

*Full Length Research Article***Aboveground Phenology of *Tectona philippinensis* Benth. & Hook.f.: Insights into Its Adaptive Mechanisms**

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## ABSTRACT

The present study investigated the leaf flushing, leaf shedding, flowering, and fruiting cycles in *Tectona philippinensis* Benth. & Hook.f., shedding light on its adaptation mechanisms for reproductive success and survival. A plotless inventory of tree individuals was undertaken from predetermined observation points from January 2022 to February 2023 in Lobo, Batangas. All 430 sampled trees exhibited leaf shedding and leaf flushing, while flowering and fruiting events were observed in only 201 and 133 trees, respectively. Major leaf flushing of trees was observed in mid-October, and they generally shed in summer (peak: March). Trees bloomed in early May and reached its peak in June. Fruiting occurred in the wet season (early July to September). There was a general pattern of leaf shedding, flushing, and varying flowering and fruiting cycles, indicating adaptability to environmental changes. The species also exhibited a significant time lag (7–8 months) between leaf flushing and shedding, potentially serving as adaptive features to promote reproductive success and survival in response to changing environmental conditions. Thus, the aboveground phenology of *T. philippinensis* may vary depending on environmental conditions. The findings are relevant for developing *in-situ* conservation strategies for the species.

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**1. Introduction**

Plant life cycle timing, duration, and synchronization are important components of community dynamics. Plant phenology, which is recorded by monitoring the occurrence of vegetative and/or reproductive events, is important for plant functioning, ecosystem services, and their biophysical and biogeochemical feedback to the climate system (Zulkarnaen et al. 2023). However, climate change has altered the timing of significant phenological events, caused phenological mismatches, and desynchronized seasonal interactions across taxonomic groups and trophic levels, particularly in complex ecosystems (Gill et al. 2015; Jeong et al. 2011; Renner and Zohner 2018). Documentation of aboveground phenological patterns and climate data is crucial in assessing the impacts of a changing climate on plant systems. Thus, new plant phenological studies will help us understand and address problems related to climate-induced shifts in phenological events, which affect demography, interactions, and ecosystem dynamics.

Plants rely on environmental signals like rainfall, air and soil temperature, and relative humidity as seasonal triggers. For example, abiotic stress (e.g., drought stress) caused by climate change can alter growth and leaf and floral development, thereby affecting phenological patterns (Gray and Brady 2016). Several studies have documented the profound impact of altered precipitation and temperature patterns on plant phenology, such as delayed or early leaf senescence and flowering (Bao et al. 2021; Rodríguez-Calcerrada et al. 2022). The climate-fruiting/ripening relationship also suggests indirect climatic influences on fruiting dynamics (Pires et al. 2018). In a tropical forest in Hawaii, certain plants' seed production decreased with increasing maximum temperatures and increased with rainfall, while others remained unchanged, demonstrating that climate may affect various species in different ways (Pau et al. 2019). Hence, although plant phenology research is well documented in literature across the globe, observed patterns on the extent, duration, and synchrony continue to show contrasting results. These contrasting results can be attributed to various factors, including ecosystem diversity, spatial and temporal variation, species-specific responses, climate change, and methodological constraints. As a result, further research is needed, particularly in threatened tree species, to provide insights into their adaptive mechanisms for conservation and management use.

*Tectona philippinensis* Benth. & Hook. (Lamiaceae) is one of only three species found in the genus *Tectona*. It is known locally as malabayabas, bunglas, and Philippine teak. Its habitat is primarily limited to Ilin Island in Occidental Mindoro and Batangas Province in Luzon Island, where it can be found on arid slopes and exposed limestone ridges along coasts, and it is a deciduous species (Caringal et al. 2015). Hernandez et al. (2016) found that the species is likely equipped with adaptation mechanisms in drylands or xerophytes based on the habitat's characteristics and the species' restricted existence in the Philippines. According to IUCN and DAO 2017-11, *T. philippinensis* is a critically endangered species, a status that could be potentially linked to habitat destruction owing to land conversion and development activities, as well as the overall state of its natural environment. A phenological survey was already undertaken during the species' general flowering time in 2008, and it was stated that practically every canopy individual has been observed in mass flowering, although blooming might not occur regularly. Nonetheless, the species' population continues to decline after over a decade, underscoring the necessity for further investigations into its phenological patterns to elucidate the factors contributing to this decline.

