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REPRODUCTIVE PHENOLOGY OF TWO *Rhizophora* SPECIES IN SUNGAI PULAI FOREST RESERVE, JOHOR, MALAYSIA

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ABSTRACT

The reproductive phenology of two mangrove tree species, *Rhizophora apiculata* and *Rhizophora mucronata*, were observed monthly for one complete annual cycle from March 2010 until February 2011 at Sungai Pulai Forest Reserve (FR). The objectives of this study were to identify and compare the reproductive phenological patterns of the two species, to determine the duration of flowering and fruiting development, to investigate the percentage of successfulness for each species, and to look at the relationship between rainfall and temperature with reproductive phenological patterns of the two *Rhizophora* species. Results revealed that both species produced all reproductive units (flower bud, open flower, and fruit) throughout the study period. The flower bud season for *R. apiculata* was from November until May whilst *R. mucronata* was from November until April. The flowering season was from June until August for *R. apiculata* and January until May for *R. mucronata*. The fruiting season of *R. apiculata* was from July until January while March until May for *R. mucronata*. Development from young flower buds to mature propagules took about 14 to 16 months in *R. apiculata*. Results showed that 7.3% flower buds of *R. apiculata* gave rise to open flowers and only 1.4% were fertilized. The production of *R. mucronata* flower buds was significantly ($p < 0.05$) inversely correlated with the total monthly rainfall and its fruits production was positively correlated with the mean temperature.

ABSTRAK

Fenologi pembiakan dua spesies pokok bakau, *Rhizophora apiculata* dan *Rhizophora mucronata* telah dikaji melalui pemerhatian bulanan selama satu kitaran tahunan lengkap dari Mac 2010 sehingga Februari 2011 di Hutan Simpan Sungai Pulai. Objektif kajian adalah untuk mengenal pasti dan membandingkan corak fenologi pembiakan kedua-dua spesies, untuk menentukan tempoh masa perkembangan fasa pembungaan dan pembuahan, untuk menyiasat peratus kejayaan setiap spesies, dan mengenal pasti hubungan di antara hujan dan suhu dengan corak fenologi pembiakan kedua-dua spesies *Rhizophora*. Hasil kajian menunjukkan kedua-dua spesies mengeluarkan unit pembiakan (kudup bunga, bunga mekar, dan buah) sepanjang tempoh kajian. Musim pengeluaran kudup bunga *R. apiculata* adalah dari November hingga Mei manakala *R. mucronata* dari November sehingga April. Musim pengeluaran bunga mekar adalah dari Jun hingga Ogos untuk *R. apiculata* dan Januari hingga Mei bagi *R. mucronata*. Musim pengeluaran buah *R. apiculata* adalah dari Julai hingga Januari manakala Mac hingga Mei bagi *R. mucronata*. *Rhizophora apiculata* mengambil masa 14 hingga 16 bulan untuk berkembang dari kudup bunga muda menjadi propagul matang. Hasil menunjukkan 7.3% kudup bunga *R. apiculata* berkembang menjadi bunga mekar tetapi hanya 1.4% disenyawakan. Pengeluaran kudup bunga *R. mucronata* mempunyai hubungan yang signifikan dengan hujan bulanan ($p < 0.05$) manakala pengeluaran buah mempunyai hubungan yang positif dengan purata suhu.

Key words: mangrove forest, phenology, reproductive strategies, *Rhizophora*

INTRODUCTION

Mangroves are trees or large shrubs, including ferns and palms, which normally grow in or adjacent to the harsh intertidal zone. They have diverse evolutionary origins but in moving to this harsh ecological niche, several species have developed convergent adaptation in morphology, physiology or reproductive strategies (Polidoro *et al*., 2010; Spalding *et al*., 2010). These include viviparous (Tomlinson, 1986) or cryptoviviparous seeds adapted to hydrochory; pneumatophores or aerial roots that allow oxygenation of roots in hypoxic soils; and salt exclusion or salt excretion to cope with high salt concentrations in the saline waters in which mangroves grow (Polidoro *et al*., 2010).

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Mangroves offer numerous benefits (Ewel *et al*., 2001; Nagelkerken *et al*., 2008). However, human activities and interventions within and near mangrove areas have led to the degradation of mangroves and the resources therein (Ong *et al*., 1995; Valiela *et al*., 2001; Alongi, 2002; FAO, 2007). Mangrove areas are converted into fishponds (Ellison, 2008), saltponds, agriculture and coastal projects (Hamilton & Snedaker, 1984; Ong *et al*., 1995; Alongi, 2002). Mangrove forests can be rehabilitated and maintained (Palis, 1998) and it is not too late to renew the lost productivity of our mangrove areas.

