Reproductive phenology period of the five threatened species in Cibodas Botanic Gardens

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Abstract. Agathis borneensis, Castanopsis argentea, Diospyros celebica, Merrillia caloxylon, and Saurauia bracteosa are some threatened species, which have been planted in Cibodas Botanic Gardens as a garden collection. As part of the plant conservation program, their vegetative and reproductive phenology knowledge is crucial to understand when to harvest the seeds used for further propagation and restoration. The study aimed to investigate the phenology phases of these species as well as the impact of microclimates. The study used a descriptive-quantitative analysis based on the records of the exploratory-inventory observation of flowering and fruiting phase data and microclimate circumstances in 2018. Except for precipitation, the data revealed that CBG's microclimate was considerably less diversified. The results also described that A. borneensis has flowering and fruiting almost throughout the year. C. argentea flowers at the end of the year and then develop into fruit at the beginning of the next subsequent year. D. celebica is also a low-intensity flowering plant that bears fruit almost all year. S. bracteosa has a long period of flowering from May to the end of the year. And then it started to develop into fruits from July to the end of the year and continued to January of the following year. Unfortunately, M. caloxylon is not shown a reproductive stage throughout the year. According to the findings, reproductive phases prominently occur early and at the end of the year, along with the rainy season. It also implied the appropriate time for seed harvesting conducted during these periods.

1. Introduction

As one of the mega-biodiverse countries, Indonesia faces the complex pressure of biodiversity loss, severe over time. The losses have been caused by various factors: habitat degradation, over-exploitation, deforestation, forest fires, illegal natural resources harvesting, and trading, as a consequence of the demands of economic progress, and also corrupt behavior [1, 2]. The survival of wild plants in their natural habitats is becoming increasingly threatened and degraded. Therefore, along with these damages and pressures on its natural ecosystems, it is no wonder that many plant species will be more threatened [3].

These rapid losses should be reduced, then as a consequence, ex situ and in situ conservation should be working together with one another [4]. Ex situ plant conservation has been widely understood as a crucial policy action, and botanic gardens have a vital role in conducting these efforts. Botanic gardens have been effective in preserving efforts and increasing the diversity of the plant [5].
are *ex situ* plant conservation areas with a documented collection of plants arranged based on taxonomic, bioregional, or thematic classification patterns, or a combination of these patterns, for conservation, research, education, tourism activities environmental services [6]. Cibodas Botanic Gardens (CBG) is one of the Indonesian botanic gardens conducted by the National Research and Innovation Agency (BRIN), concerned with the plant conservation of tropical montane rainforests [7]. Many wild plants from these regions have been collected, acclimatized, preserved, reproduced, investigated, researched, and displayed as part of the garden collection as living collections.

CBG, as an *ex situ* plant conservation site, has been collecting and maintaining various plant species which are threatened in their natural habitats. These threatened species are commonly listed based on the Red Lists and Red Data Books of the International Union for Conservation of Nature and Nature Resources (IUCN) – the World Conservation Union [8]. Determination of the threat status of a species in the IUCN Red List established based on some information, including taxonomic information, distribution area, occurrences, population data and trends, habitat and ecology, use and trade, threat factors, and other information which is needed to conserve the species [9].

Some of these species collected and managed in CBG are *Agathis borneensis*, *Castanopsis argentea*, *Diospyros celebica*, *Merrillia caloxylon*, and *Saurauia bracteosa*. *A. borneensis* and *C. argentea* are endangered, and *D. celebica*, *M. caloxylon*, and *S. bracteosa* are vulnerable [8]. These species are native range in Indonesia. However, severe exploitation of their natural habitats and over-use and trade [8] make these species crucial to be conserved immediately.

To support the conservation efforts, we need to assemble detailed data regarding the phenology development, especially the blooming and fruiting periods of these species. This information would be beneficial to arrange the seed gathering periods and generate harvesting the seedling to enrich the stock. The seasonal period of life experiences, or phenology, is a living history feature that allows plants to conform to the landscape circumstances they are in [10]. The reproduction period is one of the crucial occurrences in a plant’s life cycle. It has a substantial influence on reproductive success and, therefore, plant vigor [11].

Hence, the flowering and fruiting period has to be harmonized with the environmental circumstances to permit maximization of robustness, for example, by optimizing pollination, reducing predation enforcement, or enabling maximum resource to absorb before seed assembled [11, 12]. In general, flowering phenology is consistent with the present local abiotic and biotic conditions [13], and the beginning of flowering time may also vary over the different plant species [14].

