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Original Article

Phenology of urban trees in a tropical urban forest in Thailand

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Abstract

Urban forests are important for ameliorating urban heat loads and the urban microclimate may have an impact on tree phenology. Understanding these interactions is important to urban planners to select suitable trees for the urban forest. For one year we tracked leaf cover, flowers and fruit of 22 tree species in Bang Kachao Peninsula and explored correlations between phenology and climatic factors. Tropical lowland trees, with exception of mangroves, had reduced leaf cover in the dry season. Mangroves flowered and fruited throughout the year as compared to 1-3 times a year for tropical lowland forests. Positive correlations were found between flowering of *Diospyros decandra* with temperature; flowering of *Aglaia cucullata* and *Elaeocarpus hygrophilus* with rainfall; and fruiting of *Dillenia indica* and *Diospyros malabarica* with rainfall and relative humidity. We intend to apply tree phenology results to urban forest restoration and to monitor any adaptation to climate change for future mitigation strategies in tropical urban forests in Thailand.

Keywords: tree phenology, tropical urban forest, mangrove, Bang Kachao Peninsula

1. Introduction

Close relationships between climate and phenology can impact phenological patterns in tropical forests, such as the timing of flowering or fruiting (Chen *et al.*, 2017; Kurten, Bunyavejchewin, & Davies, 2017). Furthermore, global climate change is beginning to impact flowering in tropical forests (Pau, Okamoto, Calderon, & Wright, 2017). However, the majority of studies have addressed forest structure and composition rather than phenology (Deb, Phinn, Butt, & McAlpine, 2018). Most tree phenology studies in tropical forests in Southeast (SE) Asia have been conducted on natural forests (Corlett & Lafrankie, 1998; Harrison *et al.*, 2016; Kuaraksa, Elliott, & Hossaert-Mckey, 2012; Williams, Bunya vejchewin, & Baker, 2008) where synchronous reproduction is reported to take place (Appanah, 1985).

Urban forests are becoming increasingly important as cities promote greening for environmental and health concerns. Whilst climate change can impact on tree phenology across broad landscapes (Han, Geping, & Chaofan, 2013), in urban environments the spatial pattern of change in phenology can vary with land development, construction, air pollution and other perturbations. Hence, knowledge of both temporal and spatial parameters is desirable to understand tree pheno-

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logy in urban environments. In tropical forests in SE Asia, flowering tends to occur during November to May (Kurten *et al.*, 2017) but in Malaysia flowering in some species occurs in the spring and fall (Chen *et al.*, 2017). However, urban environments often contain trees sourced from different climates and forest types. Hence, urban tree behavior may differ from those observed in natural habitats.

Phenology can be affected by human activities, with urbanization transforming vegetation patterns (Xu, Yang, Huang, Fang, & Shi, 2008) and ecosystem processes controlled by climate. Hung, Uchihama, Ochi, and Yasuoka (2006) reported significant day-time thermal contrasts of up to 5 - 6 degrees celsius between large urban parks in Bangkok (Chatuchak and Lumpini) and their urban surrounding as a result of the Urban Heat Island (UHI) effect (Zipper *et al.*, 2016). The UHI can affect tree phenology (Dhami, Kathryn, Timothy, Rico, & Sudiksha, 2011) with differences in plant phenology reported between urban and semi-rural or rural areas (Liang, Shi, & Li, 2016). However, these studies on vegetation phenology in urban environments using remote sensing were conducted at the stand scale and not at the individual tree scale. Thus, there is a large gap in our understanding of the phenology of individual trees or indeed of particular tree species in urban tropical areas. Information on the annual and seasonal activity of trees informs the selection of species for urban greening as well as the management of trees in urban environments.

The Bang Kachao Peninsula (BKP) is a prominent large green area surrounded by the Chao Phraya River and the city of Bangkok. The Peninsula contains rehabilitation forests, mangrove forests, home-gardens and parks (Sommeechai, Wachrinrat, Dell, Thangtam, & Srichaichana, 2018) as well as residences and industry. BKP plays an important role for biodiversity conservation and ecotourism, and is a very important green space positively impacting the well-being of people in the city and nearby. This study aimed to monitor tree phenology at the individual tree scale, as leaf cover, flowering and fruiting, in BKP and to examine any correlation between phenology and climate. Understanding interactions between climate and the environment should enhance the management of trees in BKP towards a sustainable urban green space.

