

PHENOLOGY, CLIMATE, AND ADAPTATION: HOW DOES DIPTEROCARPS RESPOND TO CLIMATE?

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PHENOLOGY, CLIMATE AND ADAPTATION: HOW DOES DIPTEROCARPS RESPOND TO CLIMATE?. Temperature, rainfall and extreme weather have been indicated to affect the phenological patterns and forest productivity by shifting flowering and fruiting seasons and patterns, as well as crop production. Dipterocarpaceae are high value trees for both timber and non-timber forest products. This study aims to determine the response of phenological patterns of flowering and fruiting of Dipterocarps to climate variables. The study was conducted at Way Canguk Research Station of the Bukit Barisan Selatan National Park (BBSNP), Lampung during May-November 2012 by analyzing 14 years (1998-2012) of phenological data of Dipterocarps. The phenology surveys were carried out on monthly basis by estimating the percentage of flowering, fruiting (divided into 0-4 scoring) and the crop production. The results indicated that the phenological patterns of Dipterocarps in the area depicted major and minor patterns without mass-flowering time, different from what have been reported for Kalimantan or North Sumatra. Minor peak flowering season showed regular flowering, particularly during March to July every year. However, there were major flowering seasons in November 2002 (20.2%), September 2006 (21%), and October-November 2011 (20.3%). Average monthly fruit production showed a peak at the end of the dry season. Major flowering season seemed to coincide with the period of major El Nino events in November 2002 and September 2006, while others associated with La Nina. This study suggest that phenology and climate change may have implications in designing strategies for collection of seed materials to support the conservation and plantation programs of the Dipterocarps.

Keywords: Dipterocarpaceae, phenology, climate, Bukit Barisan Selatan National Park

FENOLOGI, IKLIM DAN ADAPTASI: BAGAIMANA DIPTEROCARPACEAE BEREAKSI TERHADAP IKLIM?. Subu, curah hujan, dan cuaca ekstrim telah diindikasikan mempengaruhi pola fenologi dan produktivitas hutan dengan menggeser musim berbunga dan berbuah, menggeser pola, serta produksi buah. Dipterocarpaceae adalah pohon bernilai tinggi untuk hasil hutan kayu dan non-kayu nya. Tulisan ini mempelajari respon dari pola fenologi pembungaan dan pembuahan Dipterocarpaceae terhadap peubah iklim. Penelitian dilakukan di Stasiun Penelitian Way Canguk Taman Nasional Bukit Barisan Selatan (TNBBS), Lampung selama Mei-November 2012 dengan menganalisis 14 tahun (1998-2012) data fenologi Dipterocarpaceae. Survei fenologi dilakukan secara bulanan dengan melakukan estimasi persentase berbunga dan berbuah (dibagi menjadi skoring 0-4) serta estimasi produksi buah. Hasil penelitian menunjukkan bahwa pola fenologi Dipterocarpaceae di daerah ini digambarkan berupa pola mayor dan minor tanpa waktu berbunga massal, yang berbeda dari laporan sebelumnya untuk Kalimantan atau Sumatera Utara. Puncak musim berbunga minor menunjukkan pola berbunga teratur terutama selama Maret-Juli setiap tahunnya. Namun, terdapat musim berbunga mayor, yang terjadi pada bulan November 2002 (20,2%), September 2006 (21%), dan Oktober-November 2011 (20,3%). Rata-rata produksi buah bulanan menunjukkan puncak pada akhir musim kemarau. Musim berbunga mayor tampaknya bertepatan dengan periode El Nino utama pada bulan November 2002 dan September 2006, sementara yang lain terkait dengan La Nina. Hasil penelitian ini menunjukkan bahwa fenologi dan perubahan iklim mungkin memiliki implikasi dalam merancang strategi pengumpulan bahan benih untuk mendukung program konservasi dan hutan tanaman Dipterocarpaceae.

Kata kunci: Dipterocarpaceae, fenologi, iklim, Taman Nasional Bukit Barisan

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I. INTRODUCTION

The change of climate can have an impact on the ecosystems and biodiversity from land to sea (McCarty, 2001; Parmesan, 2006). In plants, climate change will affect photosynthesis, plant respiration, decomposition of organic matters and micro-biochemical processes. At the community and ecosystem levels, the combination of temperature and precipitation could shift the composition of vegetation resulting changes in habitat types (McCarty, 2001). Additional variabilities may also increase the effects of climate change such as forest fires and other human interferences. Changes in precipitation and temperature can cause changes in the pattern of plant phenology (Cleland, Chuine, Menzel, Mooney, & Schwartz, 2007). Several studies depicted changes in phenological response to climate change. Climate change may occur if there are changes in pattern of wet and dry months. In fact, changes in phenological pattern are considered as the first responses of plants to climate change and can cause adverse effects on wildlife that depend on seasonal food resources (Corlett & LaFrankie, 1998).