Besides monitoring these reproductive cycles in the natural habitat, rigorous supervision is also possible to arrange in an organizable landscape, for instance, botanic gardens. In botanic gardens, the reproductive cycle monitoring of a species is continually be managed. This study permitted to analyze the reproductive cycle phenology of *A. borneensis*, *C. argentea*, *D. celebica*, *M. caloxylon*, and *S. bracteosa* in 2018 and to construct an early presumed of the influences of the microclimate related to the phases. The study result can help promote these species’ conservation efforts, especially the time of seed harvesting and restocking for further propagation actions. It is a significant effort to cultivate these species as a part of species restoration and reintroduction in the plant conservation frameworks.

2. Methods

The study was conducted at Cibodas Botanic Gardens, Cipanas-Cianjur, West Java. CBG is located at 6.735 to 6.747 S and 107.003 to 107.017 E, on the eastern side of Mount Gede Pangrango. The altitude of the site is approximately 1,300 to 1,425 meters above sea level. The average temperature is between 15 to 20 °C, humidity 80 to 90%, and average precipitation above 2,500 mm year\(^{-1}\). The number of dry months is less than the wet months. Based on Koppen, CBG has been included in the tropical rainforest or A-type, with the most drought season, the minimum precipitation is 60 mm month\(^{-1}\) (Af). This type of climate, based on Schmidt-Ferguson, is C to B-type or less moist to moist, with Q approximately 41.4% [15].

2.1. Data acquisition
The collectible data consisted of two primary data. There was reproductive cycle phenology of the five species and microclimate circumstances of CBG. They were both inventoried monthly during 2018.

Table 1. Details of the observed specimens.

| Species                | Family            | Established in the garden since | IUCN Redlist [8] |
|------------------------|-------------------|---------------------------------|------------------|
| *Agathis borneensis* Warb. | Araucariaceae     | 1996                            | Endangered A4cd  |
| *Castanopsis argentea* (Blume) A.DC. | Fagaceae         | 1996                            | Endangered A2c   |
| *Diospyros celebica* Bakh. | Ebenaceae         | January 2010                     | Vulnerable A1cd  |
| *Merrillia caloxylon* Ridl. | Rutaceae          | May 2003                         | Vulnerable B1+2c |
| *Saurauia bracteosa* DC. | Actinidiaceae     | 1998                            | Vulnerable B1+2c |

![Photographs by Uus Rustandi](image_url)

Figure 1. Morphological previews of the observed specimens: (a) habitus of *A. borneensis*; *C. argentea* (b) habitus, (c) leaf, (d) fruit; *D. celebica* (e) habitus, (f) leaf, (g) fruit; *M. caloxylon* (h) habitus, (i) leaf; *S. bracteosa* (j) habitus, (k) leaf, (l) fruit. (Photographs by Uus Rustandi).

The inventoried microclimate units are temperature, relative humidity, the volume of rainfall, wind speed rate, and solar radiation. The data were gathered from the weather station installed at CBG,
established in front of the management building. The operated weather station was *Precision Weather Station Davis Instruments Vantage Pro2 Plus™*. The instruments automatically continuously send the latest data to the server relating to the microclimate conditions of CBG. The collectible data accurately represented the microclimate conditions surrounding the instruments approximately in a range of a one-kilometer square.

The study's subjects were five species, each with one observed individual. The observed specimens of *A. borneensis* and *C. argentea* have been established as the garden collection since 1996, *S. bracteosa* in 1998, *M. caloxylon* in 2003, and *D. celebica* in 2010. The detailed descriptions of these specimens and their previews of each individual are presented in table 1 and figure 1.

The reproductive phenology of the five species was acquired based on data records in the Registration Unit of CBG. The data was weekly sequential observatory documentation of the frequency of the reproductive occurrences. This reproductive growth consists of stages of flower buds, flowering, young fruits, and ripe fruits. These occurrences are recorded based upon the following five defined classifications: rank 1 is without flowering or fruiting, 0% (nothing); rank 2, the estimated number of flowers or fruits is up to 30% of the cross-sectional area of the tree canopy (rare); rank 3, the number of flowers or fruits between 30 to 60% of the cross-sectional area of the tree canopy (moderate); rank 4, the number of flowers or fruits between 60 to 80% (moderately abundant); and rank 5, is classified by the number of flowers or fruits more than 80% (abundant) [21].

### 2.2. Data analysis

The microclimate units data is presented quantitative-descriptively. To resolve the dissimilarity among the data, especially in value and unit, the numbers are normalized into their log transformation, \( \ln(x) \). A standard deviation (\( \sigma \)) analysis was applied to assess the variation number of this series data. A low \( \sigma \) represents that the data points lead to enclose the mean or less variety, while a high \( \sigma \) shows that the data disperse over a large range of values or much variety. A monthly time series of the reproductive stages of each species is presented based on the rank of each stage. All the gathered data would be presented in a graphic form.

### 3. Results and discussion

The data series in 2018 shows microclimate conditions and reproductive stages of the five species are presented below. There was a dynamic level in each month. The monthly microclimate units data series in Cibodas recorded in 2018 is presented in table 2. For the records, the temperature, relative humidity, wind velocity, and solar radiation were calculated based on their average value or mean, but the precipitation was accumulative.