2. Materials and Methods

2.1 Study site

Tree phenology was monitored in BKP, Samut Prakan province, Thailand (13º40’44’’N, 100º33’53’’E) from January to December 2016. BKP is a large urban green area close to Bangkok and surrounded by the Chao Phraya River (Figure 1). It is a wetland which is influenced by the tide. The ecological system is a combination of freshwater, brackish water and salt water. The habitats in this area are beach forest, swamp forest, moist evergreen forest, dry evergreen forest, abandoned orchard, home-garden agroforestry and park (Sommeechai *et al.*, 2018).

2.2 Climate data

We used monthly average temperature, rainfall and relative humidity from January to December 2016 (Figure 2) from the Bangna agrometeorological station of the Thai Meteorological Department. In BKP the climate is influenced by the tropical monsoon and the average daily high temperature was stable over the year with the range 31-35 ºC. The BKP has a wet season from May to October and dry season from November to April (Sommeechai & Wachrinrat 2017).

2.3 Tree species and monitoring phenology

We used the tree database of Sommeechai, Pan charoen, Maelim, and Poompuang (2015) which contains 37 species (33 genera, 15 families). We selected 22 species (Table 1) to monitor tree phenology with the following criteria: (1) tree species for restoration, 15 native tropical lowland forest tree species; (2) trees for protecting river banks against wave action, seven native mangrove species. We randomly selected three replicate trees for each species, giving a total of 66 trees. The trees were located within 6 districts in BKP as follows: Bang Kachao 24 trees, Bang Nam Phueng 18 trees, Bang Krasop 10 trees, Bang Kor Bua 9 trees, Bang Yo 2 trees, and Song Khanong 3 trees (Figure 1).

We observed and estimated the percentage of leaf cover, flowering and fruiting of trees by scanning the canopy with binoculars and scoring as a linear scale comparing with a modified crown density method (Figure 3) for different phenology phases (Koelmeyer, 1959; Kuaraksa *et al.*, 2012). The leaf cover was defined as the percentage of leaves per crown density (the amount of crown branches, foliage and reproductive structures that blocks light visibility through the crown). We revised the method by using the percentage of crown area covered by leaf, flower and fruit and data were collected in the middle of each month for one year (January to December 2016). The surveyors were trained before collecting field data and we used the same people every month to reduce the error from measuring.

2.4 Data analysis

The monthly mean percentages of leaf cover, flower, and fruit of each species were calculated. To assess variable relationships between phenology (leaf cover, flowering and fruiting) and climatic factors (temperature, rainfall and relative humidity), we calculated correlation coefficients with R statistical software (R Core Development Team 2013).

3. Results and Discussion

3.1 Leaf cover

We classified the leaf habit of 22 tree species into 3 groups as the dry deciduous, facultatively deciduous and evergreen. The mangrove tree species (7 species) comprised the group of evergreen trees whilst the tropical lowland tree species were composed of evergreen trees (6 species), dry deciduous trees (8 species), and facultatively deciduous trees (1 species) (Table 1).

Leaf cover of the mangrove species was generally higher than 80%, except in the dry season where the leaf cover was 71, 67 and 62% for *Sonneratia caseolaris*, *Intsia bijuga* and *Terminalia catappa*, respectively. Leaf cover of *Sonneratia caseolaris* and *Iantsia bijuga* was lowest in October to January, and for *Terminalia catappa* it was reduced in