Mangrove communities in tropical rainforest in Malaysia are some of the most species rich in the world (Japar, 1994), yet surprisingly little is known of their phenology on the reproductive processes and success rate of propagule production (Coupland *et al*., 2005; Sharma *et al*., 2011). The lack of quantitative data on reproductive phenology and propagule production for mangrove forests in Malaysia makes it difficult to predict the supply of seed for further planting of mangrove forest in the region (Clough *et al*., 2000). Reproductive phenology in Malaysia is limited because the present studies have focused on species with high economic importance such as *Gonystylus bancanus* (Ramin melawis) (Ismail, 2008) and several *Shorea* spp. (Meranti) (Chan, 1980; Marzalina *et al*., 2003). Recent studies on mangrove phenology in Peninsular Malaysia were carried out by Marzalina *et al*. (2009, 2010) and Farihah (2011). Many other phenological studies (Clarke & Myerscough, 1991; Tyagi, 2003; Coupland *et al*., 2005; Mehlig, 2006) were carried out in countries with seasonal climate.

The importance of phenology lies in the relation of seed or propagule production to nutrient enrichment, seed selection, treatment and nursery operation (Palis, 1998). Phenological data are essential for prediction of the tree's ability to adapt growth and propagation strategies to ambient condition (Mehlig, 2006; Sharma *et al*., 2011). Phenological events in mangroves (Fernandes, 1999; Gwada *et al*., 2000) and other tropical trees (Liebermann, 1982; Wright, 1996; Bach, 2002) can be influenced by environmental conditions including air temperature (Sasekumar & Loi, 1983; Saenger & Moverley, 1985; Heideman, 1989; Duke, 1990) and rainfall (Fernandes, 1999). According to Post and Stenseth (1999) and Chmielewski *et al*. (2004), temperature changes have altered the phenology of the world's plants. Research done by Woodroffe (1984) has proved that the global climate change will result in variations of length of time, and coordination in the phenological process on mangrove forests. Information on the relationships between phenology and climate allow inferring the evolution of ecosystems under the foreseen alteration of climate (Malhi &Wright, 2004; Boisvenue & Running, 2006; Koenig, 2008). The study on the seasons of buds, flowers and fruits production conducted in the Sg. Pulai FR is a pilot study in the southern part of Peninsular Malaysia following a study in the west coast by Farihah (2011) in Pantai Morib, Port Dickson and Tanjung Tuan, Melaka and Marzalina *et al*. (2009, 2010) in several areas of the west coast of Peninsular Malaysia.

The *Rhizophora* is considered the most important of all mangrove genera across the Pacific tropical and subtropical region (Sharma *et al*., 2010). In this study, *R. apiculata and R. mucronata* were selected for phenological monitoring because these two species are important in the rehabilitation and regeneration of mangrove forests in Southeast Asia. In addition, the two species has high economic value due to endless demand in construction projects and charcoal production (Clough *et al*., 2000; Salina, 2009). When the peak of phenophase is known, the method of propagules collection for mangrove replanting project can be carried out in a sustainable approach (Palis, 1998).

Phenological events can be assessed directly by observation (Christensen & Wium-Andersen, 1977; Wium-Andersen & Christensen, 1978; Duke *et al*., 1984; Tyagi, 2003; Ismail, 2008; Farihah, 2011) and also indirect evidence i.e from litter fall data (Duke, 1990; Sharma *et al*., 2011). The current study aims to describe the phenology of *Rhizophora apiculata* (Bakau minyak) and *Rhizophora mucronata* (Bakau kurap). The specific objectives were to identify and compare the reproductive phenological patterns of *R. apiculata* and *R. mucronata* in Sungai Pulai FR; to determine the duration of flowering and fruiting development; to investigate the percentage of successfulness for each species; and to look at the relationship between climatic factors that includes rainfall and temperature and reproductive phenological patterns of the two *Rhizophora* species.

MATERIALS AND METHODS

Study site

The study was conducted in Sg. Pulai Forest Reserve (01° 27' 14" N, 103° 33' 30" E) which is located at southwest of Johor in the Pontian and Johor Bahru district (Fig. 1). Sg. Pulai Forest Reserve consists of 393 compartments covering an area of 5488.93 ha (pers. comm., En. Mohd Noor b. Ismail, Gelang Patah Forest Range). The Sg. Pulai Forest Reserve is the largest mangrove forest in Johor and the second largest in Peninsular Malaysia. Sg. Pulai has been declared as a Ramsar site on the 31st

