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ORIGINAL ARTICLE – Conservation of Nature

Phenology of Tree Species in an Open Ombrophilous Forest: Bases for Silviculture and Conservation

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Abstract

Phenological information contribute to silvicultural actions and conservation strategies. Here, we carried out the phenological monitoring of six tree species that were prominent in the structure of an open ombrophilous forest fragment in northeastern Brazil. Over two years, among September 2015 and August 2017, eight individuals of each species (48 trees in total) were visited every two weeks to record the reproductive and leaf phenophases, following the Fournier intensity scale. We calculated the intraspecific synchrony of the phenophases and the correlation of the phenophases of each species with meteorological variables (temperature, air precipitation and photoperiod). The species showed synchronous characteristics for the phenophases. Precipitation stood out in terms of a higher frequency of significant relationships with the reproductive phenophases. The results indicates that the end of the dry season is the most favorable period for seed collection and the monitoring of dispersers in this type of tropical forest.

Keywords: Atlantic forest, fruiting period, seed collection, tropical forestry, forest ecology.

1. INTRODUCTION AND OBJECTIVES

The planning of silvicultural interventions and conservation measures still faces obstacles related to the lack of information that allows an efficient management of tree species and their ecosystem services (Morellato et al., 2016; Luna-Nieves et al., 2017). In a context where strategies for the conservation and sustainable use of native species in tropical forests become increasingly urgent in view of the fragmentation of their naturally occurring areas, the study of phenology can contribute with important information for the optimization of decision-making (Buisson et al., 2016).

The Phenology has practical and theoretical implications for the phases or periodic and repetitive events of life cycle of tree species and their temporal variation throughout the year, as well as the relationship these events have with the environment in which these tree species occur (Sakai & Kitajima, 2019). Among the practical implications, the contribution to silviculture stands out, especially in the planning of the collection of fruits, seeds and other non-wood forest products (Schmidt et al., 2007; Luna-Nieves et al., 2017), as well as for conservation strategies of pollinators, dispersers, genetic interaction between forest fragments and ecosystem processes (Morellato et al., 2016). Among the theoretical implications, phenological studies have helped to explain the influences of environmental factors on the reproductive behavior and distribution of tree species (Borchert et al., 2005; Pau et al., 2020) and their evolutionary history (Reich, 1995).

In the context of open rain forest formations, there is still little information on the phenological behavior of tree species, which prevents the identification of patterns in Brazil and worldwide (Vieira et al., 2002; Medeiros et al., 2017). Among the existing experiences, it is noteworthy mentioning Viera et al. (2002). In that study, the researchers monitored 25 tree species monthly for five years in an open rainforest area in Rondônia, in the northern region of Brazil. Most species were perennial, with flowering in the dry period and fruiting at the end of the dry season and beginning of the rainy season. If this phenological behavior were observed in different geographical contexts, we would have important clues about the adaptive responses of tree species to the environmental conditions of the open ombrophilous forest.

Therefore, it is necessary to add efforts that contribute to the identification of phenological patterns in open ombrophylous forests. Thus, we seek to answer the following question: how is the phenological behavior of tree species related to meteorological variables (precipitation, air temperature and photoperiod) in areas of open ombrophilous forest? We understand that the understanding of this relationship can contribute to the adequate planning of silvicultural actions, as well as of use and conservation of species inserted in these formations.

When we consider that high rainfall is a determining factor in the distribution of open rain forest formations, we assume the hypothesis that precipitation is the meteorological variable most related to the reproductive phenological behavior of tree species inserted in these formations. Therefore, we aimed to describe the phenology of six native forest species in an open ombrophilous forest fragment, as well as their relationship precipitation, air temperature and photoperiod in the period.

2. MATERIALS AND METHODS

2.1. Study area

The study was conducted in a forest fragment of Atlantic Forest, inserted in an Area of Permanent Preservation (APP), of approximately 188 hectares, located in the municipality of Rio Largo - Alagoas, northeast of Brazil (09º 28' 02" S; 35º 49' 43" W, 127m). The fragment has an open ombrophilous forest formation (IBGE, 2012). This type of forest formation, presents floristic factions that alter the ecological physiognomy of the Ombrophilous Dense Forest due to the formation of clearings. In addition to the discontinuous canopy, one of the main characteristics of this formation is the climatic gradients with more than 60 dry days per year. According to the Köppen classification, the region's climate is classified as As' - hot and humid, with autumn and winter rains.