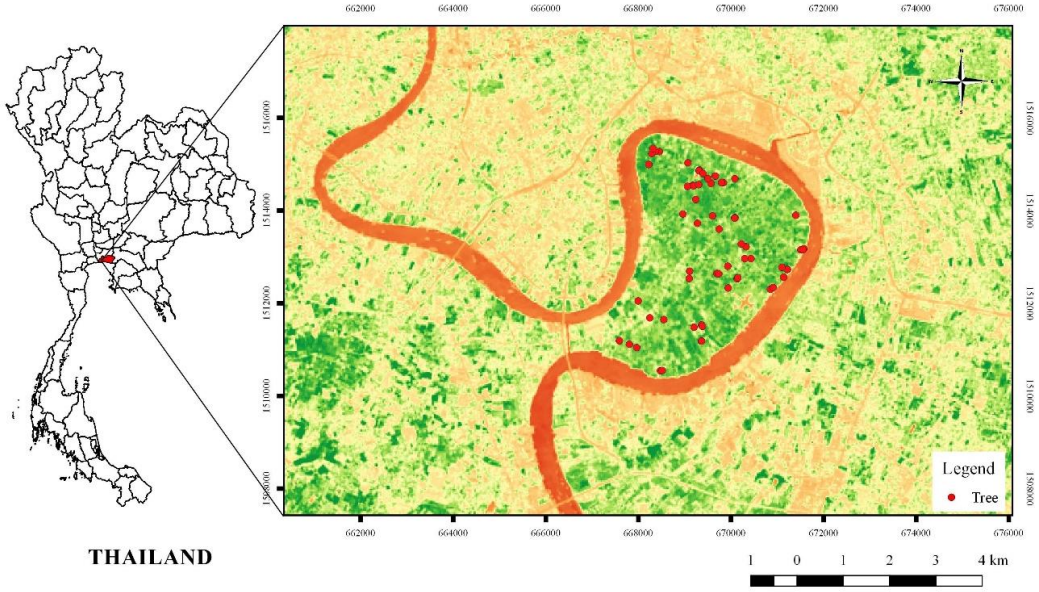


Figure 1. Study site and the location of sample trees (red dots) in Bang Kachao Peninsula, Samut Prakan province, Thailand.

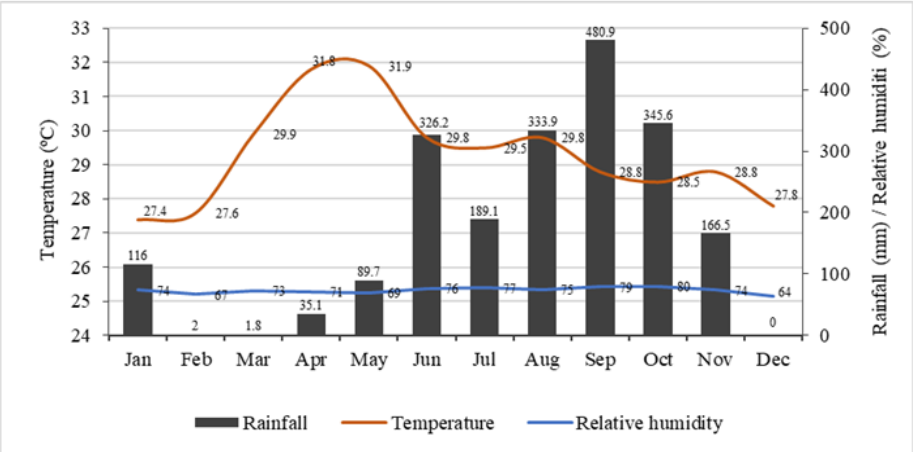


Figure 2. Monthly average temperature, rainfall and relative humidity in Bang Kachao Peninsula from January – December 2016 recorded by the Bangna agrometeorological station.

Table 1. Tree species and their characteristics in this study.

No.	Species/Family	Leaf habit	DBH (cm)	Tree characteristic (left to right: leaf cover, flowering, fruiting)		
1.	*Aglaia cucullata* (Roxb.) Pellegr.[1] (MELIACEAE)	Evergreen	42.0 - 45.5			
2.	*Bruguiera sexangula* (Lour.) Poir.[1] (RHIZOPHORACEAE)	Evergreen	28.3 - 44.6			
3.	*Cerbera odollam* Gaertn.[1] (APOCYNACEAE)	Evergreen	71.1 - 136.3			

Table 1. Continued.