Thus, the present study analyzed the patterns of leaf flushing, leaf shedding, flowering, and fruiting in *T. philippinensis*, providing valuable insights into its adaptive mechanisms concerning reproductive success and survival within its natural habitat. The potential effects of environmental conditions (rainfall, air temperature, and relative humidity) were also described in the study. Overall, the findings of the present study can inform targeted conservation efforts by identifying critical periods for reproductive success and adaptation. This knowledge can guide habitat restoration and management strategies to support the survival of this critically endangered species.

## 2. Materials and Methods

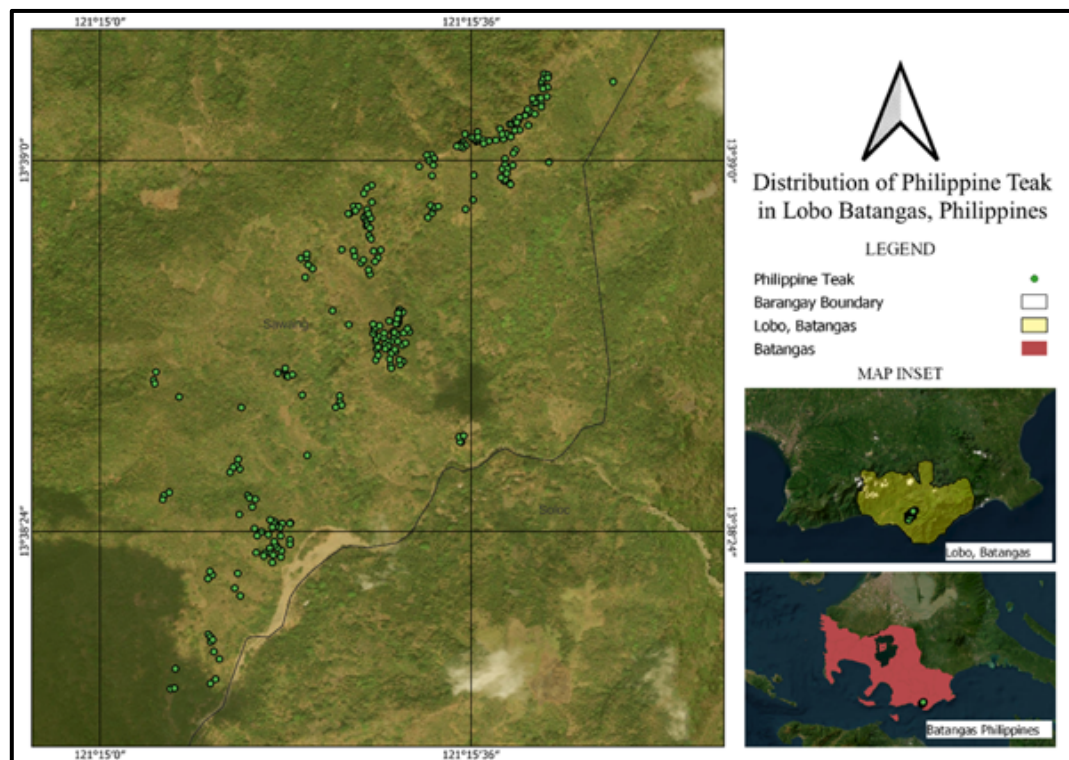
### 2.1. Study Site Description

A phenological inventory was undertaken in semi-deciduous forests in Lobo, Batangas (**Fig. 1**). Lobo is one of the municipalities of Batangas, which lies on the province's Southeastern coast.

It covers 26 barangays. It is bounded by Batangas City on the west, the town of Taysan and Rosario on the north, San Juan on the east, and the Verde Island Passage on the south. Lobo is about 145 kilometers from Manila, located near the southern tip of Batangas province. It is bounded by hills and mountains on both the north and west sides, with an elevation of about 768 meters above sea level.

The most dominant species in the study area is Bagiraua (*Terminalia polyantha* C. Presl), with a 73.68% importance value (IV). This is followed by Philippine teak (*T. philippinensis*) with an IV of 38.64%. The third dominant species is Ipil-ipil (*Leucaena leucocephala* (Lam.) de Wit), with an IV of 24.34%. Next in rank with an IV of 10.75% is Molave (*Vitex parviflora* Juss.) followed by Kulis (*Memecylon ovatum* Sm.) and Malabulak (*Berrya ammonilla* Roxb.) with IVs of 10.69% and 10.06%, respectively.

The soil pH ranged from 5.3 to 6.0. The organic matter (OM) content decreases as the elevation increases. The textural class of soil in the study area is generally sandy loam. Further, a few patches of limestone karst and/or rocky forest floor were evident in the study area, particularly near streams.



