Modeling the Impact of Climate Change on General Flowering in Bukit Barisan Selatan National Park, Sumatera

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Abstract. In Southeast Asian dipterocarp forests, a general flowering (GF) occurs at the multiannual interval. At this phenomenon, at least 40% of the trees in the stands flower in synchrony, dominated by the flowering of the Dipterocarpaceae family that hypothesized to be caused by changes in climate factors, especially ENSO. This study aimed to determine the pattern of flowering trees in Bukit Barisan Selatan National Park (BBSNP) and to determine a model for predicting flowering patterns associated with climatic factors in 2021-2050. Flowers and fruits were observed every month from February 1998 to September 2020 at Way Canguk Research Station, BBSNP. The climatic factors used were temperature, rainfall, humidity, wind speed, and the ENSO index. We used a generalized linear model to link climatic factors and flowering and model future flowering. The results showed no GF in BBSNP because the highest flower synchronization only reached 37.8%. The climatic factor with the highest coefficient was ENSO, but flowering was mostly influenced by fluctuations in climate factors, not its absolute value. The model estimated that the flowering in 2021 - 2050 will peak to 34.4% in December 2044 and further ensure good forest regeneration. Thus, BBSNP can still be suitable for conservation purposes.

1. Introduction
Bukit Barisan Selatan National Park (BBSNP) as a lowland tropical rain forest ecosystem is a habitat for the biodiversity of Sumatra. This biodiversity lives in rain forests with a complex structure and composition of vegetation, dominated by species from the Dipterocarpaceae family, which is the primary vegetation constituting tropical rainforests in Southeast Asia [1]. In its position as an emergent tree [2], Dipterocarpaceae impacts the distribution of rainfall, light, and microclimate for the plants listed below [3]. Dipterocarp trees also have an important role for fauna in BBSNP, for example, as nesting sites for several protected hornbill species and as a source of animal feed [4]. Thus, this family plays an essential role in the complex dynamics of tropical rainforests.

Dipterocarpaceae have an irregular flowering and fruiting season [5]. In the aseasonal tropical rain forests of Southeast Asia, once every 3 – 8 years, a spectacular phenomenon occurs at the population level, namely mast-fruiting that is associated with general flowering (GF) at the community level [6]. GF is a phenological pattern indicated by the number of tree communities in the forest that flower synchronously in a multi-year period [7].

Previous research conducted by Brearley et al. [6] in the Barito Ulu tropical rain forest, Central Kalimantan, shown that GF occurs when at least 40% of Dipterocarpaceae species flower and 18% of
other tree species flower simultaneously. Numata et al. [8] showed GF occurrence in Peninsular Malaysia with a flowering intensity of at least 44% trees in November 2001. Research by Satake et al. [9] in Pasoh forest, Malaysia, for 14 years showed GF occurred three times in 2005, 2009, and 2010 with a flowering intensity of five Shorea species reaching 60%, 52%, and 71%.

Research on the GF phenomenon in BBSNP is very limited. However, various Dipterocarpaceae species in BBSNP generally flower on an annual pattern, even some species can flower more than once a year. In addition, several previous studies reported that Dipterocarpaceae in other regions of Southeast Asia (Kalimantan, Peninsular Malaysia, and Pasoh) generally flower in a supra-aural pattern [3]. This difference led to the need for research to analyze the presence of GF in BBSNP until 2020.

Several hypotheses suspect to be the cause of the GF phenomenon, such as the abundance of seed predators, successful pollination, and changes in climatic factors triggered by ENSO (El Niño-Southern Oscillation) [3,5,6,7,10]. Generally, plant phenology is closely related to climatic factors. For example, changes in temperature, rainfall, irradiance, wind speed, and extreme weather can trigger flowering and fruiting [9,11].