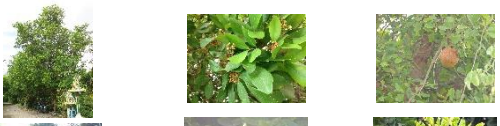
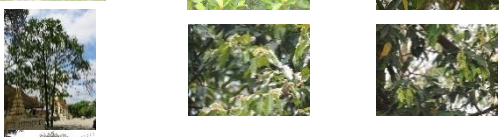
No.	Species/Family	Leaf habit	DBH (cm)	Tree characteristic (left to right: leaf cover, flowering, fruiting)
4.	*Intsia bijuga* (Colebr.) Kuntze[1] (FABACEAE)	Evergreen	38.9 - 44.9	
5.	*Sonneratia caseolaris* (L.) Engl.[1] (LYTHRACEAE)	Evergreen	65.9 - 92.4	
6.	*Terminalia catappa* L.[1] (COMBRETACEAE)	Evergreen	43.5 - 53.7	
7.	*Xylocarpus granatum* J. Koenig[1] (MELIACEAE)	Evergreen	34.2 - 50.6	
8.	*Diospyros malabarica* (Desr.) Kostel.[2] (EBENACEAE)	Evergreen	39.0 - 41.2	
9.	*Ficus microcarpa* L. f.[2] (MORACEAE)	Evergreen	36.2 - 45.5	
10.	*Hopea odorata* Roxb.[2] (DIPTEROCARPACEAE)	Evergreen	24.5 - 66.6	
11.	*Horsfieldia irya* (Gaertn.) Warb.[2] (MYRISTICACEAE)	Evergreen	48.0 - 55.7	
12.	*Madhuca esculenta* H. R. Fletcher[2] (SAPOTACEAE)	Evergreen	19.3 - 33.7	
13.	*Sterculia foetida* L.[2] (MALVACEAE)	Evergreen	35.5 - 51.6	
14.	*Albizia procera* (Roxb.) Benth.[2] (FABACEAE)	Dry deciduous	29.6 - 34.4	
15.	*Diospyros decandra* Lour.[2] (EBENACEAE)	Dry deciduous	14.6 - 21.9	
16.	*Dillenia indica* L.[2] (DILLENIACEAE)	Dry deciduous	13.6 - 26.4	

Table 1. Continued.

No.	Species/Family	Leaf habit	DBH (cm)	Tree characteristic (left to right: leaf cover, flowering, fruiting)		
17.	Diospyros mollis Griff.2 (EBENACEAE)	Dry deciduous	20.4 - 40.8			
18.	Elaeocarpus hygrophilus Kurz2 (ELAEOCARPACEAE)	Dry deciduous	6.7 - 29.6			
19.	Garcinia dulcis (Roxb.) Kurz2 (CLUSIACEAE)	Dry deciduous	8.6 - 25.2			
20.	Millettia leucantha Kurz2 (FABACEAE)	Dry deciduous	14.3 - 18.5			
21.	Terminalia calamansanay (Blanco) Rolfe2 (COMBRETACEAE)	Dry deciduous	35.2 - 45.9			
22.	Erythrina fusca Lour.2 (FABACEAE)	Facultatively deciduous	35.7 - 42.5		No flowering	No fruiting

Remark: [1] Mangrove trees, [2] Tropical lowland trees, DBH = diameter at breast height