2.2. Sample selection

Six species were chosen, belonging to five botanical families: *Parkia pendula* (Willd.) Benth. ex Walp. (Fabaceae), *Didymopanax morototoni* (Aubl.) Decne. & Planch. (Araliaceae), *Bowdichia virgilioides* Kunth (Fabaceae), *Tapirira guianensis* Aubl. (Anacardiaceae), *Cariniana legalis* (Mart.) Kuntze (Lecythidaceae) and *Xylopia frutescens* Aubl. (Annonaceae). The choice of these species was due to their phytosociological importance in the fragment (Lima et al., 2019), which led us to believe they are interesting species for forest restoration and restoration actions, which require phenological information about them for seed collection. Also, for this purpose, we have collected information in the literature on the dispersion and pollination syndromes of these species.

Each species was represented by eight individuals, totaling 48 tree individuals selected based on the following criteria: height greater than 10 m; good canopy visibility; good phytosanitary condition; and, in reproductive age. In an attempt to ensure greater genetic variability, an attempt was made to maintain a minimum distance of fifty meters between individuals of the same species. All individuals were georeferenced and tagged with an aluminum plate containing an acronym for the species and an identification number. In addition, botanical samples of the species were collected for identification at the Herbário MAC, of the Environment Institute of the State of Alagoas.

2.3. Data collection

2.3.1. Meteorological

The meteorological data used in this study were collected in the vicinity of the forest fragment, around 850 meters away in a straight line, through the Automatic Meteorological Station, located at the Agricultural Sciences Center of the Federal University of Alagoas, Rio Largo - AL (Latitude: 9° 28' 29.1" S; Longitude: 35° 49' 43.6" W; Altitude: 127 m). The photoperiod (N), also called the length of the day, is defined as the time, in hours, between sunrise and sunset. The photoperiod data was determined for the location studied (Equation 1), using the previous calculations of solar declination (δ) and the hour angle at sunrise or sunset (H), respectively, by applying Equations 2 and 3 (Iqbal, 1983). Ultimately, the N is a function of latitude (ϕ) and day of the year (D).

$$N = 2H/15 \tag{1}$$

$$H = \mathrm{arcccos}(-\,\mathrm{tg}\,\phi\,\mathrm{tg}\,\delta) \tag{2}$$

$$\delta = 23,45\,\mathrm{sen}(360/365(284 + \mathrm{D}) \tag{3}$$

In the period from September 2015 to August 2017, the months with the highest monthly precipitation values occurred from May to July 2017, with 584.7 mm, 477.8 mm and 418.1 mm respectively. November 2015 and February 2017 had the lowest monthly values, 10.9 mm and 12.2 mm, respectively. Regarding air temperatures, the maximums occurred in February and March 2017, both 26.5°C, while the lowest was 22°C, recorded in July 2017. These are monthly average values of the daily average of air temperature (Figure 1). The photoperiod at the study site has an amplitude of 1.12 hours throughout the year, the maximum occurs in December, with 12.54 hours and the minimum in June, with 11.45 hours.