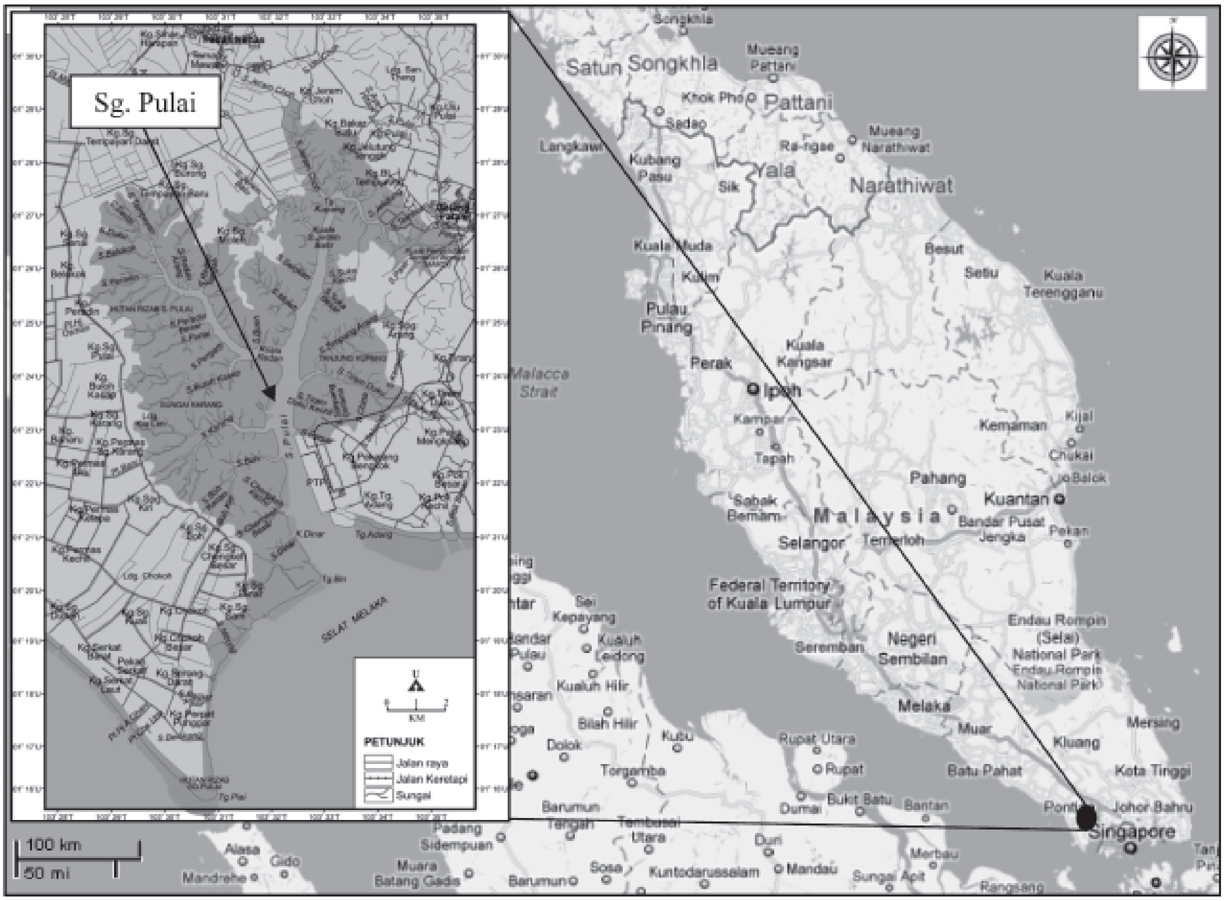

Fig. 1. Map of Johore State showing the study area in the Sungai Pulai FR (Source: Google maps)

January 2003 (Maimon *et al*., 2008) and is the largest riverine mangrove forest in Peninsular Malaysia.

Phenological monitoring

Five individual trees with diameter at breast height (DBH) > 5 cm for each species (*Rhizophora apiculata* and *R. mucronata*) were selected at the study site. All trees were mature individuals. The smallest tree of the *R. apiculata* was 6.0 cm DBH and the largest was 15.8 cm. As for the *R. mucronata*, the smallest tree was 8.3 cm DBH while the largest was 18.5 cm. The mean DBH of the *R. apiculata* was 12.38±1.82 cm and 14.48±1.84 cm for the *R. mucronata*. The locations of all the trees for both species were at the river banks of the Sg. Pulai FR and the coordinates of each tree were recorded (Table 1). All sample trees were located within a homogeneous habitat of a mixed mangrove forest type that was relatively dominated by the *R. apiculata* (Nordatul Akmar *et al*., 2011). The trees were sprayed with permanent paint. Then, five branches with almost similar in size were chosen and marked with aluminium tag. The number of reproductive units (flower bud, open flower and fruit) (Fig. 2) were observed with the frequency of once in every three to four weeks from March 2010 to February 2011 and the number of the reproductive units were recorded. The mean was calculated by dividing the total number of reproductive units (from all five branches) with the number of trees (n= 5) for each species. The peak and production period of reproductive units were compared between species. This method is a modification from Clarke and Myerscough (1991) and Coupland *et al*. (2005). From modification of Coupland *et al.* (2005), the production period or season was identified from the month where reproductive units started to increase until the month it declined. The month with the highest reproductive units was recorded as the peak of production. The duration of a development phase for each species were identified by counting the month between the peak of phase I to phase II (Duke *et al*., 1984; Coupland *et al*., 2005).