Phenology is the study of recurrent phases in an organism either animal or plant affected by climatic factors (Sakai, 2001; Cleland et al., 2007). The emerging and falling of leaves, flowering, and fruiting in terms of duration, frequency and quantity of production will describe the patterns of plant phenology (Newstrom, Frankie, & Baker, 1994). An understanding of these patterns is important to know how a plant can grow and reproduce, as well as providing a source of food for the animals at a time in a region (Van Schaik, Terborgh, & Wright, 1993). Phenology is also useful for understanding the process of restoration in the selection of tree species and seed harvesting time for a seed bank (Ehrenfeld & Toth, 1997). Plant phenological patterns are influenced by environmental factors, such as temperature and precipitation (Cleland et al., 2007). Phenological patterns of tropical regions are very diverse with very little information due to lack of available long-term data (Corlett & LaFrankie, 1998). Several

research have been conducted on phenological patterns of Dipterocarpaceae in Asia such as in Kalimantan (Brearley et al., 2007), northern Sumatra (Van Schaik, 1986), and the Malay Peninsula (Ashton, Givnish, & Appanah, 1988; Yasuda et al., 1999; Numata, Yasuda, Okuda, Kachi, & Noor, 2003). However, the patterns of mass-flowering may vary (Corlett & LaFrankie, 1998).

Dipterocarpaceae are trees of the Asian tropical regions occupying a variety of habitats (Ashton, 1988; Appanah & Turnbull, 1998). This family is known as the main trees composing the tropical forests of Southeast Asia (Kettle, 2010) and therefore popular as timber trees. In fact, Indonesia is one of the major timber producers of Dipterocarps from tropical countries (Blaser, Sarre, Poore, & Johnson, 2011). In addition to timber, the Non-Timber Forest Products (NTFP) have also been used, i.e. fruit, bark, resin, leaves and sap (Rahayu, Susiarti, & Purwanto, 2007). Dipterocarps has become the target TPTII (SILIN/Intensive Silviculture) of the Ministry of Forestry. The trees are also important for the biodiversity. The large trees of Dipterocarps provide nesting cavity for hornbills (Kinnaird, & O'Brien, 2007) and the seeds are food for terrestrial mammals such as wild pigs and squirrels. In addition, many dipterocarp species are fast-growing species used in the restoration program of degraded land such as *Shorea acuminata* and *S. leprosula* (Shono, Davies, & Kheng, 2006; Shono, Davies, & Chua, 2007; Kettle, 2010). Several dipterocarp species are protected species with Endangered (EN) to critically endangered (CR) one according to IUCN (2015) such as *Anisoptera costata* (EN), *Dipterocarpus hasseltii* (CR), *Hopea sangal* (CR) and *Vatica obovata* (CR). The growth and regeneration of dipterocarp in logged forest is low (Pamoengkas, 2010). In general, flowering and fruiting of Dipterocarpaceae are not occurring annually. The seeds are recalcitrant in which the viability decreased after storing and treatment (Farnsworth, 2000). The regeneration of Dipterocarps as the main component of the dipterocarp lowland tropical

forests in Southeast Asia is important.

Bukit Barisan Selatan National Park (BBSNP) in southern Sumatra contains significant populations of globally important wildlife, including Sumatran rhinoceros, tiger, elephant, and over 300 bird species. BBSNP, similar to other protected areas in Indonesia, is suffering from on-going pressure of deforestation (Suyadi & Gaveau, 2007) where lowland forest is the most critical habitat of many animals and species but is exposed to a high pressure of encroachment (Kinnaird, Sanderson, O'Brien, Wibisono, & Woolmer, 2003; Gaveau, Wandono, & Setiabudi, 2007). Surrounded by human settlements, BBSNP is an important economic source for the surrounding communities while also suffering from continuous deforestation at a rate of 1.69% per year between 1972-2002 (Gaveau, Wandono, & Setiabudi, 2007). In the last three decades, forest cover has been reduced by 50% (3,470 km²) in West Lampung and South Bengkulu, the districts in which the park lies, and by 17% (520 km²) in the park (Gaveau et al., 2007). Progressing threats due to deforestation increase the pressure on the lowland dipterocarp forests of the Bukit Barisan Selatan National Park.

Climatic factors such as temperature, rainfall and extreme weather events could affect the pattern of phenology and forest productivity through the shifting of flowering and fruiting seasons, as well as flower and fruit productions. This is clearly affecting the harvesting time of timber and non-timber products. Dipterocarps are known as emergent trees and the main component of lowland tropical forests (Ashton et al., 1988; Whitmore, 1998). Although the phenological patterns of Dipterocarpaceae is not widely known, but mass-flowering or fruiting were noted in Kalimantan and Sarawak and can occur within a few years associated with ENSO/El-Nino (Yasuda et al., 1999; Sakai, 2001). In Leuser, the flowering of dipterocarp was affected by the increase in temperature (Wich & Van Schaik, 2000). It is suggested that there is variability in phenological patterns that may be related to climatic conditions and the

local environment. Thus, understanding the phenology is important as an adaptation to climate change. This study aims to determine the response of phenological patterns of flowering and fruiting of Dipterocarps to climate variables in Bukit Barisan Selatan National Park, Lampung.