Unfortunately, climatic conditions have changed over time due to climate change, which means the changes in the average climate and certain climate variability that occurs over a long time [12]. Climate change is difficult to detect in tropical rainforests, which tend to be wet throughout the year. However, plant phenology is one of the most responsive traits to climate change that is relatively easy to observe [13]. Climate change can change the phenological pattern of trees, which will ultimately impact pollination success, forest productivity, and will affect the interaction between trees and heterotrophic organisms such as the survival of seed and fruit predators. Therefore, this study aims to determine the flowering and fruiting pattern of tree stands, especially from the Dipterocarpaceae family at the Way Cangguk Research Station (WC CRS), BBSNP, and determine a model for estimating flowering patterns associated with climatic factors in the period 2021-2050. With the model obtained, it is possible to anticipate conservation actions to maintain the suitability of the primary forest of BBSNP as a habitat for a variety of protected biodiversity.

2. Method

2.1. Time and study area
The research was conducted at Way Cangguk Research Station (WC CRS), BBSNP, Pesisir Barat, Lampung (5°39’325” S and 104°24’21” E) on an area of 800 ha. Phenological data and climatic factors were taken at the beginning of every month from February 1998 – September 2020 (22 years 7 months).

2.2. Data collection

2.2.1. Phenological data. Phenological data were taken on 100 permanent plots with 10 m x 50 m for each plot (figure 1). The vegetation observed was trees with a minimum diameter (DBH) of 10 cm. The phenological data used were the presence of flowers and fruits, which are categorized in a score of 0 to 4 [14], with the following conditions:
- score 0 = no flowers or fruit at all,
- score 1 = 1% – 25% closure of the canopy area,
- score 2 = 25% – 50% closure of the canopy area,
- score 3 = 50% – 75% closure of the canopy area,
- score 4 = 75% – 100% closure of the canopy area.
2.2.2. Climate data. The climate data used are temperature, rainfall, relative humidity, wind speed, and ENSO (El Niño-Southern Oscillation). Temperature and rainfall variables were measured every morning between 06.00 to 09.00 AM. The temperature was measured using a thermometer and rainfall was measured using an ombrometer. There are two types of temperature data measured: the temperature under the tree canopy and the temperature outside the canopy. Both are measured as the maximum and minimum values.

Meanwhile, climatic data for relative humidity and wind speed were obtained from Meteorological, Climatological, and Geophysical Agency of Indonesia in Pesawaran Climatology Station, Lampung. In addition, ENSO data in the form of the MEI index (Multivariate ENSO Index) for the Indonesian region was obtained from the National Weather Service through the website https://origin.cpc.ncep.noaa.gov/ with reference to the ONI index (Oceanic Nino Index).

Future climate projection data was obtained from the World Climate Research Program CMIP5 via https://esgf-data.dkrz.de/ using the MPI-ESM-LR model with the RCP4.5 scheme. Furthermore, spatial data in “nc” format was converted into a temporal form for the period January 2021 – December 2050 using the “ncdf4” package [15] in the RStudio software [16].

2.3. Data analysis

2.3.1. Phenological pattern. The tree phenological pattern in the form of flowering and fruiting synchronization was analyzed using Time Series Analysis with R Studio [16]. Flowering and fruiting data were converted to a binary scale and grouped by month, year, and phenophase. Phenophase consists of flowering and fruiting data, represented as a percentage (the number of flowering/fruiting trees multiplied by 100 and divided by the total number of the tree). The data is plotted in the form of a graph with a period from 1998 to 2020. Pearson correlation was also used to analyze the relationship between phenophases.

2.3.2. Relationship between climatic factors and flowering. The relationship between climatic factors and flowering was analyzed using a generalized linear model (GLM) with the Poisson family distribution [28] using the following equation 1:

$$y = a + b_1x_1 + \ldots + b_8x_8 + \varepsilon \quad (1)$$

The y variable in the equation is the flowering intensity, a is the intercept, while x consists of the following variables: maximum temperature under the canopy (Timax), minimum temperature under the
canopy (Timin), maximum temperature outside the canopy (Tomax), minimum temperature outside the canopy (Tomin), rainfall, wind speed, relative humidity, and ENSO.