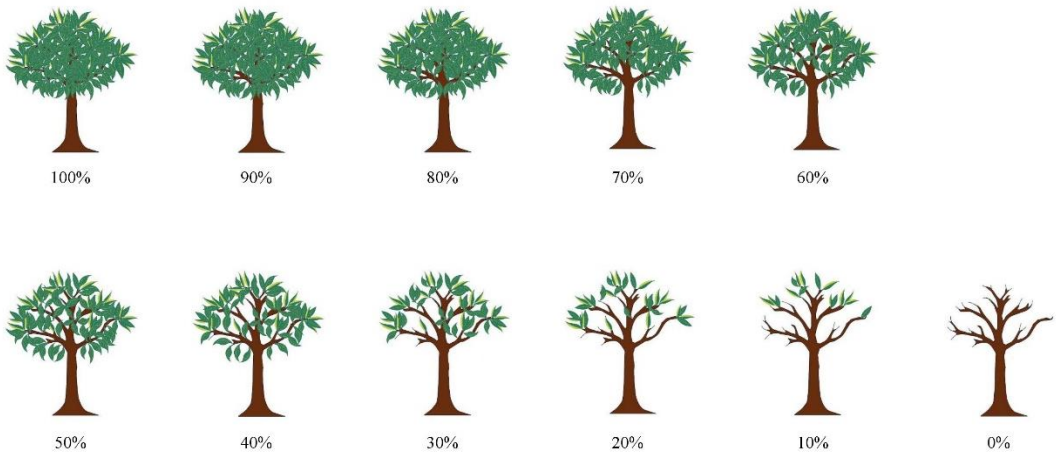


Figure 3. Technique for evaluating the percentage of leaf cover and used the same technique for flowering and fruiting per crown, modified from Kuaraksa *et al.* (2012) and Koelmeyer (1959).

3.2 Flowering

Although the mangroves flowered throughout the year, the cycle of peak flowering enabled the species to be classified into three categories: Group 1 with one flowering peak; Group 2 with two peaks; and Group 3 with three peaks a year. There was one tree species in Group 1 (*Aglaia cucullata)* with all flowering occurring from August to September; two species in Group 2 with flowering peaking in April and November (*Cerbera odollam*) and February and November *(Bruguiera sexangular)*; and four species in Group 3. For the latter group, flowering in *Xylocarpus granatum* peaked in March, June and October; *Sonneratia caseolaris* in February, June and October; *Intsia bijuga* in February, June and

December; and *Terminalia catappa* in February, May and September.

For the tropical lowland trees, 11 species flowered once a year, one species flowered twice a year and two species flowered three times a year. For the first group, flowering peaked either once or twice in the flowering period and varied with species. The nine species with one flowering peak were *Horsfieldia irya* (March to August, peak in June), *Hopea odorata* (February to May, peak in April), *Albizia procera* (June to October, peak in August), *Ficus microcarpa* (February to May, peak in April), *Diospyros mollis* (March to May, peak in April), *Madhuca esculenta* (June to August, peak in July), *Terminalia calamansanai* (August to December, peak in October), *Diospyros decandra* (February to August, peak in June) and *Diospyros malabarica* (April to July, peak in June), with peak percentages being 100, 63, 100, 21, 33, 67, 83, 33 and 13%, respectively. Two species flowered once a year with two flowering peaks, namely *Elaeocarpus hygrophilus* flowering from July to November with peaks in August and October (38% each) and *Garcinia dulcis* flowering from January to June with peaks in March and June (63% and 67%, respectively). *Dillenia indica* flowered twice a year, from April to June and then from July to September with peaks in May (4%) and August (4%). Two species flowered three times a year: *Sterculia foetida* from February to May, May to July and August to October with peaks in March (56%), June (25%) and September (13%); and *Millettia leucantha* from January to March, March to June and June to August with peaks in February (21%), April (63%) and July (8%). Lastly, *Erythrina fusca* did not flower in the study year.

Mangroves flowered throughout the year in BKP similar to the mangroves in India (Upadhyay & Mishra, 2010). The peak cycle of flowering in mangroves in BKP occurred in both the wet and dry seasons, whereas in mangrove species in Brazil the peak cycle occurred in the wet season (Nadia, Morellato, & Machado, 2012). We found flowering of tropical lowland trees in BKP occurred either in the wet or the dry season. This contrasts with a wet seasonal evergreen forest in Khao Chong in southern Thailand where flowering of most species occurred in the dry season (Kurten *et al.*, 2017).