II. MATERIAL AND METHOD

2.1. Study Area

This research was conducted in Bukit Barisan Selatan National Park (BBSNP), Sumatra in Way Canguk area (5°39' S; 104°24' E), which is located in the south western part of the park (Figure 1). This park is the third largest protected area (3,568 km²) in Sumatra and lies in the extreme southwest of Sumatra spanning two provinces, Lampung and Bengkulu (O'Brien & Kinnaird, 1996). BBSNP contains some of the largest remaining tracts of lowland rain forest in Sumatra and functions as the primary watershed for southwest Sumatra (O'Brien & Kinnaird, 1996). This research station is located in the lowland forest and has a high diversity of wildlife including some endangered mammals, such as Sumatran Tiger (*Panthera tigris*), Sumatran rhino (*Dicerorhinus sumatrensis*), primates, and more than 200 species of birds. A human trail crossed the study area to Way Haru enclave which is approximately 7 km from the research station. The human trail has opened access to human presence in the park.

The study area encompasses an 800 ha forest with a grid of trails at 200 m intervals. The study area is bisected by the Canguk River and the two sections are referred to as North and South study sites. All transects are permanently marked at 50-m intervals. During the 1997 forest fire, approximately 165 ha was burned, some of the southern part of the study area (O'Brien et al., 1998; Kinnaird & O'Brien, 1998). This forest fire has changed the vegetation structure with higher tree as well as seedling and sapling mortality in the post-burned area (O'Brien et al., 1998; Sunarto, 2000).

2.2. Methods

The study was conducted at Way Canguk Research Station of the Bukit Barisan Selatan National Park (BBSNP), Lampung during May-November 2012 by analyzing 14 years (1998-2012) of phenological data of Dipterocarps. Phenology monitoring was conducted at 100 plots (10 x 50 m); 75 plots in the south and 25 plots in the north of the study site on trees with DBH ≥ 10 cm (Figure 2). Phenology observations were conducted using binoculars. The phenology monitoring were carried out on a monthly basis during the first week of the month by estimating the percentage of flowering and fruiting which was divided into 0-4 scoring (1=1-25%, 2=26-50%, 3=51-75%, 4=76-100%) and estimated the crop production following Kinnaird, O'Brien, and Suryadi (1999).

Estimation of fruit production was based on the exponential scale, where the abundance estimates were divided into class intervals, namely 1-3, 4-6, 7-9, 10-30, 40-60, 70-90 and so on. Only the median values were then taken for further analysis (Leighton, 1982).

Rainfall and temperatures (maximum and minimum) were recorded daily at Way Canguk Research Station, BBSNP. Two types of temperature data were collected, within canopy and canopy free temperature. In this analysis, within and canopy free temperatures were averaged so that there was only one maximum and one minimum temperature.

Phenology and climate data were then synthesized to see if there was any particular pattern during the past 15 years. TLinear regression was carried out between particular climate variables of a particular month and particular phenological patterns in order to explore any relationship between climate variables of a particular month. Correlation of phenology and climate variables was carried out using Spearman Rank Correlation. All analysis was carried out using SPSS 16.

III. RESULTS AND DISCUSSION

A. Climate Variables

Minimum temperature in *Way Canguk*, BBSNP ranged between 19 and 25°C, while maximum temperature was between 24 and

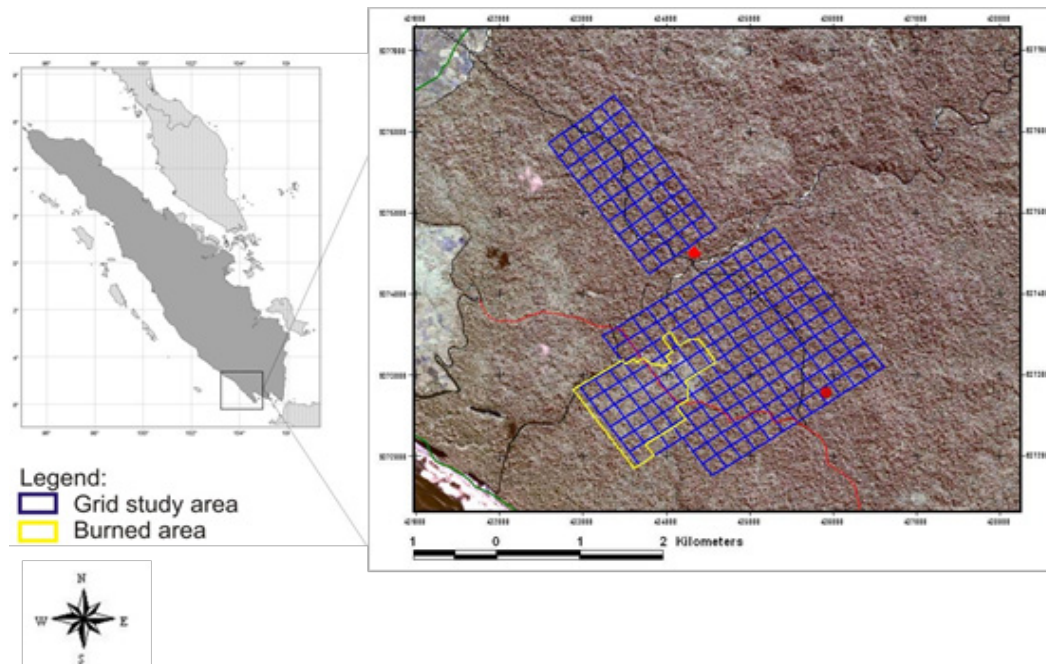


Figure 1. Location of Way Canguk Research Station and study area relative to Bukit Barisan Selatan National Park (BBSNP)