The variables chosen as predictors were variables that do not have multicollinearity (Variance Inflation Factor (VIF) < 10) [17]. Prior to regression analysis, the predictor data were standardized with a scale function on R Studio. Then, stepwise regression was performed to eliminate the insignificant predictor variable and obtain a model with the lowest Akaike information criterion (AIC). The equation from the stepwise regression results was used as a model for predicting climatic factors that affect phenology by referring to the lowest AIC value and the highest $R^2$. The prediction for 2021 – 2050 was carried out with a predict function, which is then mapped with a time series on R Studio.

3. Results and discussion

3.1. Stand Phenological Pattern in WCRS

The general flowering (GF) followed by the mast fruiting phenomenon is the unique reproductive phenological patterns that occurs irregularly in multi-annual intervals. In this phenomenon, most of the Dipterocarpaceae tree species and other species from the various family in tropical forests flower together synchronously and create a flowering peak that is very prominent compared to other times [10].

Observations over a long period in multi-year intervals need to be carried out to determine this phenomenon. In this 22-year and 7-month study, a total of 2,201 individual trees from 62 families and 296 species were observed. The dominant tree families are Phyllantaceae (10.58%), Annonaceae (10.08%) and Dipterocarpaceae (9.54%), and Euphorbiaceae (7.19%). Meanwhile, the Dipterocarpaceae family constituted 4.95% of the observation plot, including nine species: Hopea sangal, Shorea ovalis, Dipterocarpus humeratus, Dipterocarpus costulatus, Dipterocarpus kunstleri, and Dipterocarpus gracilis.

Based on these data, the average percentage of flowering synchronization in WCRS was 19%, with a maximum flowering of 37.9% and a minimum of 4.4% (Standard Deviation/SD = 6.1%). The highest flowering synchronization or called peak flowering (with a percentage of more than 35%) occurred three times, namely in the 12th month of 2006 with a percentage of 37%, the 11th month of 2011 with a percentage of 37.9%, and the 10th month of 2018 with a percentage of 36.4% (figure 2). However, when compared to other studies that state the percentage of GF is at least 40-44% [6,8] and can reach 88% [18], peak flowering in WCRS cannot be categorized as GF because of its low percentage.

The occurrence of the GF phenomenon is often associated with the flowering of the Dipterocarpaceae family [6,8,9,10]. Several previous studies that found the occurrence of GF stated that Dipterocarpaceae was the most dominant family in their study area [6,8,10,18]. For example, the percentage of individual Dipterocarpaceae in the Brearley et al. [6] study was 22.8% of the total trees, with a diversity of up to 22 different species. Ashton [29] said that dipterocarp forests that experienced GF generally had a percentage of dipterocarp up to 10% of all tree species. In fact, in WCRS, the dominant family is not Dipterocarpaceae, but Phyllantaceae and Annonaceae. Both families tend to flower continuously throughout the year. Unlike previous studies [6,8,29] Dipterocarpaceae constitute only 4.95% of the total trees in the stand. In addition, the diversity of Dipterocarpaceae species in WCRS is also low compared to tropical forests in other studies, its only consists of 9 species.

Previous studies have shown that when GF occurs, generally, the species that flower in the highest percentage are Dipterocarp species [6,18]. In WCRS, in the 12th month of 2006, when the stand flowering percentage was 37%, the flowering percentage for the Dipterocarpaceae family was only 15.08% (figures 2 and 3). Meanwhile, in the 11th month of 2011, the percentage of flowering Dipterocarpaceae was 20.63%, and in the 10th month of 2018, the Dipterocarpaceae flowering was 24.35% (figure 3). This low flowering percentage of Dipterocarpaceae could explain why no GF events were found in WCRS. This result is very different from studies that have been found previously in lowland tropical rain forests in other regions [6,8,10,18].