Climate

The total of each reproductive unit were correlated with rainfall and temperature data recorded at the nearest meteorological station, Hospital Pontian. The total amount of rainfall throughout the study period was 2104.1 mm. The

Table 1. The locations of the two *Rhizophora* species sample trees at the Sungai Pulai FR

Sample trees	Location	DBH (cm)
R. apiculata 1	01° 27' 14" U, 103° 33' 30" T	15.6
R. apiculata 2	01° 27' 15" U, 103° 33' 23" T	6.0
R. apiculata 3	01° 27' 20" U, 103° 33' 26" T	11.0
R. apiculata 4	01° 27' 20" U, 103° 33' 23" T	13.5
R. apiculata 5	01° 27' 24" U, 103° 33' 19" T	15.8
Mean DBH		12.38±1.82
R. mucronata 1	01° 27' 14" U, 103° 33' 31" T	17.6
R. mucronata 2	01° 27' 14" U, 103° 33' 30" T	12.8
R. mucronata 3	01° 27' 15" U, 103° 33' 23" T	18.5
R. mucronata 4	01° 26' 18" U, 103° 33' 04" T	8.3
R. mucronata 5	01° 27' 20" U, 103° 33' 23" T	15.2
Mean DBH		14.48±1.84

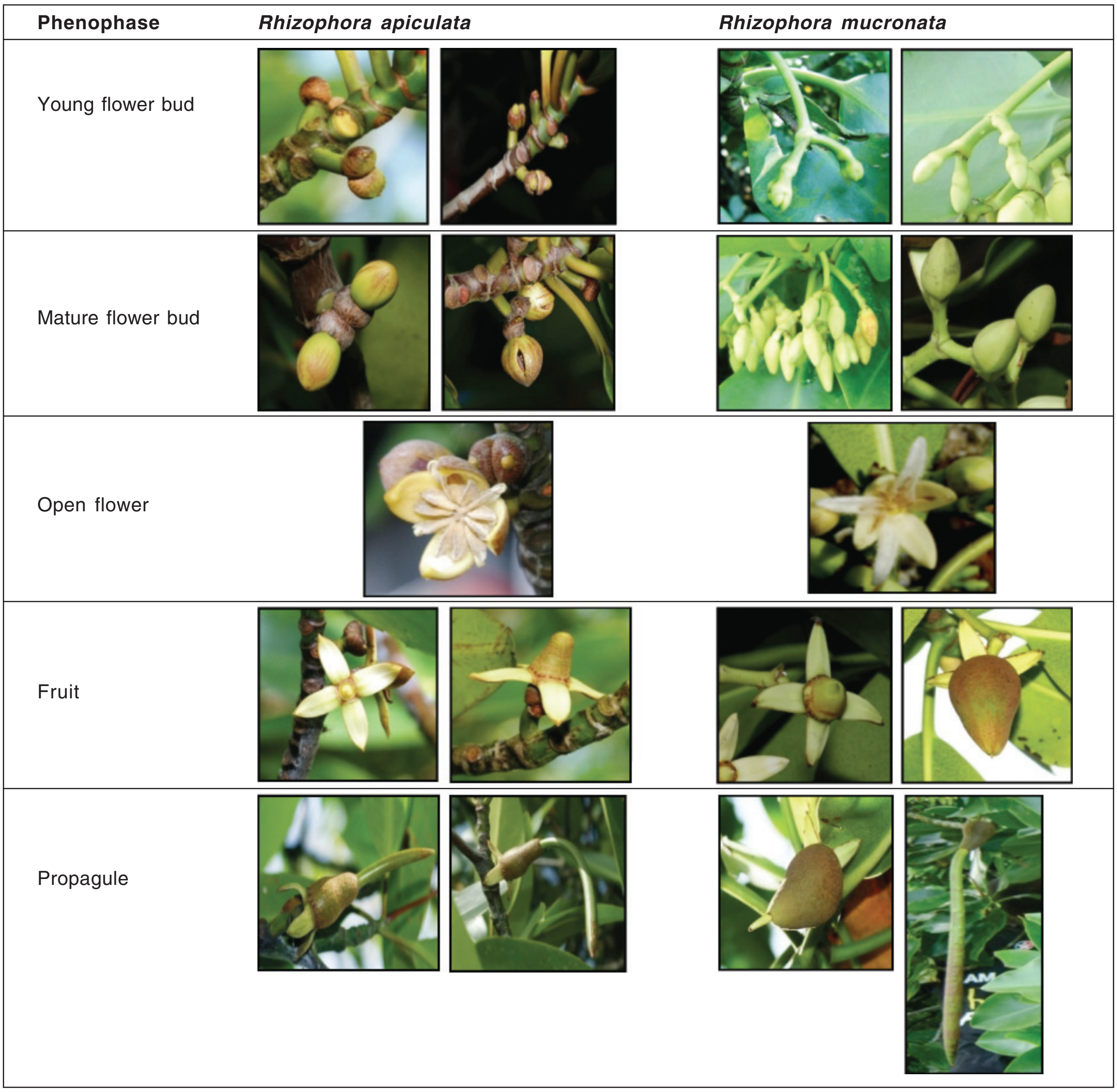

Fig. 2. The phenophases of *Rhizophora apiculata* and *Rhizophora mucronata*

highest rainfall was in July 2010 (302.9 mm), followed by October 2010 (279.2 mm) and January 2011 (277.0 mm). The lowest rainfall was in April with 84.4 mm. Air temperature was the highest in May 2010 with 29.5°C and the lowest was in January 2011 of 26.0°C.