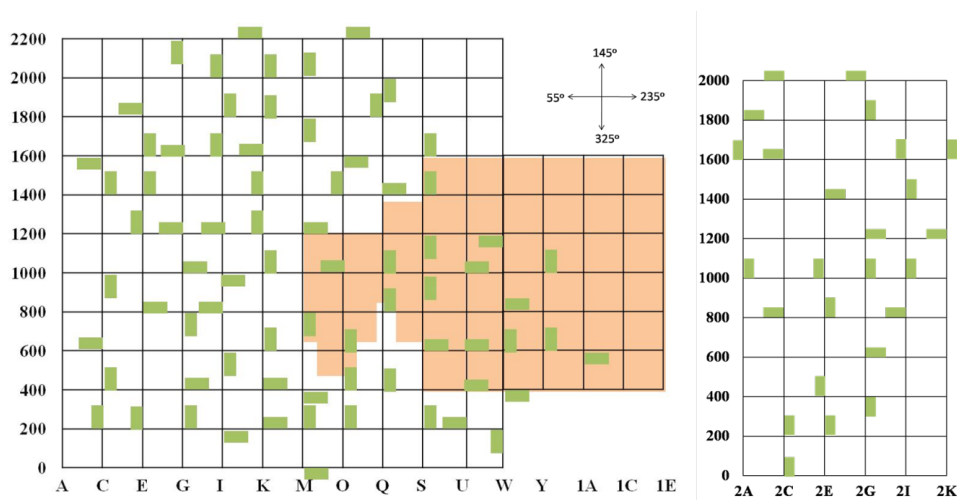


Figure 2. Phenology plots in Way Canguk Research Station, BBSNP

40°C. Average minimum temperature was 22.3°C while average maximum temperature was 37.8°C. The maximum temperature was increasing by 0.15°C per year while the minimum temperature outside canopy was decreasing by 0.19°C per year. In some years (2005, 2006, 2010, 2011, and 2012), average minimum temperature could drop below 21°C. Pattern of rainfall was unimodal with annual rainfall between 2000 and 4000 mm. The wettest year was 1999 (4005 mm) and the driest year was 2005 (2585 mm). The unimodal pattern is different from Leuser, North Sumatra which has bimodal pattern with two peaks of rainy seasons (Van Schaik, 1986) since Leuser is closer to the equator (Van Schaik, & Pfannes, 2005). In some months, rainfall could drop below 100 mm and sometimes there was no rainfall at all (Figure 3 and 4). Average daily rainfall was 13.17 mm. The wet season occurred during September – May while the dry season occurred during June – September.

B. Flowering

The phenological observations recorded 116 individuals from 11 Dipterocarpaceae species (*Anisoptera costata*, *Dipterocarpus gracilis*, *D. hasselti*, *D. humeratus*, *D. palembanicus*, *D. retusus*, *Hopea sangal*, *Shorea javanica*, *S. ovalis*, *S. ovata*, and *Vatica obovata*). The results indicated that the phenological patterns of Dipterocarps

during 14 years (1998-2012) in the area depicted no mass-flowering time, different from what has been reported for Kalimantan or North Sumatra. The period of mass-flowering is usually marked with 80% flowering of all Dipterocarpaceae species (Ashton, et al., 1988). In BBSNP, the phenological pattern showed regular minor peak flowering during March to July every year. However, it is noted that there were major flowering seasons, in November 2002 (20.2%), September 2006 (21%), September-October 2008 (16.67%) and October-November 2011 (20.3%) (Figure 5). Within those years, minor peak flowering has also occurred. However, in 1999 the peak flowering season shifted in October. Shifting in the peak of flowering is thought to be correlated with the forest fires in 1997-1998. This percentage of flowering is much lower when compared to the peak flowering season in Barito Ulu, Central Kalimantan or Pasoh, Peninsular Malaysia where it reached more than 50% (Numata et al., 2003); (Brearley et al., 2007). The lower percentage of flowering could be due to the number of Dipterocarp species was fewer than that of in Borneo and Peninsular Malaysia. In Central Kalimantan, the composition of Dipterocarp species reached 39 species while there were only 11 species in BBSNP (Brearley et al., 2007).