The correlation between stand flowering with flowering of the Dipterocarpaceae family in WCRS was not very high (p = 0.56). The peak flowering of the Dipterocarpaceae is generally higher than the GF phenomenon but with a lower percentage (figure 3).
In the Dipterocarpaceae family, the average flowering synchronization was 5.58% (SD = 6.24%), with a maximum flower synchronization of 24.78% occurring in the 9th month of 2019 and the minimum flowering of 0 occurring multiple times (53 out of 248 months of monitoring, or 27.37%) with an uncertain time (figure 3). The peak flowering of this family has the same time as the GF occurrence. Several species of this family, such as from _Dipterocarpus_ genus flower at GF time, but with a low percentage (only about 20%). This low percentage is because Dipterocarp species generally flower at multi-annual intervals with an irregular pattern so that many species do not flower during the GF period.

Apart from dipterocarp flowering factors, it can be seen in figure 2 that the flowering pattern of the stands is not too fluctuating, meaning that the difference between peak flowering and normal flowering is not too large when compared to other studies. Brearley _et al._ research [6] showed that apart from the GF phenomenon, only about 1.3% of the trees in the stands were flowering. Another study by Medway [19] in Peninsular Malaysia showed that although at peak flowering, the percentage of flowering stands was only 35%, in the non-flowering phase, the flowering only ranged from 0-7%. Meanwhile, in WCRS, the minimum flowering percentage is only 4.4% and the average monthly flowering is 19%. Generally, GF with a highly fluctuating pattern only occurs in lowland tropical forests in Southeast Asia [10]. Meanwhile, on other continents, such as the Brazilian Atlantic, flowering fluctuations are between 2% and 32% with an average of 15% [20] and in the lowland tropical forests of Costa Rica with a percentage of 10% to 30%, it is less fluctuating [21]. The cause of the long and fluctuating flowering intervals in Southeast Asia is because the soil in this region has less fertility than in Western regions such as Brazil and Costa Rica [10]. There have been no further studies related to soil fertility in WCRS. However, this study can explain that geographical factors such as soil affect flowering in various tropical regions [8].

Other factors such as climatic factors can also explain the cause of GF’s absence at WCRS. The relationship between climatic factors and flowering not only affects the percentage of flowering but can also affect the timing of the plant phenological events, such as flowering time, fruiting time, and
flowering success. Based on figure 2, the peaks flowering in WCRS with a high intensity occur between months 9 – 12, with the predominance of month 11 (35.7%). The initiation of flowering time in tropical forests often occurs at the dry season [22]. Drought causes plant phenological responses to water stress and increased sunlight is usually a trigger for flowering trees [22]. While the flowers development to reach the peak season was affected by rainfall intensity and humidity [30].

Based on the average rainfall distribution in WCRS, month 8 is the driest, month 9 is the time of transition from the dry season to the rainy season, while months 11 and 12 are the peak of high rainfall. Different from studies by Schmidt [22], flowering in WCRS generally begins after the driest month, August, towards the rainy season's transition. Peak flowering occurs during the rainy season due to a very high climate fluctuation pattern in 11 months. This indicates that in this study, the main trigger of flowering is the pattern of climate and rainfall fluctuations, not drought.

Flowering is often followed by fertilization, which occurs about 2-3 months after flowering. In WCRS, the success of flowers to fruit is 52.56% (figure 2). Fertilization failure for the remaining 47.44% can be due to various factors, such as the absence of pollinators, unsuitable climatic conditions, and lack of tree carbohydrate reserves can also inhibit flowering [6]. Besides, in young trees, flowering is usually followed by little or no fertilization [22].

### 3.2. The effect of climate factors on tree flowering in WCRS

At WCRS, climatic conditions did not change much from February 1998 – September 2020. The minimum monthly average temperature conditions both inside and outside the canopy have an average of 20.16°C (inside, SD = 1.77°C) and 20.91°C (outside, SD = 1.29°C), while the maximum temperature inside the canopy has an average of 35.75°C (SD = 2.2°C) and the temperature outside the canopy is 38°C (SD = 3.76°C). Thus, the air temperature outside the canopy has a more fluctuate pattern every month than the temperature below the canopy.

