Phenology of four tree species of an Atlantic Forest fragment in Southern Minas Gerais

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Abstract

Periodic behaviors in plants are biological events that determine the successful development and reproduction of individuals of plant species and can be investigated through phenological studies. In this context, a phenological study of the tree species *Croton floribundus* Spreng., *Cedrela fissilis* Vell., *Machaerium nyctitans* (Vell) Brenth. and *Machaerium villosum* Vogel. was carried out in an Atlantic Forest fragment. This spot is located in the Federal Institute of Southern Minas Gerais - Campus Muzambinho, which is inserted in a region with well-defined double climatic seasonality, being individuals of the species monitored monthly between November 2020 and October 2021. The objective was to monitor the occurrence of vegetative and reproductive phenophases, which included growth and leaf fall, flowering and fruiting, which were observed with the aid of binoculars and then evaluate the correlation between these behaviors and the climatic variables of the study region. Correlations were obtained between climatic variables and vegetative and reproductive events expressed by the species. It was then observed that endogenous characteristics along with seasonal pressures influenced the time and period of phenophases, as well as the pollination and dispersal syndromes linked to these behaviors. This understanding reinforces the intricate relationship between seasonal cycles and species adaptations, contributing to a deeper comprehension of the autoecology and population dynamics of these species.

Keywords: Seasonality; Population dynamics; Environmental Pressures; Reproductive Biology.

Introduction

Phenology is a science adopted to investigate the periodic vegetative and reproductive behaviors of plant species, and the relationship with climate factors that potentially influence the expression of these behaviors (WADGYMAR *et al*., 2018). These studies are extremely important for understanding the complex dynamics of forest ecosystems. Therefore, the knowledge and understanding of phenological factors of tree species provides bases for ecological studies of biodiversity, with information on the organization and dynamics of tree populations and communities (MORELLATO *et al*., 2016).

Phenological patterns may vary due to regional climatic variations, along with intrinsic characteristics within a species, and can also vary when evaluated between different populations and between individuals with their different ontogenetic phases (PAU *et al*., 2011). Therefore, the time and frequency at which vegetative and reproductive behaviors occur in plant species are determinant in reproductive success, as well as in the recruitment and establishment of individuals in their respective populations (KUMAR, TRIPATHI, KHANDURI, 2023).

In tropical environments, phenological events in plants are determined by seasonal variations in climate and by endogenous rhythms of the species (DAVIS *et al*., 2022). Factors such as precipitation, insolation, evaporation, relative humidity and temperature are subject to seasonal oscillations during the year, or over a period of time, and are related to oscillations in the expression of phenophases in plant species in these locations (NOVAES *et al*., 2020). Specifically, in Semideciduous Seasonal Forests, such as those found in the south of Minas Gerais, summers are characterized by high temperatures and heavy rainfall, followed by winters with lower temperatures and dry (LIMA, FERREIRA, CRUZ, 2019). This seasonality potentially affected the ecology and evolution of species, imposing the need to investigate the existence of these correlations between climatic seasonality and the phenology of populations of plant species (SAXENA, RAO, 2020).

In addition, phenology is an important tool for understanding the ecology of plant species and the temporal supply of floral resources in the community. Therefore, phenological studies are fundamental to understanding the ecosystem services provided by plants (MORELLATO et al., 2016). Thus, conservation and ecological restoration actions in forest environments need to take into account phenological information about the species, since this information is indispensable for effective actions that guarantee the restoration of the community's ecological processes (DAVIS et al., 2022). In this sense, the phenological study of pioneer species in the forest community is essential for understanding the initial role of these species and the services they provide to the community.

Species such as *Cedrela fissilis* Vell., *Croton floribundus* Spreng., *Machaerium nyctitans* (Veel) Benth. and *Machaerium villosum* Vogel. play a fundamental role in structuring the plant community in semi-deciduous forest formations, since they have pioneer to late establishment, thus playing a vital role in restoring these ecosystems (SWAINE, WHITMORE, 1988). In this scenario, this study was developed with the aim of investigating and characterizing the vegetative and reproductive phenological patterns of four tree species in an Atlantic Forest fragment in the south of Minas Gerais over the course of one year. This information is essential for understanding the autoecology of these species, helping to identify their adaptive strategies and assess how environmental factors, such as climate and seasonality, influence their phenological cycles.

Material and methods

This research was carried out in a fragment of Montana Seasonal Semideciduous Forest under Atlantic Forest domain, which is located at Federal Institute of Southern Minas Gerais - Campus Muzambinho. In the region, the climate presents rainy summers with mild temperatures, and a winter marked by water deficit and low temperatures. The average temperature is equal to 19.7 ºC, while the annual precipitation corresponds to 1.446 mm (APARECIDO, SOUZA, 2021). The region has rugged relief with altitude ranging from 950 m to 1.000 m.