**Fig. 1.** Location of the study site in Barangay Soloc and Sawang in Lobo, Batangas, Philippines.

## 2.2. *T. philippinensis* Trees Inventory

This study employed a plotless inventory of tree individuals of *T. philippinensis* from pre-determined observation points from January 2022 to February 2023 following the modified procedure in Caringal et al. (2015). These points (N = 6) were pre-determined based on the population density of the species, the presence of purple blooms, and other plant characteristics (e.g., flaky bark, deciduousness). Trees were identified and tagged, and their diameter at breast height (DBH) and total height were also measured. Saplings/seedlings were excluded from the inventory. The ocular counting of the presence and absence of leaf shedding and flushing,

flowering, and fruiting was conducted once a week by researchers. Specifically, leaf buds, flowers, and unripe/ripe fruits were recorded from each identified tree (**Fig. 2**). Additional *ad-lib* observations were also done in some cases.



**Fig. 2.** (a) Representative *Tectona philippinensis* tree tagged and identified for the study, showing its flaky bark characteristic, (b) purple inflorescence and young fruits, and (c) mature seeds (Note: One unit on the ruler represents 1 mm).

### 2.3. Environmental Data Measurement

The mean monthly air temperature, relative humidity, and light intensity were obtained using the HOBO Pendant Coupler data logger installed on the site throughout the monitoring period. The mean monthly rainfall was obtained from the nearest meteorological center (13° 38' 8" N latitude and 121° 12' 7" E longitude).

### 2.3. Data Analysis

Watson–William F-tests in circular statistics were performed to test for differences in the start and end of shedding, flushing, flowering, and fruiting time. Circular statistics were performed in R statistical package software (v. 3.4). Graphs were generated in SigmaPlot Version 10.0.

## 3. Results and Discussion

Of the 430 individual trees sampled, leaf shedding and leaf flushing were observed at least once for all trees, whereas flowering and fruiting were observed at least once for 201 and 133 trees, respectively (**Table 1**). For some individuals, they flowered, but no fruit was recorded. Neither flowering nor fruiting was recorded for some individuals of *T. philippinensis* over one year of monitoring. The result implies that *T. philippinensis* is of the “extended flowering” type, in which individuals flower less synchronously and for more extended periods (Bawa 1983). It can be due



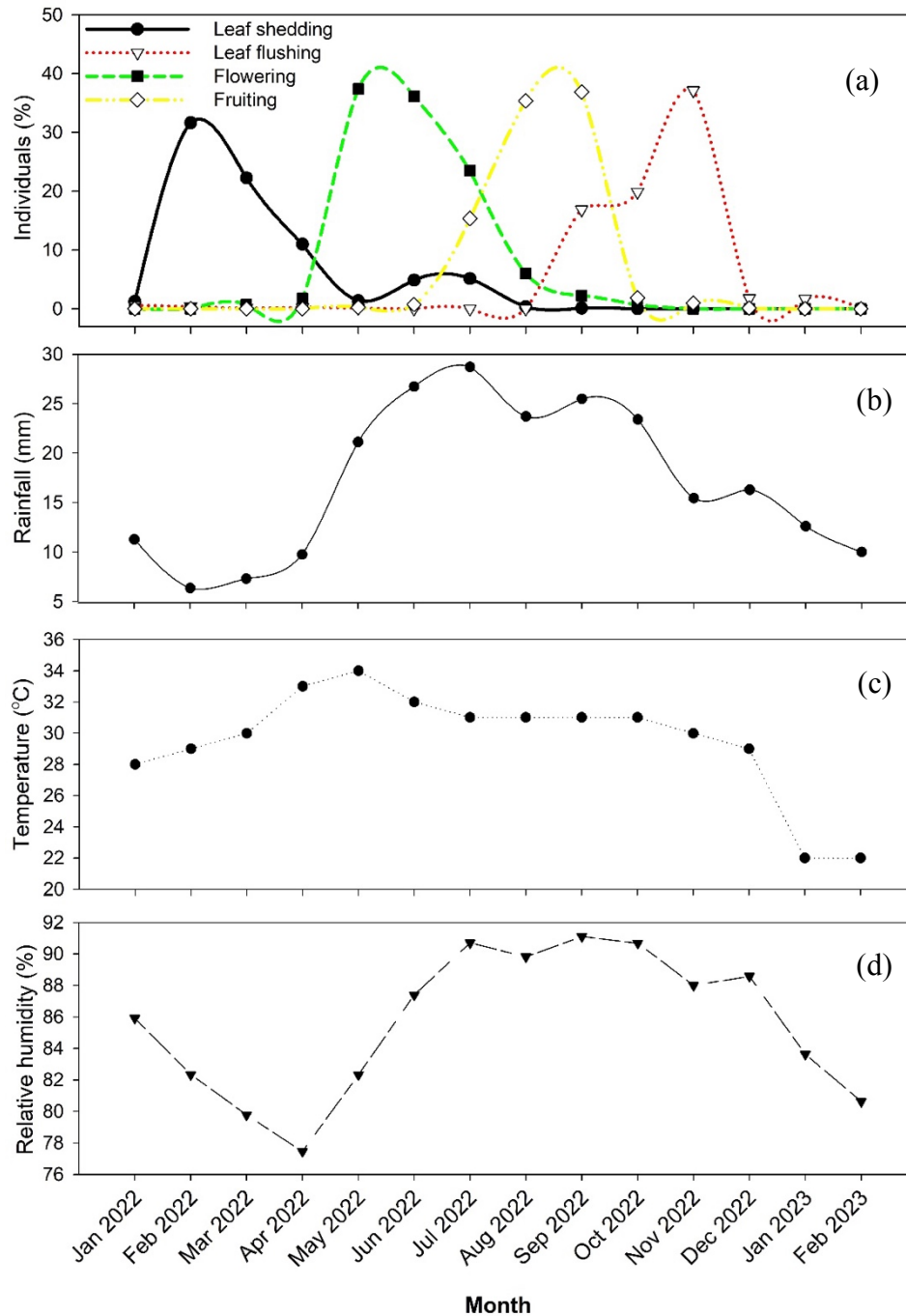
to variability in their flowering and fruiting patterns and resource availability in their habitats (Nagahama and Yahara 2019) that do not align with our monitoring period.