Rainfall conditions have a unimodal pattern (one peak in the dry season in August and one peak in the wet season in December) with an intensity ranging from 0 to 928 mm/month with an average of 284 mm/month (SD = 19.34 mm/month), dominated by wet months in all years except 2015. This temperature and rainfall affect the value of humidity. The average monthly relative humidity in the WCRS is 83.5% (SD = 7.64%), indicating that the WCRS is a humid area. Meanwhile, the monthly wind speed at WCRS has an average of 2.36 m/s (SD = 4.32 m/s). The extreme phase of El Niño, which caused a long dry season occurred at the end of 1997, 2003, 2006, 2010, and 2015. The extreme phase of La Nina occurred in 1999, 2000, 2008, 2011, and 2020, causing high rainfall in Indonesia.

From these eight climate variables, the minimum external temperature variable was not included in the model because it was not significant. The standard equation for this model is:

\[
Y = 6.0807 - 0.0872X_1 + 0.0591X_2 + 0.0373X_3 + 0.0177X_4 - 0.0464X_5 + 0.0394X_6 + 0.1288X_7
\]

\[
(R^2 = 0.604, AIC = 7359.3)
\]

A complete description of this model can be seen in table 1.

| Variable                  | Symbol | Estimates coefficient | Pr(>|z|) |
|---------------------------|--------|-----------------------|---------|
| Intercept                 |        | 6.0807                | < 2e-16 *** |
| Minimum inside temperature | X_1    | -0.0872               | < 2e-16 *** |
| Maximum inside temperature | X_2    | 0.0591                | < 2e-16 *** |
| Maximum outside temperature | X_3    | 0.037                 | < 2e-16 *** |
| Rainfall                  | X_4    | 0.0177                | 7.79e-06 *** |
| Relative humidity         | X_5    | -0.0464               | < 2e-16 *** |
| Wind speed                | X_6    | 0.0394                | 5.46e-07 *** |
| ENSO                      | X_7    | 0.1288                | < 2e-16 *** |

*** significant for α = 0%
Table 1 shows that the ENSO variable has the highest coefficient, which means that this variable has the greatest contribution to the occurrence of flowering compared to other climate variables in this model. The correlation between the two is a positive linear correlation (figure 4). The huge amount of data used causes very high data variation. Figure 4 shows that flowering tends to increase with increasing ENSO index, which means that El Niño phenomena tend to trigger flowering.

Several previous studies [6,18,23,24] showed that GF and mast fruiting are closely related to the El Niño phenomenon, which causes prolonged drought and decreases night temperatures. Flowering increases because the length of sunlight triggers photosynthesis and further increases photosynthate production to be allocated to the reproductive parts of plants [24]. However, a high percentage of flowering in WCRS in 2008 and 2011 (figure 2) occurred in the La Nina, when rainfall intensity is high. This result is in line with the research conducted by Numata et al. [8] and Chechina and Hamann [25] who showed that flowering synchronization generally occurs at the transition time or during La Nina. According to them, the trigger for flowering is variations in climate anomalies between years and not climate variables as an absolute value [25]. If the trigger for flowering synchronization is drought due to El Niño, this study did not show a negative correlation between flowering and rainfall. The coefficient estimates between the two show a value of 0.0177, which means that rainfall positively correlates to the model, but with a very weak effect. The graph of the GLM function between rainfall and flowering shows a linear correlation that tends to be positive even though it looks straight (figure 4).

Figure 4. Correlation between climatic factors and flowering.
Drought cannot be categorized as a trigger for flowering (especially GF) if the correlation between the intensity of flowering with the geographical conditions of the location or the availability of water at the study site has not been studied [24]. Water shortages are also influenced by regional topography, soil type, elevation, and other factors other than microclimate. Different regions have different flowering times even though they have the same dry months and average rainfall. Therefore, no clear relationship has been found between rainfall and the occurrence of GF [10].