Individuals from *Cedrela fissilis* (11), *Croton floribundus* (29), *Machaerium villosum* (24), and *Machaerium nyctitans* (12) were selected for this study. These species and the number of individuals were selected based on their representative abundance and accessibility at the study site (OLIVEIRA, GARCIA, 2018). For the phenological study, the individuals of the tree species were visually monitored, with the aid of binoculars, monthly for 12 months. To identify the phenophases, field trips were made from November 2020 to October 2021, totaling twelve months of sampling. As vegetative phenophases, events related to leaf fall and leaf growth were monitored. Simultaneously, there was monitoring of the reproductive phenophases, flowering and fruiting, in the degree of flower development (floral bud and flowers in anthesis) and fruits (immature/mature). The Fournier Intensity categories were adopted to identify fluctuations between 100 %, 75 %, 50 %, 25 % and 0 % - in the presence and intensity of the vegetative and reproductive phenophases (FOURNIER, 1974).

As for the vegetative development, the stem was monitored with the aid of a measuring tape, with measurement of the circumference at breast height (CBH); from the CBH measurements, the basal areas were calculated, which allowed the computation of parameters of population dynamics linked to the increment and decrement in biomass. As for the increment in basal area, since this research did not predict the recruitment of new individuals, therefore, only the basal area accumulated over the time interval was considered for computing the rates. For this, population dynamics rates were obtained assuming changes in population sizes per time interval in constant proportion (SHEIL, BURSLEM, ALDER, 1995; SHEIL, MAY, 1996), according to the exponential expressions below:

$$P=\left\{1-\left[\frac{Ab_0\left(Ab_a+Ab_m\right)}{Ab_1}\right]^{\frac{1}{t}}\right\}\times 100$$

$$G=\left\{1-\left[1-\left(\frac{Ab_r+Ab_i}{Ab_1}\right)\right]^{\frac{1}{t}}\right\}\times 100$$

Where: t corresponds to the length of the time interval; Ab corresponds to the basal area, obtained for the community at t0 (Ab_0) and t1 (Ab_1), for the population of dead (Ab_m) and recruits (non-existent in this research, Ab_r) and for the basal area reduced by decrement (Ab_d) or raised per increment (Ab_i).

To evaluate associations between biological events and climate variables, with the help of the Agrometeorological Station present at Federal Institute of Southern Minas Gerais – Campus Muzambinho, temperature, precipitation and wind speed variables were obtained. These variables were filtered in time intervals of 30 days, to reconcile the climate record with the collection of phenological data, with special attention to the first set of climate data that must be related to the period of 30 days prior to the beginning of this research, seen the immediate non-reaction of plants to environmental changes.

For each species, the quantification of individuals with leaf fall and production, flowering and fruiting was analyzed in detail, correlating these phenological events with previously mentioned climatic variables, such as temperature, rainfall and relative humidity, using Spearman's Correlations, a robust statistical approach widely used to measure monotonic associations between variables (ZAR, 2010). The correlation tests were carried out using Past 4.03 software, a renowned tool for analyzing ecological and paleontological data, which enables precise and reliable results to be obtained. The results of the analyses were organized into tables to facilitate interpretation and comparison between phenological events and climatic variables.

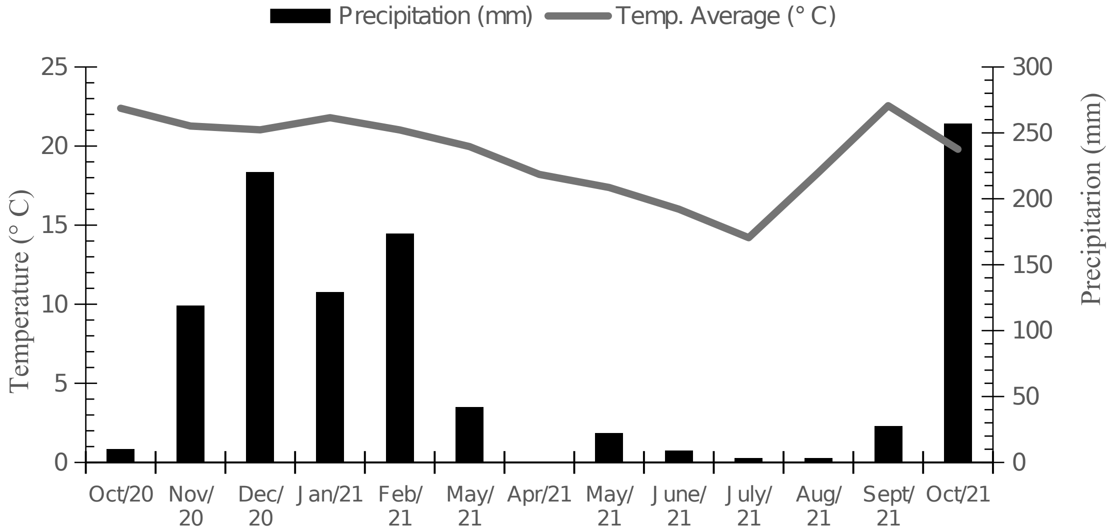
In addition, linear graphs representing the climatic data on temperature and rainfall over the study period were elaborated, offering a clear visualization of the seasonal oscillations. Circular graphs were also drawn up of the phenological data of each species analyzed, an effective methodology for representing temporal cycles. In this format, each interval between the radii of the circle symbolizes the interval between collections, highlighting seasonal phenological patterns and allowing a visual analysis of temporal variations in phenological events. These graphic resources, combined with statistical analyses, provide an integrated understanding of the interactions between climatic factors and phenological behavior in the species studied.