The monthly average minimum temperature is 17.18 °C occurred in July, and the highest occurred in April, with 19.214 °C. This data shows that the differences between months are low, only 2.034 °C. This low difference has also happened in wind velocity when the difference between the highest and lowest is 3.247. Solar radiation has a moderate difference with 85.254. Precipitation has the greatest difference between months, 308 mm, with the lowest occurring in July and the highest occurring in November.

To enhance a better understanding, then the data is presented in the graphic form in figure 2. Based on figures 2(a) and 2(b), the temperature, wind velocity, and relative humidity tended to be stable throughout the year, with only a slight decrease from November to December. Next, in figure 2(a), solar radiation increases from March to April but remains relatively stable until July, with a slight decrease in August followed by an increase in September and a gradual decrease until the end of the year. In figure 2(c), the most dynamic unit of the microclimate is precipitation. The volume of rainfall is very high in the early months of the year, from January to April, averaging around 250 mm month\(^{-1}\). When entering the dry season, the rain gradually decreases until barely a total drought in July. Then, in August, this gradually increases and continues until November but decreases in December and still concludes as a wet month (≥ 100 mm month\(^{-1}\)).
### Table 2. Monthly microclimates unit data series in Cibodas, 2018.

| Month    | Temperature (°C) | Relative humidity (%) | Precipitation (mm) | Wind velocity (kph) | Solar radiation (W/m²) |
|----------|------------------|-----------------------|--------------------|---------------------|------------------------|
| January  | 18.735           | 89.499                | 253.8              | 4.159               | 84.056                 |
| February | 18.537           | 92.584                | 249.4              | 2.050               | 88.390                 |
| March    | 18.554           | 93.579                | 242.6              | 1.277               | 98.781                 |
| April    | 19.214           | 91.588                | 254.4              | 1.620               | 136.313                |
| May      | 18.932           | 89.719                | 135.4              | 1.815               | 136.686                |
| June     | 18.484           | 90.585                | 65.4               | 1.993               | 130.387                |
| July     | 17.180           | 86.969                | 1.6                | 2.340               | 139.621                |
| August   | 17.497           | 87.601                | 11.4               | 2.071               | 120.563                |
| September| 18.358           | 86.879                | 38.0               | 1.413               | 169.310                |
| October  | 18.966           | 87.334                | 100.8              | 1.923               | 133.212                |
| November | 18.891           | 93.215                | 309.6              | 1.311               | 98.272                 |
| December | 19.110           | 70.548                | 162.2              | 0.912               | 100.775                |

![Figure 2](image-url)  
**Figure 2.** Graphical conditions of the microclimate in Cibodas, 2018: (a) Temperature, Relative humidity, and Solar radiation; (b) Wind velocity; and (c) Precipitation.
These data are also consistent with the standard deviation ($\sigma$) analysis. When all the microclimate units have transferred into their logarithm, $ln (x_i)$, the highest value of the $\sigma$ is precipitation with 1.582. The others relatively result in minor variety (less than 0.5) (table 3). It is presumed due to the position of CBG in the tropical lower mountain with ever-wet region attributes [22]. Inside this zone, temperature and relative humidity are less diverse between months or years. On the other hand, a significant difference between temperature and relative humidity occurs between day and night. High annual rainfall occurring at the beginning and end of the year (rainy season) is an important variation to the microclimate conditions surrounding CBG. The number of dry months is only four to five months in a year, lesser than wet months, and cumulative the volume is higher than 1,000 mm of yearly rainfall [15, 23].

**Table 3.** Standard deviation ($\sigma$) value of the normalized microclimate units, $ln (x_i)$. Due to the differences between units and the scale range, each value has to transfer into its natural logarithm, $ln (x_i)$. This new series was analyzed using standard deviation ($\sigma$) estimation.

| Microclimates unit | Standard deviation ($\sigma$) |
|--------------------|-----------------------------|
| Temperature        | 0.0342                      |
| Relative humidity  | 0.0751                      |
| Precipitation      | 1.5818                      |
| Wind velocity      | 0.3778                      |
| Solar radiation    | 0.2162                      |

Furthermore, microclimate dynamics are thought to influence the development of flowering and fruiting phenology. However, it seemingly does not apply to *A. borneensis*. This species’ flowering and fruiting tend to occur throughout the year (figure 3(a)). From early January to the end of December 2018, flower buds and flowering continue to grow. It also happened during fruiting, with young and ripe fruits becoming available almost every month in 2018. Based on this pattern, the seed harvesting of *A. borneensis* would be fit to be conducted throughout the year regardless of the season.