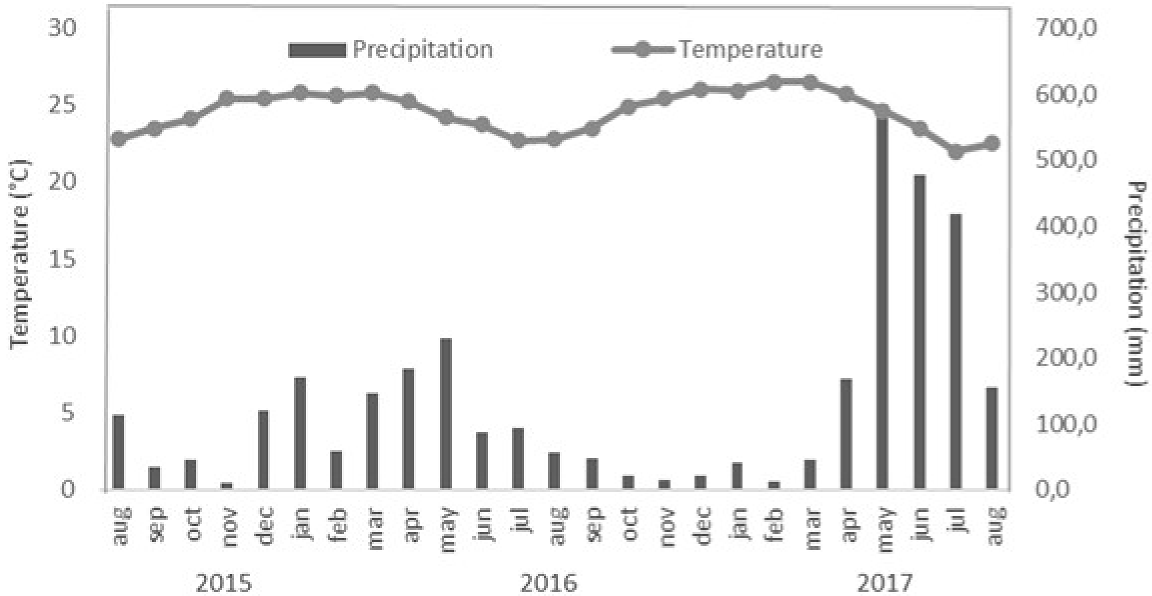

Figure 1. Monthly precipitation and air temperature in "Mata da Frascalli" forest fragment, Rio Largo, Alagoas, for the period of phenological observations.

2.3.2. Phenological

Phenological data were collected between September 2015 and August 2017, in visits undertaken biweekly to all selected individuals. With the aid of binoculars, the following phenological events were observed: leaf out, leaf fall, flowering and fruiting. The intensity of these phenophases was estimated according to the method of Fournier (1974). This method uses a semi-quantitative scale, ranging from 0 to 4, to classify the intensity of the event. The classification is as follows: 0 corresponds to the absence of the phenophase; 1 the presence of the phenophase with an intensity of 1 to 25%; 2 the presence of the phenophase with an intensity of 26 to 50%; 3 the presence of the phenophase with an intensity of 51 to 75%; 4 the presence of the phenophase with an intensity of 76 to 100%.

2.4. Data analysis

For the analysis of the phenological data, the frequency of appearance of each phenophase over the period was calculated. In addition, it was also calculated the intraspecific synchrony was calculated in the period of maximum activity of the species. Thus, a species was considered asynchronous when less than 20% of the individuals presented the phenophase; of low synchrony when between 20-60% of individuals presented the phenophase; and of high synchrony when more than 60% of the individuals were in the phenophase (Bencke & Morellato, 2002).

To evaluate the relationship between phenophases (flowering, fruiting, launching and leaf fall) and meteorological variables (air temperature, precipitation and photoperiod) the Spearman's correlation test was performed (Zar, 1996). We used the RStudio statistical program, version 1.3.1056, using the "PerformanceAnalytics" package. We evaluated the relationship between the monthly averages of the climatic variables and the monthly averages of the phenophases for each species separately, as well as for all species together.

3. RESULTS

3.1. Flowering and fruiting

Over the two years of monitoring, all species presented reproductive phenophases with varying intensities. However, in the first year of monitoring these phenophases were more intense.

Among the species studied, *X. frutescens* had the shortest flowering period - only three months throughout the monitoring period, followed by *B. virgilioides* and *P. pendula*, which had flowers for five months (Figure 2). Conversely, the species *D. morototoni* had the longest flowering period, observed during 15 months throughout the monitoring period (Figure 2). This species even presented two blooms in the same year, with an interval of just one month between them. The first, with a longer duration, was more intense and synchronous (between September 2015 and July 2016), while the second, with a shorter duration, was less intense and with low synchronization between individuals of the species (between September and December 2016).

In relation to fruiting, it was found that the individuals of *C. legalis* and *X. frutescens* had a peak of this phenophase in December 2016, both with two occurrences of this event during the monitoring period. The *D. morototoni* species also presented two fruiting events in the same year (September 2015 to April 2016, and from June 2016 to January 2017). The species *P. pendula* showed a continuous pattern of fruiting throughout the study, peaking in January 2016, with a decrease in the intensity of this event since then. The species *B. virgilioides* and *T. guianensis* had fruits only once and for a short period (three and five months, respectively).