After ENSO, the variable that has the greatest influence is the internal temperature, especially the minimum temperature. The minimum inner temperature has a negative linear correlation, inversely with the maximum inner temperature, which has a positive linear correlation (figure 4). This shows that changes at higher temperatures are more likely to trigger flowering than at lower temperatures. Maximum flowering occurs in the temperature range 34 - 38. However, what triggers flowering is a temperature change, not the absolute number of temperatures [26].

Relative humidity has a negative linear correlation (figure 4), meaning that it can weaken flowering. This is in accordance with the research of Dewi et al. [11], in tropical forests that tend to be wet, dry conditions will stimulate plants to flower. On the other hand, wind speed is positively correlated (figure 4), this variable can influence flowering and fruiting through ease of dispersal of pollen of several forest species with wind pollinating agents.

3.3. Model the impact of climate change
The model created is then used to predict flowering in the WCRS in 2021 – 2050 with climate data using the RCP 4.5 scheme. Flowering projections can be seen in figure 5.

![Figure 5. Flowering projection at WCRS 2021 – 2050.](image)

Based on figure 5, the flowering pattern tends to be similar to the flowering pattern in WCRS in 1998 – 2020. The projection of flower synchronization in 2021 – 2050 ranges from 14.8% - 34.4% with an average of 20.1% (SD = 3.15%). The average synchronized flowering increased by 1.1% from flowering in 1998 – 2020. The peak of flowering is expected to occur three times, namely in month 2 of 2027, month 12 of 2033 – month 1 of 2034, and the peak will occur in month 12 of 2042 – month 2 of 2043. In month 12 of 2033, a mild El Niño is predicted (MEI index = 2.4). In month 12 of 2044, an extreme El Niño is predicted as indicated by a high index (MEI index = 3.9) which is very different from other times, which generally only ranges from -2 to 2. In this model, peak flowering occurs when there are fluctuations in the ENSO index.

Estimation of flowering time is essential for forest regeneration and thus conservation. Flowering is closely related to fertilization and subsequently affects the abundance of herbivores and pollinators. The pattern shown in Figure 5 is considered safe for forest regeneration for the next 30 years. Climate change will have different impacts on various tropical forests depending on the degree of water balance in the forest [27]. For tropical forests that are always wet, like in WCRS, the changes are not predicted to be much, unlike dry forests. An increase in CO₂ can increase leaf survival while increasing temperature and decreasing rainfall will exacerbate water shortages in the dry season in dry forests [27].
However, the model obtained ($R^2 = 0.604$) shows that flowering in WCRS could not be fully explained by climatic factors; other factors can influence it. Climatic factors such as drought and decreasing night temperatures affect flowering, but their values vary depending on location and geographical conditions [8]. Geographical conditions affect soil type, water availability, and resource availability which are the main limiting factors for flowering [25,26].

In addition to geographical factors, evolutionary theory also suspects that GF can be caused by several things such as the abundance of seed predators, successful pollination, and dispersal by animals [10]. Therefore, these things also need to be studied to determine the cause of the non-occurrence of GF in WCRS.

4. Conclusion
GF did not occur in BBSNP because the highest synchronization percentage was only 37.9%. The climatic factor most correlated with flowering is ENSO, but flowering is triggered by changes or anomalies that occur in climatic factors, not the absolute value. With climatic factors, we get a model for predicting flowering in 2021-2050, which shows the peak of flowering in month 2 in 2027, month 12 in 2033, and month 12 in 2044.

This study shows that the existence of BBSNP as a conservation area for various biodiversity on Sumatra will be safe until 2050 because the estimated availability of resources is still good. Furthermore, the data from this study can also be used to estimate seed collecting times for forest restoration purposes elsewhere.

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