3.3 Fruiting

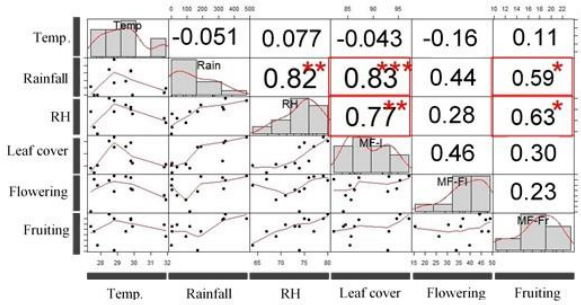
Fruiting can be influenced by the availability of pollination vectors, abundance of frugivores and other factors, hence there is not necessarily a relationship between flowering and fruiting intensity. We classified the percentage of fruiting by range as high (>75%), moderate (>50%-75%), low (25%-50%) and very low (<25%). We used the maximum percentage to identify the range of each species. In mangroves, the percentage of fruiting lay in the range between moderate and very low. We found moderate fruiting with moderate flowering in *Intsia bijuga* and *Sonneratia caseolaris*; and low fruiting with moderate flowering in *Cerbera odollam* and *Terminalia catappa*. By contrast, some mangrove species had very low fruiting even though flowering intensity was high, for example *Aglaia cucullata*, *Bruguiera sexangula* and *Xylocarpus granatum*. Overall, mangroves had a low percentage of fruit throughout the year.

In the tropical lowland habitat, fruiting intensity ranged from high to very low. Two species had high fruiting (*Albizia procera* and *Ficus microcarpa*), three species had moderate fruiting (*Dillenia indica*, *Madhuca esculenta* and *Sterculia foetida*), seven species had low fruiting (*Diospyros malabarica*, *Diospyros mollis*, *Elaeocarpus hygrophilus*, *Hopea odorata*, *Horsfieldia irya*, *Millettia leucantha* and *Terminalia calamansanail*) and three species had very low fruiting (*Diospyros decandra*, *Erythrina fusca and Garcinia dulcis*). We found that *Horsfieldia irya* and *Terminalia calamansanail* had high flowering but low fruiting.

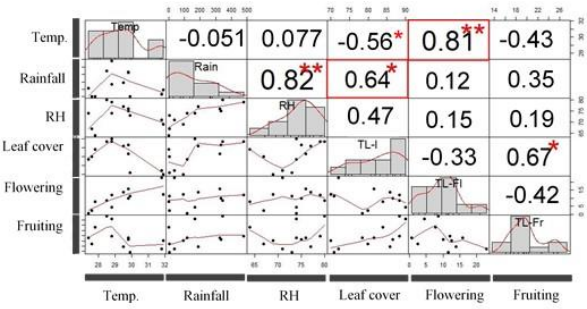
Fruiting of most trees monitored in the tropical lowland habitat of BKP was determined as low to very low. Notably, *Ficus* spp. fruited throughout the year similar to Doi Suthep-Pui National Park in northern Thailand (Kuaraksa *et al.*, 2012). *Albizia procera* had abundant fruiting.

3.4 Phenology and climatic factors

The correlation matrix revealed that temperature, rainfall and humidity contributed to the phenology of tree species in the forest habitats that were studied. Leaf cover of tree species in the mangrove habitat increased with increases in rainfall and relative humidity. For the tropical lowland tree species, flowering increased with temperature (Figure 4). Analysis at the species level revealed that flowering of *Diospyros decandra* was highly and positively correlated with temperature, and flowering of *Aglaia cucullata* and *Elaeocarpus hygrophilus* were highly positively correlated with rainfall (Figure 5). Furthermore, fruiting of *Dillenia indica* and *Diospyros malabarica* were highly positively correlated with rainfall and relative humidity (Figure 6).



(a) Mangrove habitat



(b) Tropical lowland habitat

Figure 4. Correlation between phenology (leaf cover, flowering and fruiting) with climatic factors (temperature, rainfall and relative humidity) of mangrove habitat (a) and tropical lowland habitat (b) in Bang Kachao Peninsula; where * indicates $p < 0.05$, ** indicates $p < 0.01$ and *** indicates $p < 0.001$.