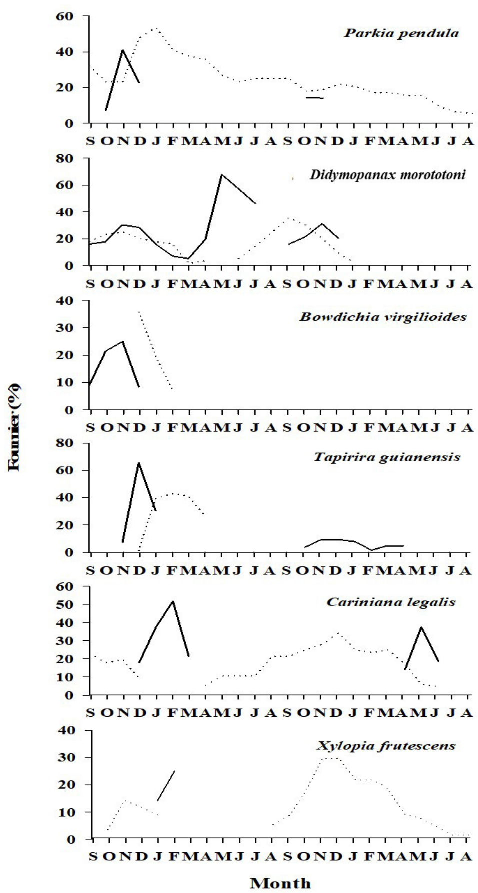

Figure 2. Reproductive phenology of the monitored species. Flowering (—); Fruiting (…).

3.2. Leaf out and leaf fall

The occurrence of vegetative phenophases was recorded in a remarkable way in all species throughout the monitoring period, with emphasis on the species *B. virgilioides* (occurrence in the 24 months of monitoring), *T. guianensis* (23 months), *D. morototoni* (22), *P. pendula* (21) and *C. legalis* (20). Regarding leaf fall, a greater occurrence was observed for *X. frutescens* (20 months), *P. pendula* (17), *D. morototoni* (16) and *T. guianensis* (15) (Figure 3).

D. morototoni presented the greatest intensity of leaf fall in November 2015, while the leaf out showed its peak in two periods, the first in February 2016 and the second in May 2017. *B. virgilioides* presented a continuous production of new leaves, with peaks in November 2015 and 2016. This species showed a very frequent leaf fall, occurring in the intervals corresponding to the driest periods. *T. guianensis* had a peak of leaf fall in January 2017 and leaf out in April of the same year. For *C. legalis* the peak of leaf fall occurred in December 2016 and the leaf out occurred in January 2017. The intensity of leaf out in *X. frutescens* was quite reduced, with a peak in October 2015, whereas the peak of leaf out was in February and March 2017 (Figure 3).

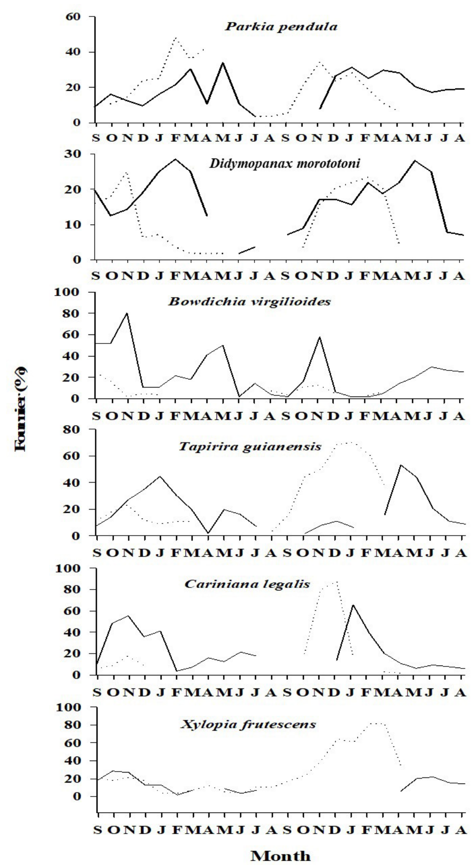

Figure 3. Vegetative phenology of the monitored species. (—) Leaf out; (…) Leaf fall.

3.3. Phenophasic oscillations and synchrony

Table 1 shows the periods of peak activity of the six tree species monitored. In addition, the dispersion and pollination syndromes of each species are also presented.