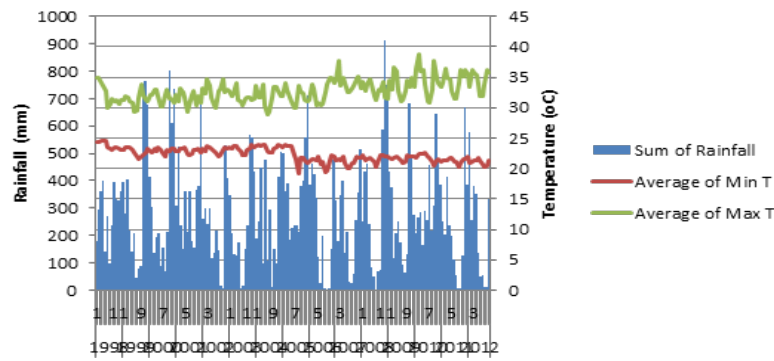


Figure 3. Pattern of rainfall as well as maximum and minimum temperatures during 1998-2012 in Way Canguk

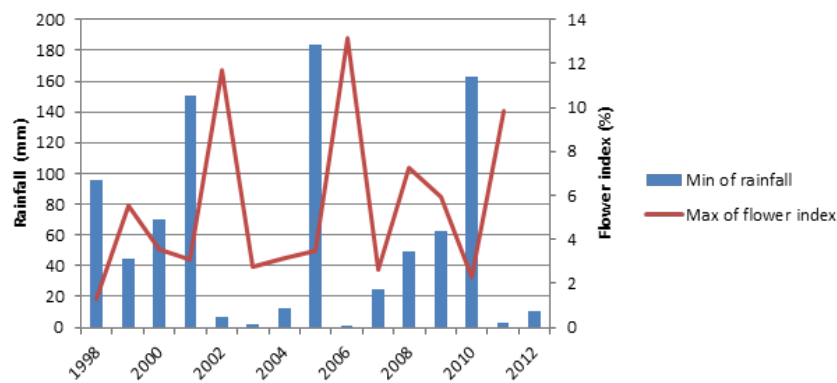


Figure 4. Minimum rainfall at particular month of each year and maximum flower index

Rainfall seemed to be an important factor in period of minor and major flowering. Mass-flowering in Central Kalimantan occurred approximately every three years as documented during 1991, 1994 and 1997 preceded by major drought periods in the previous month with more than 10 days of rainfall less than 100 mm (Brearley et al., 2007). In BBSNP, except in September 2008 where rainfall in the previous month was 74.20 mm, the period of major flowering in November 2002, September 2006, and October-November 2011 was preceded with one month with rainfall less than 10 mm. This was supported when regression was carried out between the highest percentages of flowering of each year over the rainfall of the previous month which suggested that rainfall of the previous month correlated to the peak of flowering. Comparing between linear and exponential regression, the relationship was

more likely to be exponential (Linear: $R^2 = 0.42$, $P = 0.009$, Exponential: $R^2 = 0.82$, $P < 0.001$) showing that rainfall pattern in exponential function was more likely to exceed linear function in affecting flowering (Figure 6).

This pattern was made up by 5 species of Dipterocarpaceae which has supra-annual patterns such as *Anisoptera costata*, *Dipterocarpus humeratus*, *Shorea ovalis*, *Hopea sangal*, and *Dipterocarpus palembanicus* which have similar period of major flowering to the general pattern of the major flowering of Dipterocarpaceae.

C. Fruiting

In BBSNP, the period of fruiting was following the flowering period when there was a major or minor fruiting period. The major fruiting period was one-two months following the major flowering period (Figure 4). Percentage of fruiting trees during the major

peak fruiting season happened in February 2003 (23%), February 2007 (21.7%), and February 2012 (23.5%). The average monthly fruit production showed a peak at the end of the dry season (Figure 6) showing a positive correlation with rainfall ($R^2 = 0.401$; $P = 0.027$).

D. Dipterocarps and Climate Consequences

In general, the pattern of the phenology of Dipterocarpaceae in BBSNP, southern Sumatra did not experience mass flowering season as happened in Kalimantan (Brearley et al., 2007) and Sarawak (Sakai et al., 1999). Patterns of mass flowering season is usually characterized by flowering up to 80% of the entire canopy Dipterocarp species (Ashton et al., 1988). Pattern of peak flowering and fruiting season in BBSNP showed that major flowering period occurred only 4 times in 15 years. Minor flowering season can be considered as the usual peak of annual flowering. Major flowering period occurred in the months of September, October, and November while in Kalimantan it could occur at any time of the year (Appanah, 1993).

Van Schaik and Supriatna (1996) suggested that phenology in the tropical rain forest community is more influenced by the sun rather than rainfall. Although, major flowering period occurred preceded by one driest month, general patterns of flowering trees (percentage of flowering trees) was more correlated to maximum temperature (Spearman Rank Correlation = 0.18, $P = 0.02$). Rainfall was more correlated to percentage of trees in fruiting (Spearman Rank Correlation = -0.25, $P = 0.01$) and crop production (Spearman rank correlation -0.17, $P = 0.03$) showed negative correlations.

Environmental cues such as temperature, rainfall, and drought sometimes have induced flowering (Reich, & Borchert, 1984). In several areas it was reported that mass-flowering was induced by the low night-time temperature (Yasuda, et al., 1999) while in Borneo, mass flowering was triggered by drought periods associated with ENSO (Sakai, et al., 2006).