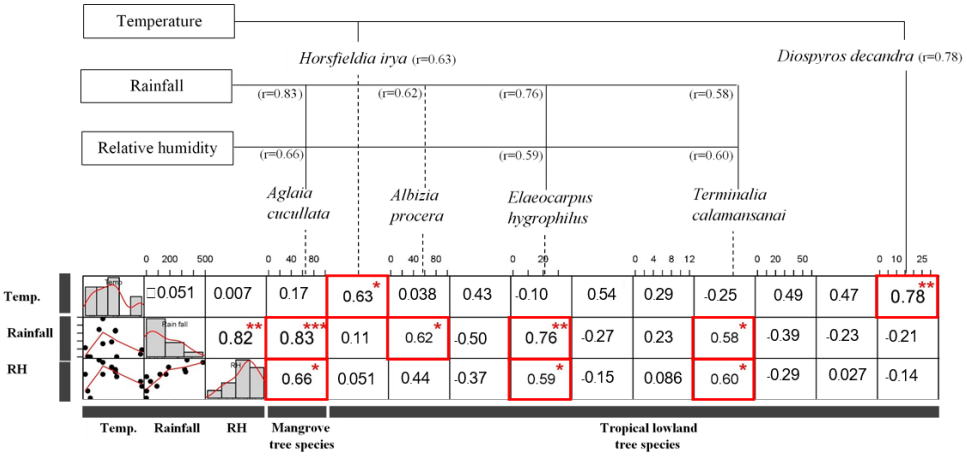


Figure 5. Correlation analyses at the species level between flowering and climatic factors (temperature, rainfall and relative humidity) in Bang Kachao Peninsula; where * indicates p < 0.05, ** indicates p < 0.01 and *** indicates p < 0.001.

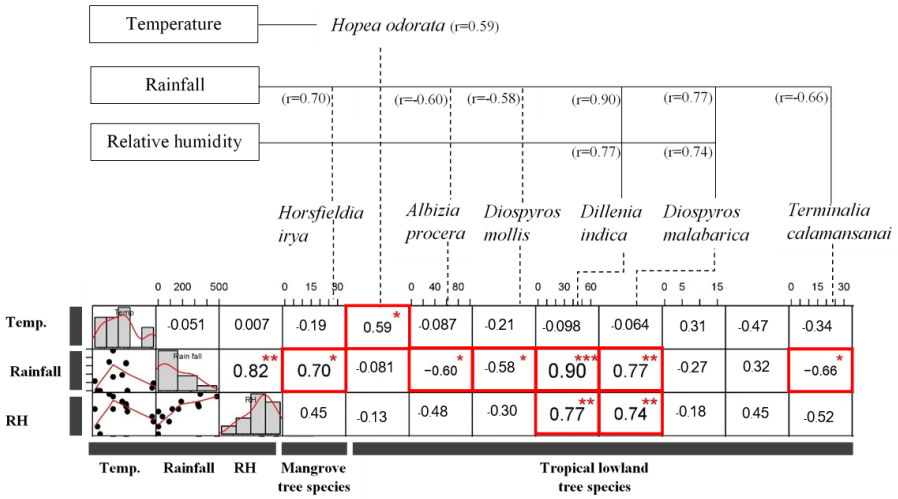


Figure 6. Correlation analyses at the species level between fruiting and climatic factors (temperature, rainfall and relative humidity) in Bang Kachao Peninsula; where * indicates p < 0.05, ** indicates p < 0.01 and *** indicates p < 0.001.

Analysis of the correlation between phenology and climatic factors showed mangrove leaf cover was directly related to rainfall and relative humidity. Pastor-Guzman *et al.* (2018) found that the greenness of mangrove tree species was related to maximum rainfall. We found that rainfall was not correlated with the flowering of mangrove trees, in contrast to mangroves in Kenya where there was a positive correlation with rainfall (Wang'ondu *et al.*, 2013). However, at the habitat level there was a positive correlation between fruiting and rainfall (r=0.59) but not at the species level for mangroves in our study. In mangrove forests in Brazil, rainfall was also found to be a driver for fruiting (Nadia *et al.*, 2012).