**Table 1.** Results summarizing the main descriptive variables of circular statistics applied to the *Tectona philippinensis* phenology data collected from dry forest in Lobo, Batangas, Philippines

Variable	Leaf Shedding	Leaf flushing	Flowering	Fruiting
Number of observations	339	339	201	133
Mean vector (̶i)	74.64	292.56	166.28	227.36
Mean group	March	October	June	August
Length of mean vector (r)	0.83	0.91	0.87	0.92
Median	75	285	165	225
Circular variance	0.16	0.08	0.12	0.07
Circular standard deviation	34.36	23.64	29.69	23.30
Standard error of mean	1.64	1.28	2.08	2.01

Here, leaf shedding and leaf flushing showed a distinct pattern within one-year monitoring (Fig. 3). Similar to the results of a previous study, sampled trees became leafless snags in summer starting in late January, reaching their peak in March (mean vector: 74.64), and concluding by early May (Caringal et al. 2015). Because *T. philippinensis* is a deciduous species, the observed shedding pattern can be attributed to the adaptive strategy of the species against water stress (Hernandez et al. 2016). Shedding leaves (abscission) during summer can help trees conserve water and minimize water loss through transpiration. This tendency could also be considered an adaptive mechanism of the species to reduce maintenance costs of keeping leaves green throughout summer. Major leaf flushing was observed from September, peaking in mid-October to November. A wide range of time lag (i.e., 7–8 months) between the first-leaf flush and first-leaf-shed phases was recorded in *T. philippinensis*, which is longer than the extent of the leafless period (i.e., 4–5 months). Such a pattern can be attributed to leaf longevity, resource allocation, and environmental adaptation (Marqués et al. 2023; Pearson and D' Orangeville 2022), which are often linked to photosynthetic rate, foliar nitrogen concentration, and plant growth (Reich et al. 1992). Results suggest longer leaf greenness of *T. philippinensis* and, thus, has a much higher carbon-gaining capacity at the plant level.

Trees started their flowering phase in early May, extended until early August, and peaked in June. The start of the flowering phase corresponded to the end of the leaf shedding, which could be advantageous for the trees to produce flower buds while exhibiting a leaf carbon economy via strategic allocation of resources and energy. This strategic energy allocation is exemplified by the occurrence of flowering and fruiting before leaf flushing, a phenomenon known as precocious flowering (Fig. 3a). The natural habitat of *T. philippinensis* in Lobo, Batangas, and San Jose, Occidental Mindoro, is predominantly dry (Hernandez et al. 2022). As a result, the species may have placed significant emphasis on leaf carbon economy through processes such as synchronized shedding and flowering events and/or precocious flowering. The species invested much energy in producing flowers and fruits early in the growing season before leaf flushing to optimize their chances of successful survival. Environmental cues may also trigger flowering and fruiting before plants put out new leaves, synchronizing with the life cycles of pollinators or seed dispersers.