Sakai et al. (2006) suggesting that droughts occurred during the transition period between La Nina and El Nino, and at the beginning of El Nino. Ashton et al. (1988) also showed that strong flowering events in eastern Peninsular Malaysia coincided with El Nino events. Avoiding predators is also suggested to be one of the reasons of mass-fruiting (Van Schaik, 1986; Corlett & Primack, 2005). In BBSNP, the major period of flowering was preceded by a dry month similar to Borneo. This flowering at BBSNP can be explained by two patterns: (1) Severe water stress during drought may induced major flowering period, but maximum temperature influenced the number of flowering trees in general and (2) Community composition of Dipterocarpaceae with less diversity in southern Sumatra than in Borneo obscured the mass-flowering period resulting in major and minor flowering periods. In the first pattern, there are two correlated climate variables responsible for flowering, period of the lowest rainfall and maximum temperature. Van Schaik, Terborgh, and Wright (1993) suggested several factors were enhancing photosynthetic and reproductive productivity such as dry years and high exposure to the sun (see also Appanah, 1993). In Costa Rica, anthesis was triggered by drought-induced leaf fall (Reich & Borchert, 1984). However, further data and analysis are still needed to ensure the response. In the second pattern, southern Sumatra has less diverse Dipterocarpaceae than Borneo and therefore gives less influence on the flowering pattern. *Shorea* spp. (six species) in Peninsular Malaysia are known to have staggered flowering which flowered sequentially to avoid competition for pollination (Ashton, et al., 1988). At least there are 14 species in Borneo (Brearley et al., 2007) while there are only three *Shorea* spp. in BBSNP. The less diversity may also obscure the effect of El Nino although geographical position may have an influence on the flowering pattern. Major flowering period in November 2002 and September 2006 seemed to coincide with a period of major El Nino in 2002 and 2006. However, other periods seemed to correlate

Table 1. Years with normal, La Nina, and El Nino months (National Weather Service 2014)*

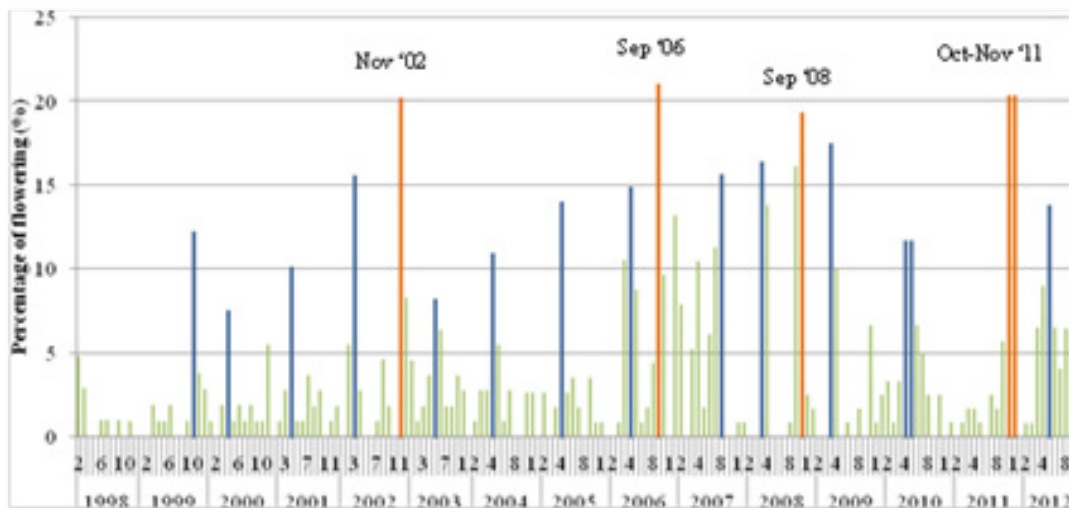
Years	Normal	La Nina	El Nino	Reported mass or major flowering
1998	0	7	5	Sakai et al. 2006
1999	0	12	0	
2000	0	12	0	
2001	8	3	0	Numata et al. 2003
2002	3	0	9	This study
2003	8	0	3	
2004	5	0	7	
2005	7	3	2	
2006	3	4	5	This study
2007	4	6	2	
2008	5	7	0	This study
2009	5	0	7	
2010	0	7	5	
2011	2	10	0	This study
2012	5	4	0	

Note : *(Climate Prediction Center Internet Team, 2012)