Statistical analysis

The independent t-test was used for the comparison of reproductive units between species. The relationships between abiotic factors (rainfall amount and temperature) and the abundance of reproductive units were determined using Pearson Correlation as conducted by Fernandes (1999). All statistical analyses were done using the PASW Statistics 18 software.

RESULTS AND DISCUSSION

Phenological pattern

Our results showed that the maximum number of flower bud production for both species were almost similar ($p > 0.05$). The flower bud season for *R. apiculata* was between November and May. In comparison, the flower bud season of *R. apiculata* at Tanjung Tuan and Pantai Morib were reported by Wan Juliana *et al*. (2011) one month later than this study. The flower bud season of *R. mucronata* in Sungai Pulai was from November until April while Wan Juliana *et al*. (2011) recorded the flower bud season in Tanjung Tuan was from January until May. The peak of flower buds production was in March for both species at Sg. Pulai (Fig. 3).

At the open flower phase, a significant difference ($p < 0.05$) of number of flowers in April and May between the two species was observed. The open flower season of *R. apiculata* was from June to August while the peak was in July. The flowering season of *R. apiculata* in this study was similar to Tanjung Tuan (Wan Juliana *et al*., 2011) but one month later than flowering at Pantai Morib (Wan Juliana *et al*., 2011). The flowering season of *R. mucronata* was from January until May and the peak was in April. In comparison, the *R. mucronata* flowering season in Tanjung Tuan was from April until June (Wan Juliana *et al*., 2011). The variation of flowering seasons in this study compared to other sites may link to the fluctuations of favourable conditions between sites (Coupland *et al.,* 2005).

For the fruit phase, t-test showed a significant difference ($p < 0.05$) of the number of fruits between

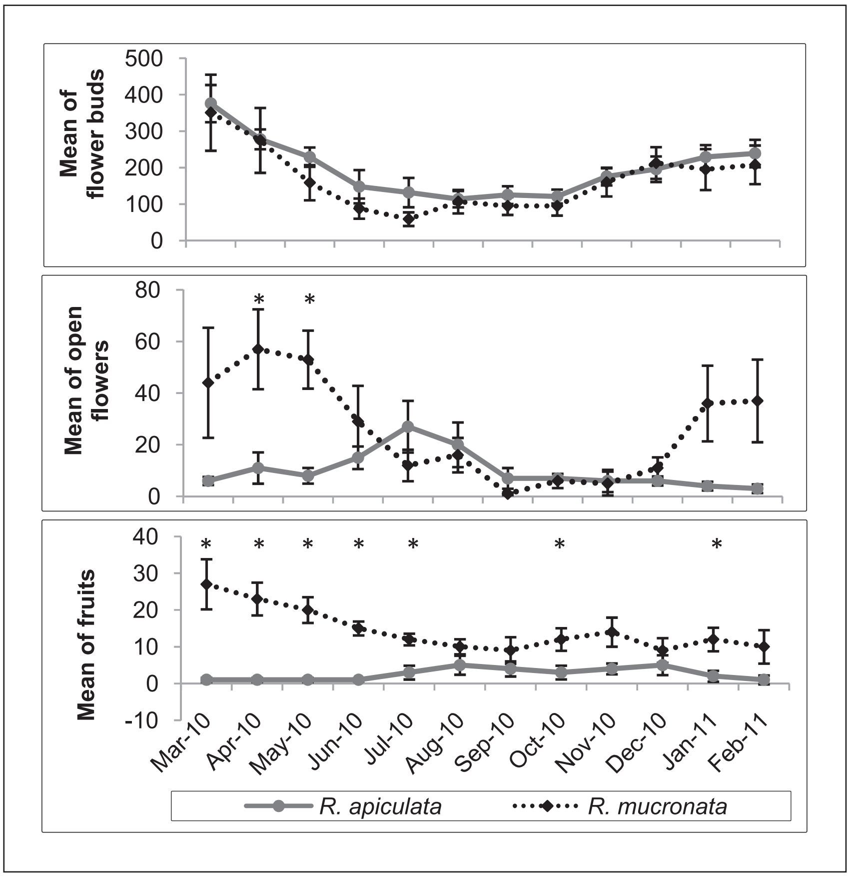

Fig. 3. Mean (±SE) reproductive units of *Rhizophora apiculata* and *Rhizophora mucronata* from March 2010 till February 2011 at Sungai Pulai FR