There was a positive correlation between leaf cover and rainfall for the tropical lowland habitat in this study, demonstrating that trees were flushing leaves in the wet season and shedding leaves in the dry season. Borchert *et al.* (2002) reported that due to higher mean temperatures in the dry season, drought led to water stress which impacted on tree deciduousness. We observed a positive correlation between flowering of tropical lowland trees and mean temperature but not for rainfall and relative humidity. Borchert (1998) considered that seasonal variability in rainfall was more important than small changes in temperature for triggering changes in phenology in tropical forests. However, plant reproductive triggers are poorly understood in the tropics (Morellato, Camargo, & Gressler, 2013).

Some longer-term studies are beginning to reveal the complexity of environmental triggers on reproduction in tropical forests. For example, Chen *et al.* (2017) monitored five species of *Shorea* in Peninsula Malaysia over 13 years and concluded that cool temperature and low rainfall, acting synergistically at seasonal time scales of two to three months, best explained flowering. In an investigation of 69 tree species over 12 years in rainforests of Madagascar, Dunham, Raza findratsima, Rakotonirina, and Wright (2018) were able to link intensity of fruiting with rainfall variability. Kurten *et al.* (2017) investigated over 300 species of trees over nine years in a wet seasonal evergreen dipterocarp forest in Khao Chong, Thailand and observed peak flowering occurred at the end of the dry season. Whether flowering in BKP is being impacted by temperature shifts due to the neighboring Bangkok (Pakarn seree, Chunkao, & Bualert, 2018) remains to be examined.

Another factor that may impact tree phenology in urban and peri-urban forests is photoperiod. Pires, Marino, Silva, Rodrigues, and Freitas (2018) showed that precipitation, temperature and photoperiod were linked to flowering and fruiting in a lowland tropical forest.

Of the 22 tree species monitored in our study, phenology in five species was strongly related to climatic factors: flowering of *Diospyros decandra* with temperature; flowering of *Aglaia cucullata* and *Elaeocarpus hygrophilus* with rainfall; and fruiting of *Dillenia indica* and *Diospyros malabarica* with rainfall and relative humidity. In general, flowering in *Diospyros* spp. in Thailand commences at the beginning of the wet season and Utsunomiya *et al.* (1998) surmised that flowering is induced by drought during the dry season. In a three year study in a tropical montane forest in South India, *Elaeocarpus hygrophilus* flowered annually in the dry season (February to April) (Mohandass, Hughes, & Davidar, 2016). Venugopal and Liangkuwang (2007) reported that *Dillenia indica* flowered and fruited in the wet season in a sub-tropical wet forest in northeast India.

These results will be useful to the city government for future climate change mitigation and adaptation strategies. For example, urban planners should increase the green cover and restore the riverbank surrounding BKP with evergreen species that provide dense leaf cover all the year to reduce the UHI. Further restoration away from the river should include a balance of tropical lowland species with reproductive strategies that provide continuous supply of nectar and fruit for maintaining biodiversity of the resident fauna.

4. Conclusions

We have shown that tree phenology was related with climate. Trees in the tropical lowland habitat, with exception of the mangrove habitat, had reduced leaf cover in the dry season. Mangrove flowering and fruiting occurred throughout the year but peaked in the wet and dry seasons. Flowering and fruiting of other tropical lowland trees peaked either in the wet or the dry season. Correlation analysis showed that mangrove habitat was related to rainfall and relative humidity whilst temperature contributed to the phenology of tropical lowland habitat. Of the 22 tree species that were monitored, phenology in five species was positively related to climate: flowering of *Diospyros decandra* with temperature; flowering of *Aglaia cucullata* and *Elaeocarpus hygrophilus* with rainfall; and fruiting of *Dillenia indica* and *Diospyros malabarica* with rainfall and relative humidity. This study can now be used to establish long-term monitoring of tree phenology and microclimate within BKP. We suggest that this can be facilitated by adopting advanced technologies (e.g. phenocam, drone, satellite). This will enhance the management of an iconic tropical urban green space.

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