All species showed synchronous characteristics for the studied phenophases. In this sense, there was a predominance of species with high synchrony, meaning they presented more than 70% of individuals in the same phenophase in the analyzed period. In total, only four cases of low synchrony were recorded, occurring specifically in the events of flowering and fruiting, these covering 50% of the species monitored, as shown in Table 2.

Table 1. Type of fruit, dispersion, pollination syndromes and peak of reproductive and leaf phenophases.

FAMILY *Species*	Common name	Fruit	Disp.	Pollin.	Peak			
					Flow.	Fruit.	Leaf Out	Leaf Fall
ANACARDIACEAE								
Tapirira guianensis Aubl.	Cupiúba	Fleshy	Zoo	melit	dez/15	fev/16	abr/17	jan/17
ANNONACEAE								
Xylopia frutescens Aubl.	Embira-vermelha	Fleshy	Zoo	cant	fev/16	nov/16 - dez/16	out/15	fev/17 - mar/17
ARALIACEAE								
Didymopanax morototoni (Aubl.) Decne. & Planch.	Sambaqui	Fleshy	Zoo	zoof	mai/16	set/16	fev/16 - mai/17	nov/15 - fev/17
LECYTHIDACEAE								
Cariniana legalis (Mart.) Kuntze	Jequitibá	Dry	Anemo	melit	fev/16	dez/16	jan/16	dez/16
FABACEAE								
Bowdichia virgilioides Kunth	Sucupira	Dry	Auto / Anemo	melit	nov/15	dez/15	nov/15	set/15
Parkia pendula (Willd.) Benth. ex Walp.	Visgueiro	Dry	Auto / Zoo	Chiropt	nov/15	jan/16	mai/16	fev/16

Where: Disp. = dispersion syndrome, Pollin. = pollination syndrome, Flow. = flowering, Fruit. = fruiting, Zoo = Zoochoric, Anemo = anemochoric, Auto = autochoric, melit = melittophily, cant = cantharophily, zoof = zoophilia, quiropt = chiroptorophilia.

Table 2. Level of intraspecific synchrony of the phenophases and their corresponding relative values.

Species	Phenophases			
	Leaf out	Leaf fall	Flowering	Fruiting
P. pendula	High sync 85,7%	High sync 85,7%	High sync 71,4%	High sync 85,7%
D. morototoni	High sync 85,7%	High sync 71,4%	High sync 100%	High sync 100%
B. virgilioides	High sync 100%	High sync 100%	Low sync 42,9%	Low sync 42,9%
T. guianensis	High sync 100%	High sync 100%	High sync 100%	Low sync 42,9%
C. legalis	High sync 100%	High sync 100%	Low sync 57,1%	High sync 87,5%
X. frutescens	High sync 100%	High sync 100%	High sync 100%	High sync 87,5%

(**) – significant p < 0,001. (*) - significant p < 0,05.

3.4. Relationship between phenological behavior and meteorological variables

The phenological behavior of the species *B. virgilioides* showed significant, albeit low, relationships between the flowering and precipitation (rs = -0.35), as well as fruiting and photoperiod (rs = 0.46). The leaf fall was correlated to the photoperiod (rs = 0.47) and, conversely, to precipitation (rs = -0.60) (Figure 4a).

C. legalis showed a significant relationship between flowering and precipitation (rs = 0.58), as well as a highly significant and inverse relationship between fruiting and precipitation (rs = -0.79). The leaf fall was highly significant and inverse with precipitation (rs = -0.67), and highly significant with the photoperiod (rs = 0.65), in addition to having a low but significant relationship with air temperature. (rs = 0.38). Leaf out phenophase showed a significant low relationship with temperature (rs = 0.40) (Figure 4b).

C. legalis showed a significant relationship between flowering and precipitation (rs = 0.58), as well as a highly significant and inverse relationship between fruiting and precipitation (rs = -0.79). The leaf fall was highly significant and inversely correlated with precipitation (rs = -0.67), and highly correlated with the photoperiod (rs = 0.65), in addition to having a low but significant relationship with air temperature (rs = 0.38). Leaf out showed a significant low relationship with temperature (rs = 0.40) (Figure 4b).

P. pendula showed no relation between the flowering and fruiting phenophases with climatic variables. However, there was a significant relationship between leaf fall with the photoperiod (rs = 0.75) and air temperature (rs = 0.66), as well as a low inverse relationship with precipitation (rs = -0.40). In addition, the leaf out phenophase showed a significant low relationship with temperature (rs = 0.55) (Figure 4c).