R. apiculata and *R. mucronata* from March to July 2010, October 2010, and January 2011. The fruiting season of *R. apiculata* was from July to January with two peaks observed that were in August and December. The lowest mean numbers of fruits produced by *R. apiculata* within the study period was only 1 (±0.4) unit. Wan Juliana *et al*. (2011) reported that the fruiting season of *R. apiculata* in Tanjung Tuan and Pantai Morib was from July until September (Wan Juliana *et al*., 2011) which is similar to this study but the fruiting season at Sg Pulai was longer than Tanjung Tuan and Pantai Morib. In this study, the fruiting season of *R. mucronata* was from March to May while the peak was in March. In contrast, the fruiting season of *R. mucronata* at Tanjung Tuan was from June to September (Wan Juliana *et al*., 2011). The lowest mean numbers of fruits produced by *R. mucronata* within the study period was 9±3.6 unit.

Our results indicated that phenological patterns variation of the two *Rhizophora* species was more pronounced at the open flower and fruit phases compared to the bud phase. The differences lied in terms of the number of reproductive units, the month of increased production and peak of production. The mean numbers of flower buds for both species are very similar throughout the year, i.e. there is a potential for flowering but in the case for *R. apiculata*, the flower buds have yet to develop into mature flowers. According to Duke *et al*. (1984), different species even from the same genus showed different patterns of phenology. Therefore, the phenological pattern of the two *Rhizophora* species at Sg. Pulai is comparable to previous findings.

Reproductive phase duration

Our results showed that, the *R. apiculata* development period from young to mature flower bud was four months while the development from mature flower bud to open flower phase took about five months. Another one to two months were taken for the open flowers to develop into fruits. The fruits then developed into mature propagules within four to five months. Our results estimated that the *R. apiculata* needed 14 to 16 months to complete its reproductive cycle. Since our study was carried out for only one year, a complete reproductive cycle that is from the bud initiation to abscission of mature propagule cannot be determined. According to Farihah (2011), *Rhizophora apiculata* at Tanjung Tuan took about 4-5 months to develop from mature bud to open flower, another 1-2 months to form fruit and another 3-4 months for the propagule to mature. Farihah (2011) reported that the duration for the development of mature bud to mature propagule was 11-12 months for *R. apiculata*. Previous studies reported that the length of reproduction phase of *R. apiculata* took longer (almost 3 years) compared to other *Rhizophora* species (Wium-Andersen, 1981; Duke *et al*., 1984). This is due to the long dormancy period recorded for the primordia and flower buds of *R. apiculata,* each of about one year, a long period of 2½ years being required for development of the flower (Christensen & Wium-Andersen, 1977).

The *R. mucronata* development period, however, cannot be determined. This situation was due to the high variation of the reproductive units between individual trees. According to El-Khouly and Khedr (2007) the distribution of *R. mucronata* is characterized by salinity, nutrient, substrate structure and tidal movement. All sample trees of *R. mucronata* in our study were located at the similar substrate of Sg. Gelang Patah river banks with low salinity. Future studies should also consider a homogeneous habitat with minimal variation of soil nutrient and tide level to minimize the variations between individuals of *R. mucronata*. Results displayed that the season of all three reproductive phases overlapped. Even the peak of each season falls within the same or adjacent month. The peak of flower bud and fruit was in March and open flower peaked in April. Previous studies reported that the length of *R. mucronata* reproduction cycle took 17 months and the dormancy period was not observed for *R. mucronata* (Wium-Andersen, 1981). A longer period of observation is needed to monitor the full development of both *R. apiculata* and *R. mucronata* reproductive phase duration at Sg. Pulai.

Success rate

Our results exhibited that only 7.3% of the flower bud of *R. apiculata* developed into flower while only 1.4% were fertilized into fruits. Our study had similar results with Christensen and Wium-Andersen (1977) in Phuket Thailand who reported that of the total flower buds, 7% were recorded as flowers and only 1-3% formed fruits. The amount of flowers found in Phuket is considered low and this is probably a reflection of the short life time of the flowers. The majority of which presumably fell off between observations dates (Christensen & Wium-Andersen, 1977). Farihah (2011) study in Tanjung Tuan Melaka showed that the survival of flower buds into open flower and then into fruits for *R. apiculata* was really low with only 3.7% and 1.2%, respectively. In comparison, Duke *et al*. (1984) in Queensland, Australia reported that 12.1% flower buds developed into open flowers and 7.2% open flowers were fertilized into fruits. Commonly in tropical trees with large fruits, only a very small proportion of flowers give rise to mature fruits (Duke *et al*., 1984).

The percentage of success rate from flower bud to open flower of *R. mucronata* cannot be determined because of the unclear phenological trend in our study site. However, Farihah (2011) reported that the success rate from flower buds to fruits of *R. mucronata* was high at 23.6% and 8.9% of open flowers developed into fruits in Tanjung Tuan. Usually, *Rhizophora mucronata* had high percentage of fertilization that is likely due to the unique characteristics of stigma which is sessile (Tomlinson, 1986) and short (0.5-1.0 mm) (Chan, 1996).