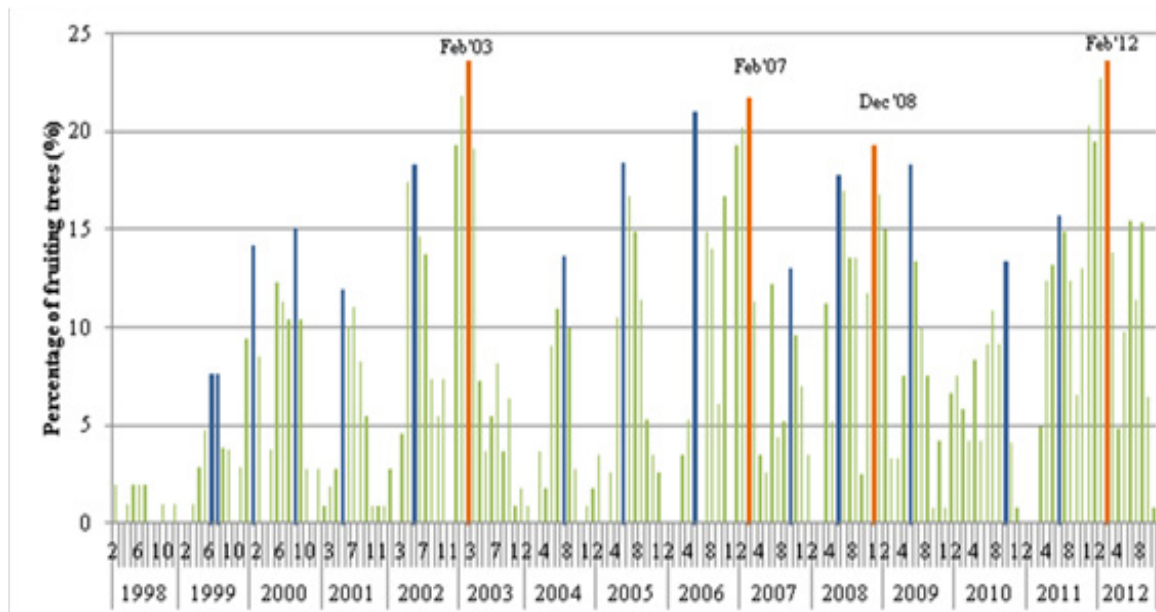
with La Nina rather than El Nino period (Table 1, Figure 7). However, only Numata et al. (2003) and Sakai et al. (2006) reported similar event associated with El Nino, other reports was based on previous El Nino-La Nina events prior to 1998. Our results confirmed that ENSO event has little impact on areas west of Malaysia as also depicted in Leuser as suggested by Wich & Van Schaik (2000). All phenological data in Borneo recorded more than 20 species in their area (Curran et al., 1999; Sakai et al., 1999; Brearley et al., 2007).

In this study, fruit production of the Dipterocarpaceae did not seem to follow the major flowering period. In effect, this will produce low fruit production and thus low fallen seeds. In Borneo, altered climatic pattern is suspected to influence fruit production which resulted in low seed production (Curran et al., 1999). Response of fruiting phenology of plants to climate change is complex and may vary among species (Chapman et al., 2005) and therefore needs a thorough analysis of different potential variables. Habitat fragmentation may also have an impact on the reduction of effective

population size (Kettle, 2010). In addition, Dipterocarps are usually shade-tolerant species showing an I-shape distribution where there are large number of young and lower number of mature individuals (Sist, Picard, & Gourlet-Fleury, 2003 see also Hartiningtias, 2013). According to strategy for collection of seed materials for supporting conservation and plantation programs, the information is important because major flowering period is correlated with preceding month of drought, water supply during droughts is also important to anticipate so that production of fruits for seed source can be available at all time. ENSO and climate prediction is important as many were associated with the major flowering period (and mass-flowering in other areas such as in Kalimantan) which can be the major source of seed bank. However, knowledge on seed collection and handling is important due to the recalcitrant character of the seeds (Kettle, 2010).



A. Flowering patterns of Dipterocarps during 1998-2012



B. Fruiting patterns of Dipterocarps during 1998-2012

Figure 5. Patterns of flowering and fruiting period of Dipterocarps during 1998-2012 (Kurniasari, Winarni, & Hartiningtias 2012)

IV. CONCLUSIONS

The study suggested that the general phenological pattern of flowering of Dipterocarpaceae in BBSNP was more correlated to maximum temperature which tended to increase during 15 years. There were no mass-flowering periods, but major flowering occurred during 2002, 2006, 2008 and 2011 preceded with one month of rainfall less than

100 mm. During major flowering, minor flowering still occurred at regular time. Rainfall in the previous month has negatively correlated with the number of trees in fruiting and crop production. Phenology and climate change may have implications in designing strategies for collection of seed materials of Dipterocarps in the natural forest.