**Fig. 3.** (a) Percentage of individuals (n = 279) shedding (black spline), flushing (red spline), flowering (green spline), and fruiting (yellow spline) of *T. philippinensis* each month from January 2022 through February 2023, (b) mean monthly rainfall, (c) mean monthly air temperature, and (d) mean monthly relative humidity.

Fruit production occurred in the wet season, specifically in early July, and matured in September, when there were relatively few leaves. Results can be attributed to several factors, including life cycle variation, resource availability, and environmental conditions (Park 2019). Since the habitat of the *T. philippinensis* is generally dry, water availability is crucial for fruit production and development. A study revealed a significant reduction in size, fresh weight, and moisture content throughout cell division, cell expansion, and fruit ripening when plants were exposed to water-deficit conditions (Medyouni et al. 2021). Such a pattern in fruiting can also

provide the species with optimal conditions for seed dispersal and germination (Hernandez et al. 2023). Moreover, the absence of new leaves during early flowering and fruiting stages may reduce competition for resources between reproductive and vegetative growth, resulting in higher fruit or seed production.

Leaf shedding and flowering events coincided in mid-May, a period characterized by an increase in both rainfall and relative humidity, as well as higher air temperatures (Fig. 3). This can be attributed to changing environmental conditions during the monitoring period, particularly changes in soil moisture due to increased rainfall. Rainfall may have provided *T. philippinensis* trees with the moisture they needed for reproductive activity, resulting in leaf loss as their energy allocation moves from maintaining older leaves to supporting new development, which includes both leaf and flower buds (Brodersen et al. 2019; Seleiman et al. 2021). A study also attributed the systematic leaf senescence of a tulip tree to increased water and nutrient demand from flowering (Martínez 2011). Here, leaf shedding peaked when rainfall was lower but declined as rainfall and air temperature increased. The decline with increasing rainfall might have been triggered by a breakdown in internal plant signals that hampered root activity and oxygen availability due to waterlogged soils caused by extreme rainfall, affecting leaf shedding (Fukao et al. 2019; Zhang et al. 2021).

Most individuals bloom in May-June, when rainfall, temperature, and relative humidity are higher than in other months (Fig. 3). Similarly, fruiting episodes were more evident between August and September when rainfall, air temperature, and relative humidity were higher (Fig. 3). Shedding, flowering, and fruiting events coincided between mid-June and mid-September, when relative humidity and rainfall were higher, although only in few individuals. Finally, major fruit production was observed when the rainfall and air temperature began to fall in November. Several studies have also reported strong effects of climate, particularly rainfall and air temperature, on flowering events/dates (Moore and Lauenroth 2017). A model also showed temperature as the major indicator of flowering of some woody plant species in southern Africa (Barrett and Brown 2021). Similarly, a phenology model revealed that 57% of Dipterocarpaceae species respond to drought and low-temperature flowering cues in Peninsular Malaysia humid forests (Numata et al. 2022). In Myanmar, the cambial growth/phenology of *Tectona grandis* L.f. was also significantly affected by climate factors (Hlaing et al. 2014). The vegetation phenology of *T. grandis* was also highly responsive to the fluctuation of climatic factors (e.g., rainfall) as shown by moderate resolution imaging spectroradiometer (MODIS)-derived enhanced vegetation index (EVI) time series data (Ghosh et al. 2019).

#### 4. Conclusions

A general pattern of leaf shedding and flushing and variable flowering and fruiting behaviors were observed in *T. philippinensis*. This variability suggests that the species has the “extended flowering” type, characterized by asynchronous and prolonged flowering periods, possibly influenced by complex reproductive cycles and resource availability. The considerable time lag between leaf flushing and leaf shedding can indicate the ability of *T. philippinensis* to optimize carbon gain via prolonged leaf lifespan. The timing of flowering and leaf shedding can also indicate an adaptive trait related to resource allocation in response to dry habitat conditions, enhancing reproductive success and survival of the species. The peak fruit production during the wet season also suggests adaptability to water availability. Moreover, leaf shedding, flowering,

and fruiting with increased humidity and rainfall underscores the profound impact of shifting environmental conditions on phenology. Overall, changing environmental conditions could influence the variability in the aboveground phenology of *T. philippinensis*. The findings can inform conservation efforts by identifying critical periods for reproductive success and adaptation in the natural habitat of the species. However, further studies with longer monitoring periods are recommended to determine the seasonal patterns of the aboveground phenology of *T. philippinensis* amid a changing climate.

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