D. morototoni presented a flowering phenophase that was not related to any of the climatic variables. However, the fruiting phenophase showed low significant relationships with the photoperiod (rs = 0.42) and with precipitation (rs = -0.51), the latter being an inverse relationship. Leaf out was related to air temperature (rs = 0.57) and photoperiod (rs = 0.37). Leaf fall, on the other hand, showed highly significant relationships with all climatic variables, with a inverse relationship in the case of precipitation (rs = -0.70) (Figure 4d).

T. guianensis showed a highly significant and positive relationship between flowering and air temperature (rs = 0.68) and photoperiod (rs = 0.79), as well as a low inverse relationship with precipitation (rs = -0.43). Fruiting did not show any relationship with any of the climatic variables. Leaf out had a low relationship with precipitation (rs = 0.45), and leaf fall was related to photoperiod (rs = 0.82), air temperature (rs = 0.62) and leaf fall (rs = -0.85), the latter being an inverse relationship (Figure 4e).

Finally, *X. frutescens* showed a low relationship between flowering and photoperiod (rs = 0.38). The fruiting of this species was highly related to the photoperiod (rs = 0.64) and air temperature (rs = 0.56), also showing a significant and inverse relationship with precipitation (rs = -0.55). As for the leaf out, there was a low positive relationship with precipitation (rs = 0.40) and an inverse relationship with air temperature (rs = -0.41). Leaf fall was related to the photoperiod (rs = 0.61), air temperature (rs = 0.62) and inversely related to precipitation (rs = -0.79) (Figure 4f).

