenology

Reproductive material was present in litter samples all over the year. Flower bud, comparising the bud primordia, immature bud and mature bud, showed the highest peak during summer and the lowest was in winter (Fig. 3). *Rhizophora stylosa* has primordia and flower buds with resting periods, about one year each, a long period of around 2 years being required for development of flower. *Rhizophora apiculata* Blume needed 2 and a half years to develop folwer [17].

For *R. magle*, more or less continuous flower production with a superimposed seasonal trend has been reported by several authors. Flower also showed the highest peak during summer, while the lowest was in winter (Fig. 3). Low temperatures generally reduce the flower production of *R. mangle* [11].

Fruit, which comparises both immature and mature fruits, also showed the higest production during summer, while the lowest was in winter (Fig. 3). It is repoted in Florida that fruit development extends over the cold season and is therefore slower [11].

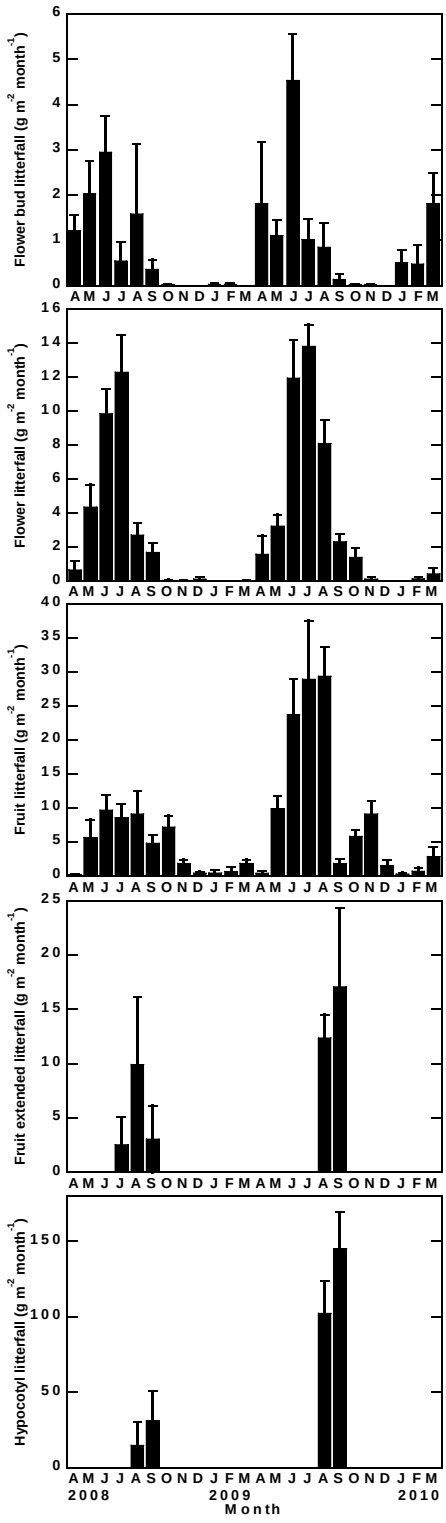

Fig. 3. Seasonal trends of montly mean reproductive litterfall. Vertical bar stands for the standard error of the mean.

Hypocotyl and fruit extended found in only from July to September (Fig. 3). In other Rhizophoraceae species, propagule development may last considerably longer [18], [19].

Table 2. Numbers of flowers, fruits, hypocotyles and fruits extended during 1st year (Apr. 2008 – Mar. 2009) and the 2nd year (Apr. 2009 – Mar. 2010).

Litterfall	Flower	Fruit	Hypocotyl	Fruit extended
1st year	422	383	3	5
2nd year	801	602	20	13

Rhizophora stylosa produced a large number of buds, however, most buds failed to develop into propagules. A large proportion of young buds became mature buds, with most mature buds becoming flowers. There was a sharp decline in survival of reproductive units, with very few of flowers fertilised (1.2 – 2.5%). Conversion of fertilised flowers into fruits was greater than half (75 – 90%), though transition of fruits to propagules was less successful (1.3 – 3.3%) (Table 2). In Northern Australia and Fiji, *Rhizophora* spp. have 1 – 3% of survival rate for flower to propagule production [20], [21]. The rate of fertilisation reported in this study was much lower than those estimated in *R. mangle* (7%) and *R. apiculata* (13%) [22], but similar to that for *R. stylosa* in north eastern Australia (4%) [18].

Immature dropping of propagules may be due to various reasons, such as insect damage, non-availability of nutrients at the time of development and tree size. This is also true with several tropical/subtropical tree species whose number of flowers is quite large as compared to fruit set percentage [21]. Low conversion of flowers to fruits is a feature common in tropical trees with comparatively large fruits [18].

CONCLUSION

Mean annual total litterfalls of the 1st year and 2nd year were respectively estimated as 931.7 ± 16.6 and 1321.9 ± 31.2 (SE) g m^{-2} yr^{-1}, of which the leaf litterfall comprised 65.2 (1st year) and 49.7 % (2nd year). All litterfalls showed a seasonal pattern: the highest peak occurred during summer and the lowest during winter. The reproductive cycle of *R. stylosa* was seasonal. *Rhizophora stylosa* requires a long period of around 2 years for development of flower. The survival rate of reproductive units was low, with very few of flowers converted into propagules (1.2 – 2.5%). *Rhizophora stylosa* hypocotyl is largest in the family Rhizophoraceae. Consequently, the low rate of fruit set recorded in this study may be reflection not only of restricted pollination, but also of resource limitation. As a large propagule of *R. stylosa* is likely to be metabolically expensive to be produced, trees may limit their output per reproductive season, or abort developing propagules when energy reserves are restricted.

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