Unlike *A. borneensis*, the reproductive characteristics of *C. argentea* are thought to be influenced by microclimate conditions. In the early years, it was observed that the young fruits have developed (figure 3(b)). It indicates that the flowering stages have occurred at the end of the previous year.

The juvenile fruits increase from the mid of February to mid-April, then turn ripe in early May. Therefore, the *C. argentea* seed harvesting is appropriate to be conducted in this period. This development still occurs in the wet seasons. Then, from mid-May to mid-August, *C. argentea* is apparently in the vegetative stages. It occurs in conjunction with the dry season. At the end of August, it starts to discover flower buds and get more in September to mid-November. The increasing volume of rainfall in this period is triggering the development [24]. And when the wet seasons are more intensive, some of those buds develop into flowers in September and begin growing into young fruits at the end of October to December. These developing sequences indicated that the reproductive stages of *C. argentea* are influenced by the microclimate conditions, especially precipitation.

Next, based on the records in 2018, the reproductive stages of *D. celebica* occur throughout the year but at a lower volume (figure 4(a)). It has also been consistent with previous studies [25, 26]. Some of the rising amounts of flower buds have been detected in July and December. And some of the young fruit is increasingly produced from the end of June to early July. When the mature and ripe fruits are in a massive amount this year, no record is set. It seems that the microclimate does not significantly affect the reproductive stages of *D. celebica* this year. However, some previous studies confirmed [25, 26] that the appropriate period to harvest the seeds is between September and November, when the ripe fruits are quite plentiful.
Figure 3. The reproductive phenology of (a) A. borneensis; (b) C. argentea.

The other reproductive stages characteristic were displayed by S. bracteosa. The flowering stages and young fruits are still occurring in January (figure 4(b)). These stages were presumed to be the continuation of the previous year's processes. However, the records show that these stages undeveloped into ripe fruits. The high volume of rainfall at the beginning of the year (253.8 mm) allegedly caused this failure. Next, from February to mid-April, the specimen did not show the reproductive stage. And only at the end of April, the tree starts to flower. This flowering event will continue to occur up to the end of the year. Young fruits, but not yet ripe, are detected from June to early July. Furthermore, eventually, the fruiting development is recorded from October to December.

Based on the prior explanation, S. bracteosa reproductive stages in CBG are indicated to occur throughout the year. It has also been supported by some previous studies [27, 28]. The reproductive development of S. bracteosa in the natural habitat also appears throughout the year. The average length of flowering and fruiting from the beginning of initiation to fruit ripening was 145 days [27]. The flowering requires about 71 days, and fruiting development occurs in 74 days [27].

The forward description is the reproductive phenology of M. caloxylon. However, unfortunately, in 2018, the reproductive stages were absent throughout the year (figure 5). Even though it discovered an increase in precipitation and solar radiation degree that began in late August to September, it did not stimulate the flowering or fruiting stage. A substantial level of precipitation associate with the severe winds during the flowering stage highly reduced pollination. Due to the microclimate conditions, the phases assumed that pollination was not yet developed. Plant development could be slowed, and
mortality could rise by up to 60% as a result of the excessive precipitation [29]. High wind speeds slow development by causing increasing cold, halting growth, or reducing photosynthesis by exposing the leaf surface to the sunlight much deficient [30].

Figure 4. The reproductive phenology of (a) *D. celebica*; (b) *S. bracteosa*.

Figure 5. The reproductive phenology of *M. caloxylon*. 
Temperature, moisture, rainfall, and photoperiod are all elements that may determine the periods of the reproductive stage [31]. The reproductive schemes in this study appear to be related to rainfall fluctuations. In 2018, the level of precipitation began to intensify around the final of the dry season, in mid-September. The growth of flower buds of C. argentea as the start of the flowering phases is triggered by an increase in rainfall following the conclusion of the dry season when precipitation tends to be lower. The period, time-length, and dimension of the phenology cycle vary greatly among tree species because of intricate relations among species physiologies, domestic circumstances, and intra-annual changes in rainfall periods [32]. Landscape heterogeneity and location-specific variation may alter the relationship between precipitation and water availability to an individual, complicating the correlation between phenology and precipitation schemes [31]. Regarding the phenological phase, location-specific refers to distinctive traits that exclusively belong to one spot and distinguish it from others.

4. Conclusion
Except for precipitation, the study found that the microclimate conditions in CBG were relatively less diversified in 2018. However, the reproductive development of A. borneensis, D. celebica, and S. bracteosa are seemingly less influenced by microclimate conditions. The microclimate is suspected of influencing the flowering and fruiting phenology of C. argentea. This reproductive stage starts to begin at the end of August, along with the rainy season coming. In 2018, M. caloxylon did not show the stages of the reproductive phase. It is presumed the microclimate conditions are unfavorable to support the development. To harvest the seeds, it is suggested that the early year is the appropriate time to conduct seed gathering.

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