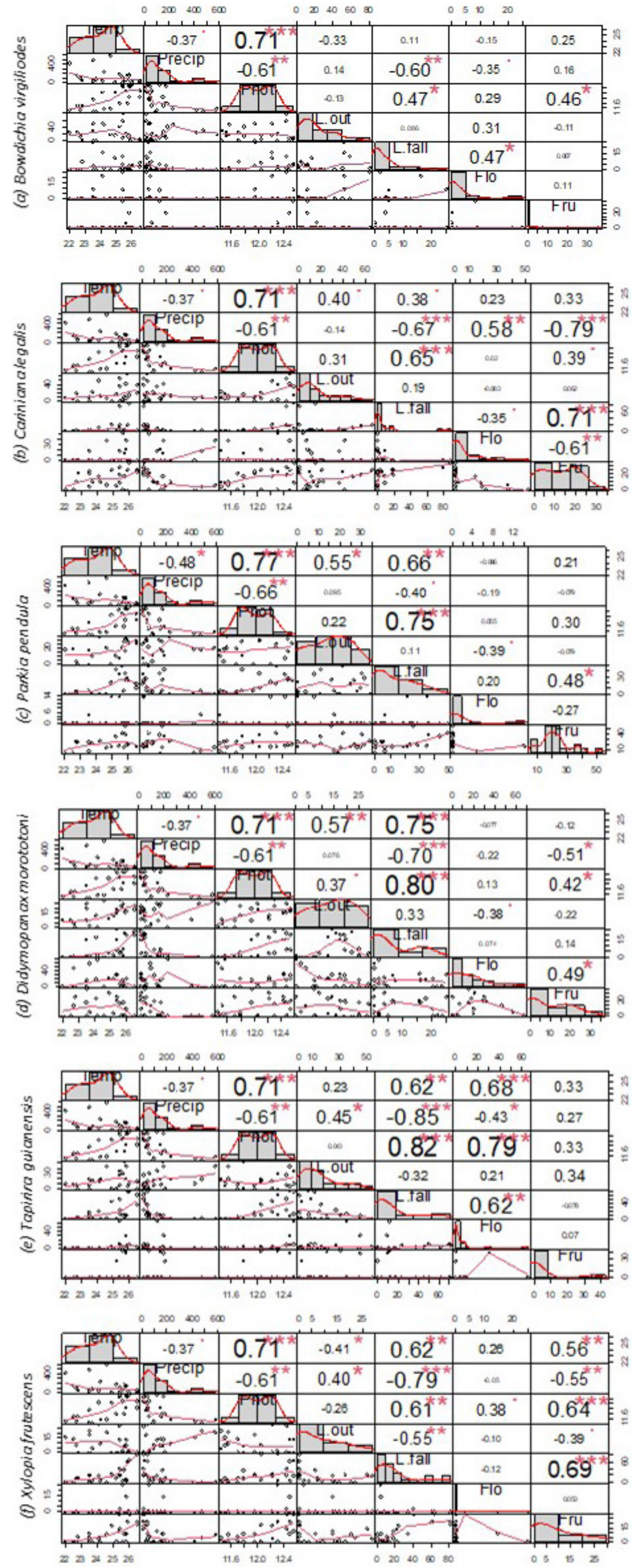

Figure 4. Spearman's correlation (rs) between the phenophases (flowering, fruiting, leaf fall and leaf out) and meteorological variables (air temperature, precipitation and photoperiod) for each species.

The mean flowering phenophase among the studied species did not show a significant relationship with the meteorological variables analyzed, but it presented a weak positive relationship with leaf out (rs = 0.45). The mean of the fruiting phenophase between the species studied showed a highly significant and positive relationship with the photoperiod (rs = 0.80), also showing a significant and positive relationship with air temperature (rs = 0.45) and a significant and negative relationship with precipitation (rs = -0.49). In addition, the fruiting phenophase showed a significant and positive relationship with the leaf fall (rs = 0.62) and flowering (rs = 0.49) phenophases. The average of the leaf release phenophase was not related to the climatic variables analyzed, whereas the average of the leaf fall showed a highly significant and positive relationship with the photoperiod (rs = 0.83) and with the air temperature (rs = 0.71), as well as strong negative relationships with precipitation (rs = -0.82), indicating that the lower the precipitation the greater the leaf fall (Figure 5).

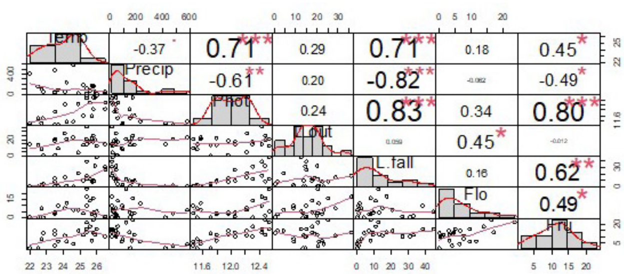

Figure 5. Spearman's correlation (rs) between the average of phenophases (flowering, fruiting, leaf fall and leaf out) and meteorological variables (temperature, precipitation and photoperiod).

4. DISCUSSION

A lower precipitation was observed along the first twelve months of phenological monitoring. In the tropical region, some evidence links the absence of rain and clouds to an increase sunlight, activating the reproductive behavior of trees (Borchert et al., 2005). According to this author, in tropical forests with low climatic seasonality, photoperiodic control is the mechanism that induces the flowering of the species. Similarly, different studies have shown an increase in sunlight in areas of clearings and edges, causing an increase in flowering and fruiting (Athayde & Morellato, 2014). Therefore, it would be possible to assume that the discontinuous canopy characteristic of open rain forest formations and the periods of low precipitation intensified the sunlight and the reproductive phenological activity in the studied context.

This would help explain why flowering peaks occurred during the period of least rainfall, even though there was no direct and significant relationship between flowering and precipitation. In addition, we evidenced a strong correlation between the averages of the fruiting phenophase and photoperiod, revealing the importance of this climatic variable in the reproductive phenological behavior of the species, when analyzed together. Similarly, we found an inverse relationship between the averages of fruiting and precipitation, indicating that the higher the precipitation, the lower the fruiting. It is noteworthy that precipitation and photoperiod also showed a significant and inverse relationship. These findings corroborate our hypothesis, which highlights the influence of precipitation on the reproductive phenological behavior of species occurring in open ombrophilous formations.

It should be noted, however, that the apparent increase in reproductive activities in a year of lower precipitation should not necessarily be interpreted as something beneficial for the forest community. This is mainly because it is a disturbed and fragmented area, where this phenomenon may actually indicate an asynchronous response caused by new environmental conditions, causing damage to pollinators and dispersers (Hagen et al., 2012). In this sense, Morellato (2007) points out that prolonged droughts can affect the timing and the sync of flowering of native tree species. Our findings corroborate this trend to some extent, as we observed low synchrony in flowering and fruiting of some species (*B. virgiliodes, T. guianensis, C. legalis*). However, for the other species, greater intraspecific synchrony was observed for the flowering event, as well as for fruiting and leaf phenophases, corroborating the results of several studies in tropical forests (see Vílchez & Rocha, 2004; Ochoa-Gaona et al., 2008; Pereira et al., 2008; Ferreira-Júnior & Moura, 2012; Freire et al., 2013).