Relationship between climatic conditions and reproductive units

Our results indicated that the amount of monthly rainfall had no relationship with all three reproductive phases of the *R. apiculata* in HS Sg. Pulai (Fig. 4). Similar results were obtained by Farihah (2011) which, showed no significant relationship between rainfall and the production of reproductive units of *R. apiculata* in Tanjung Tuan. According to Upadhyay and Mishra (2010), majority of flowering event happens in rainy season. In comparison, *Rhizophora apiculata* in Southern Thailand flowered during the dry season (Christensen & Wium-Andersen, 1977). Kitamura and Baba (1996) in Bali Island showed that the number of *R. apiculata* mature propagules was produced much greater in the rainy rather than in dry season, because fertilization rates in the dry season were higher than in the rainy season. The dry conditions are likely to facilitate pollinator and pollinations (Coupland *et al*., 2005). Coupland *et al*. (2005) reported that there is a relationship between the amount of rainfall with the production of *R. stylosa, Avicennia marina, Ceriops australis,* and *Sonneratia alba* reproductive organs.

On the other hand for *R. mucronata*, our results showed that there was a significant relationship between the flower bud of *R. mucronata* and amount of rainfall (p= 0.048, r= -0.579) (Fig. 4). The number of flower bud was inversely correlated to total monthly rainfall. No significant correlation was found between rainfall and the number of flowers and fruits of *R. mucronata* in our study. However, previous studies showed a significant relationship between rainfall and fruit or flower. Study done by

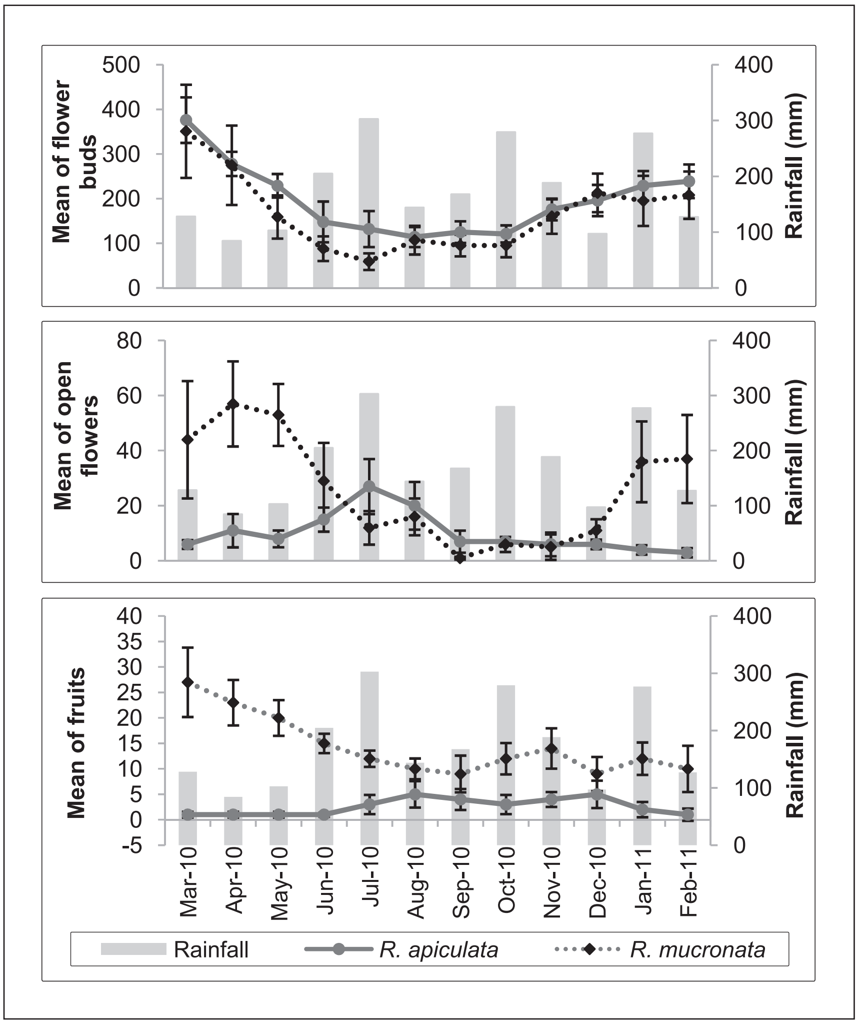

Fig. 4. Mean (±SE) reproductive units of *Rhizophora apiculata* and *Rhizophora mucronata* and rainfall from March 2010 till February 2011 at Sungai Pulai FR

Fernandes (1999) in Amazonian mangrove swamp showed that the peak of flowering partially correspond with the lowest intensity of rainfall. It seems to complement the strategy in which massive fruit production is obtained during the wet period. A study from Coupland *et al*. (2005) showed that the propagules of *R. stylosa* was released during the dry season. In West Africa, the season of *R. racemosa* occurs in the beginning of the rainy season and the similar trend was observed in Malaysia on *Rhizophora* fruiting season (FAO, 1994).