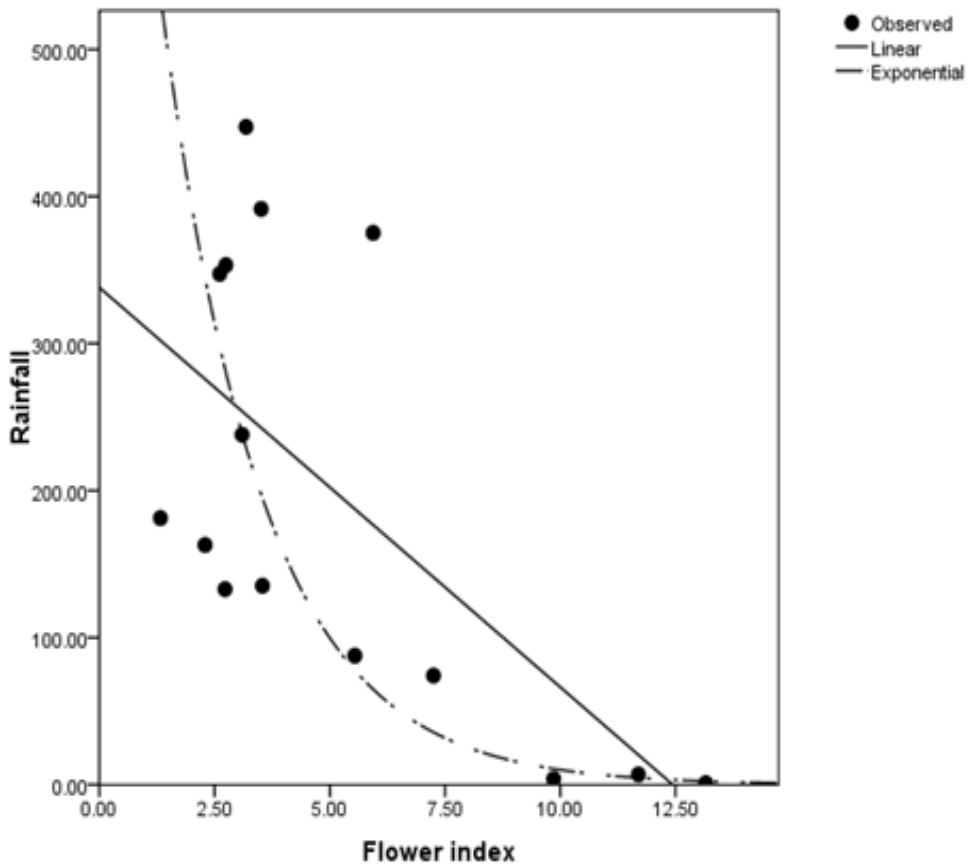


Figure 6. Correlation between rainfall in the previous month with maximum percentage of trees in flowering for each year. The figure compares linear and exponential regressions

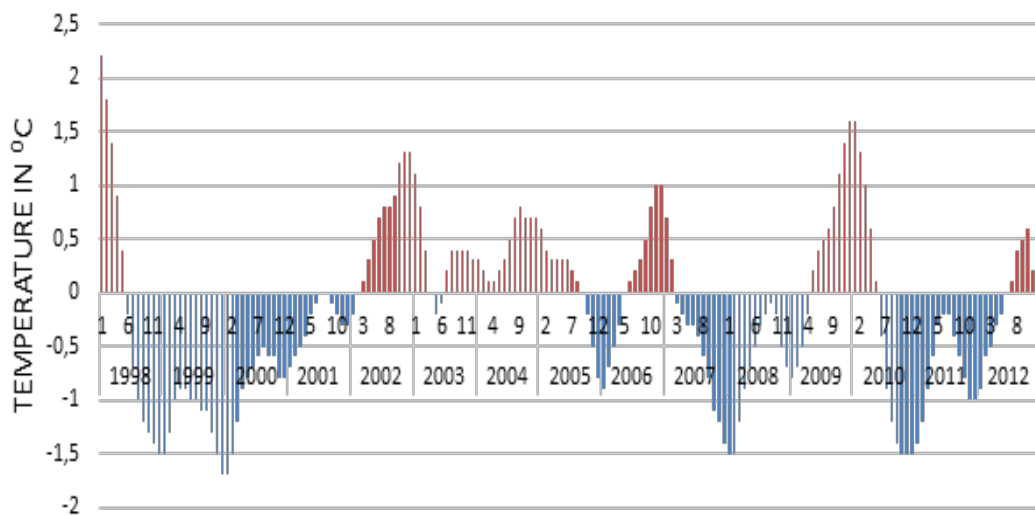


Figure 7. Years with El Nino and La Nina based on Oceanic Nino Index (ONI). The red bars indicating El Nino and blue bars indicating La Nina events Source: (Climate Prediction Center Internet Team, 2014)

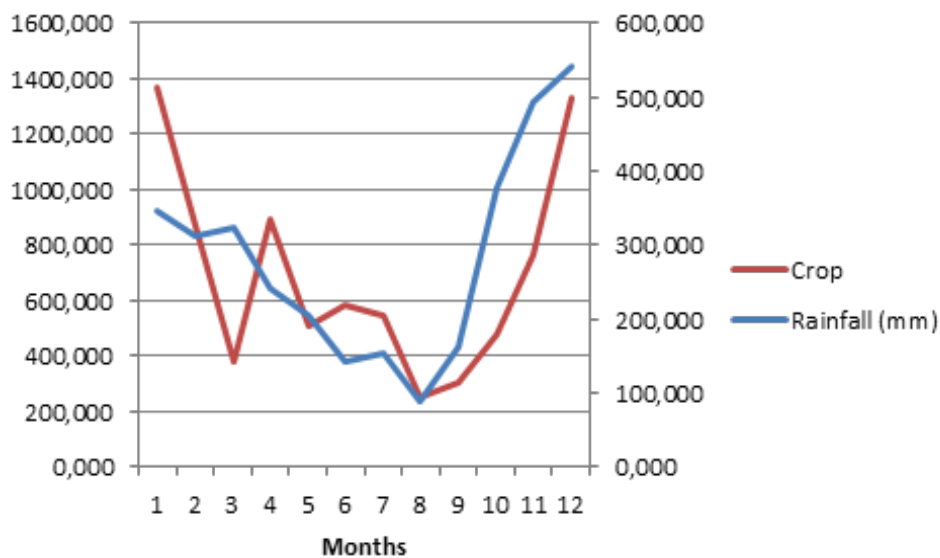


Figure 8. Monthly fruit production of Dipterocarpaceae (Kurniasari, Winarni, & Hartiningtias 2012)

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