The fruiting peaks occurred more frequently in periods of higher temperature and at the end of periods of lower precipitation. These results reinforce the trend observed by Ferreira-Júnior & Moura (2012). In this study carried out in an ombrophilous forest fragment in Alagoas it was found that the highest values of percentages of species presenting the fruiting phenophase occurred at the beginning of the rainy months. Unfortunately, the authors in question did not specify whether the studied fragment had open or dense ombrophilous vegetation. However, the study by Vieira et al. (2002), undertaken in an open ombrophilous forest but in the Amazon region, observed that most species bear fruit at the end of the dry season and the beginning of the rainy season. A possible interpretation of this pattern would be related to the optimization of seed germination rates, due to these more favorable environmental conditions (Reich, 1995). Taken together, these results indicate that the end of the dry season represents the most favorable period for seed collection actions in open ombrophilous forests.

Adequate seed collection planning is a critical point for silvicultural actions, because in addition to being expensive in terms of human, monetary and time resources, the seeds of many species are quickly perishable. This would be the case for seeds dispersed just before the beginning of the rainy season, as prevailed in our study, which tend to germinate more quickly due to no dormancy (Yang et al., 2013).

In addition, from the point of view of planning conservation strategies, it is important to know the peak of fruiting, since at the first signs of failures in these methods, measures could be implemented in order to avoid extreme hunger for frugivores and food shortages with losses to all trophic web (Hanya & Chapman, 2012). The peak fruiting period is also critical for breeding seasons of frugivorous bird species (Develey & Peres, 2000), which provide an important ecosystem service in fragmented landscapes.

The leaf fall occurred with greater intensity in periods of high temperatures, low precipitation and high photoperiod. Notably, leaf fall in periods of drought is common in tropical forests (Camargo et al., 2018), and corresponds to a mechanism for reducing water loss through evapotranspiration and water stress. The absence of leaf fall in the months of greatest precipitation (May, July and August 2017) reinforces this interpretation. Some authors argue that the reduction of leaf cover favors the anemochoric and zoochoric dispersion of fruits (Van Schaik et al., 1993; Ferraz et al., 1999), by decreasing the physical barriers to wind circulation and facilitating visibility and access to fruits by dispersing animals, such as birds for example. Our results endorsed this argument, as they revealed a highly significant relationship between the fruiting and leaf fall.

The intensity of leaf out throughout the study period was higher than the events of leaf fall. These results obtained in our study reinforce the perennial behavior of open ombrophilous forest formations, which contributes to the productivity of these ecosystems from the constant cycling of materials deposited in the soil. When water is not a limiting factor, it can be predicted that tropical plants must produce a large number of young leaves to coincide with the later periods of high insolation, resulting in greater energy gain and allowing the development and preparation of plants for the following phenological events (Van Schaik et al., 1993).

5. CONCLUSIONS

The phenological behavior of the monitored species showed significant correlations with the meteorological variables. Precipitation stood out in terms of a higher frequency of significant relationships with the reproductive phenophases of different species, corroborating the hypothesis proposed by the present study. The photoperiod proved to be the second meteorological variable most frequently related to reproductive phenological behavior. Flowering was more intense in the dry period and fruiting more present at the end of the dry season, that is, just before the beginning of periods of greater precipitation. This indicates that the end of the dry season is the most favorable period for seed collection and the monitoring of dispersers. Leaf out and leaf fall were observed throughout the period, corroborating the perennial nature of the species of the open ombrophilous forest. This information can contribute to improving the planning of silvicultural actions and conservation of ecosystem services in these tropical forest environments.

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Ricardo Cordeiro de Lima: formal analysis (Equal); investigation (Lead); writing – original draft (Lead).

Isabel Tavares Galindo Nepomuceno: investigation (Equal).

Ricardo Ferreira-Júnior: formal analysis (Equal); writing – review & editing (Equal).

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