Our results on the correlation analysis between temperature and reproductive organs showed that there was no relationship between temperature and production of the reproductive units of *R. apiculata*. However, a significant relationship was found between temperature and the production of *R. mucronata* fruits (Fig. 5). The results indicated that *R. mucronata* fruit production was higher when the temperature increased ($p= 0.033$, $r= 0.617$). According to studies conducted by many researchers such as Fernandes (1999) and Mehlig (2006), several species of *Rhizophora* showed maximum flowering season when the temperature is high. Duke (1990) reported the rates of development to flowering and fruit maturation have a linear relationship with daily air temperature. The temperature may influence the phase duration by effecting on chemical reaction rates. Usually, that development rates of reproductive-cycle doubled for each 10ºC rise in temperature.

CONCLUSION

This study showed that eventhough *Rhizophora apiculata* and *Rhizophora mucronata* produced reproductive units all year round, some variation of phenophases trend between species over time were observed. There was no significant relationship between the production of reproductive units for *Rhizophora apiculata* with temperature and rainfall

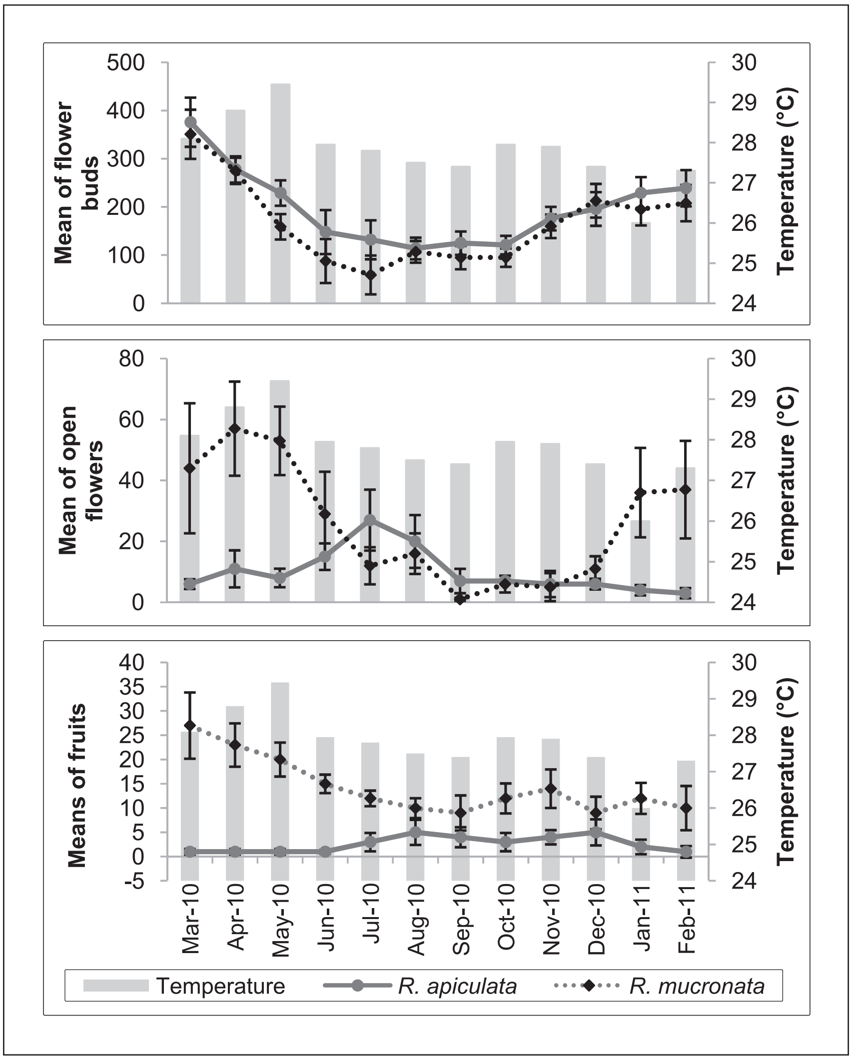

Fig. 5. Mean (±SE) reproductive units of *Rhizophora apiculata* and *Rhizophora mucronata* and temperature from March 2010 till February 2011 at Sungai Pulai FR

amount. The production of *R. mucronata* flower buds significantly decreased with the increament of total monthly rainfall. The production of *R. mucronata* fruits significantly increased when the air temperature was higher. The findings of the present work will be useful in restoration initiatives that require collection of healthy planting materials. This study indicated that there is a need to conduct a longer-term observation at the locations to be rehabilitated, because the phenology and reproductive biology of different species varies according to environmental conditions.

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