Results

During the phenological observations (November 2020 to October 2021) the average temperature in the municipality of Muzambinho-MG ranged between 14 and 22 ºC. The hottest months were October 2020 and September 2021. In terms of precipitation, December 2020 and October 2021 were the months with the highest precipitation rates (Figure 1).

The vegetative phenophases were present in the four studied species. The reproductive phenophases were not present in all species, being totally absent in *M. villosum*, partial in *M. nyctitans* and *C. fissilis*, and complete in *C. floribundus*. There was no significant

Figure 1. Monthly precipitation and temperature in the municipality of Muzambinho-MG between October 2020 and October 2021.



Source: authors (2021)

correlation between leaf growth with humidity and precipitation in *C. floribundus*, *M. nyctitans* and *M. villosum*, whereas the species *C. fissilis* had a correlation between leaf growth, the increase in mean wind speeds and the decrease of humidity (Table 1). Leaf fall had a negative correlation with humidity and precipitation, where the decrease in the rate of precipitation and humidity influenced the increase in leaf fall in the studied species. Wind speed and temperature also correlated with leaf fall, with an increase in average wind speeds and a decrease in temperature influencing the increase in leaf fall (Table 1).

The increment and decrement of biomass in the individuals had correlation only for the species *C. fissilis*, in which the loss (ρ = -0.48, p = 0.04) and gain (ρ = -0.48, p = 0.04) had a negative correlation with precipitation, with some individuals losing biomass and others gaining it during the same period with low precipitation.

Fruit production and the progression of fruiting in the species *C. floribundus* was correlated with humidity and wind speed, with the period of increase in air humidity and decrease in average wind speeds correlated with fruit development, its maturation and dispersion. In the species *C. fissilis*, the development of immature fruits had a positive correlation with the increase in humidity and a decrease in average wind speeds, while the maturation of fruits in this species had a positive correlation with a decrease in humidity and an increase in average wind speeds. Lastly, in the specie *M. nyctitans*, fruit maturation had a significant correlation with the decrease in rainfall (Table 1).

Leaf fall occurred in the four species during months with low precipitation, temperature and humidity. However, the progression of this event was different in the species. In the species *C. fissilis,* it occurred between April and August with peak intensity in August. In *C. floribundus,* it occurred throughout the sampling period but with marked intensity between May and October, with a peak in September. For *M. nyctitans*, the fall was absent only in March, and had a high intensity between May and September, peaking in August. In *M. villosum*, leaf fall started in July, peaked in the first half of August and lasted until the beginning of October (Figure 2).

Table 1. Spearman correlation (rs) between climatic variables and phenophases of tree species in the study region at Federal Institute of Southern Minas Gerais – Campus Muzambinho, in Muzambinho, southern Minas Gerais.

Species	Phenofases	Temperature (°C)	Precipitation (mm)	Air Humidity	Wind Speed
Cedrela fissilis	Leaf fall	-0.79 (p < 0.01)	-0.52 (p = 0.02)	-0.20 (p < 0.01)	
	Leaf Growth			-0.53 (p < 0.01)	0.49 (p = 0.03)
	Immature fruits			0.5 (p = 0.02)	-0.55 (p = 0.01)
	Ripe Fruits			-0.51 (p = 0.02)	0.56 (p = 0.01)
Croton floribundus	Leaf fall		-0.54 (p = 0.01)	-0.69 (p < 0.01)	0.56 (p = 0.01)
	Leaf Growth		0.55 (p = 0.01)	0.50 (p = 0.03)	
	Immature fruits		0.57 (p = 0.01)	0.49 (p = 0.03)	-0.48 (p = 0.04)
	Ripe fruits		0.53 (p = 0.02)	0.71 (p < 0.01)	-0.53 (p = 0.02)
Machaerium nyctitans	Leaf fall	-0.52 (p = 0.02)	-0.74 (p < 0.01)	-0.68 (p < 0.01)	0.53 (p = 0.02)
	Ripe fruits		-0.54 (p = 0.01)		
Machaerium villosum	Leaf fall		-0.46 (p = 0.05)	-0.63 (p < 0.01)	0.70 (p < 0.01)

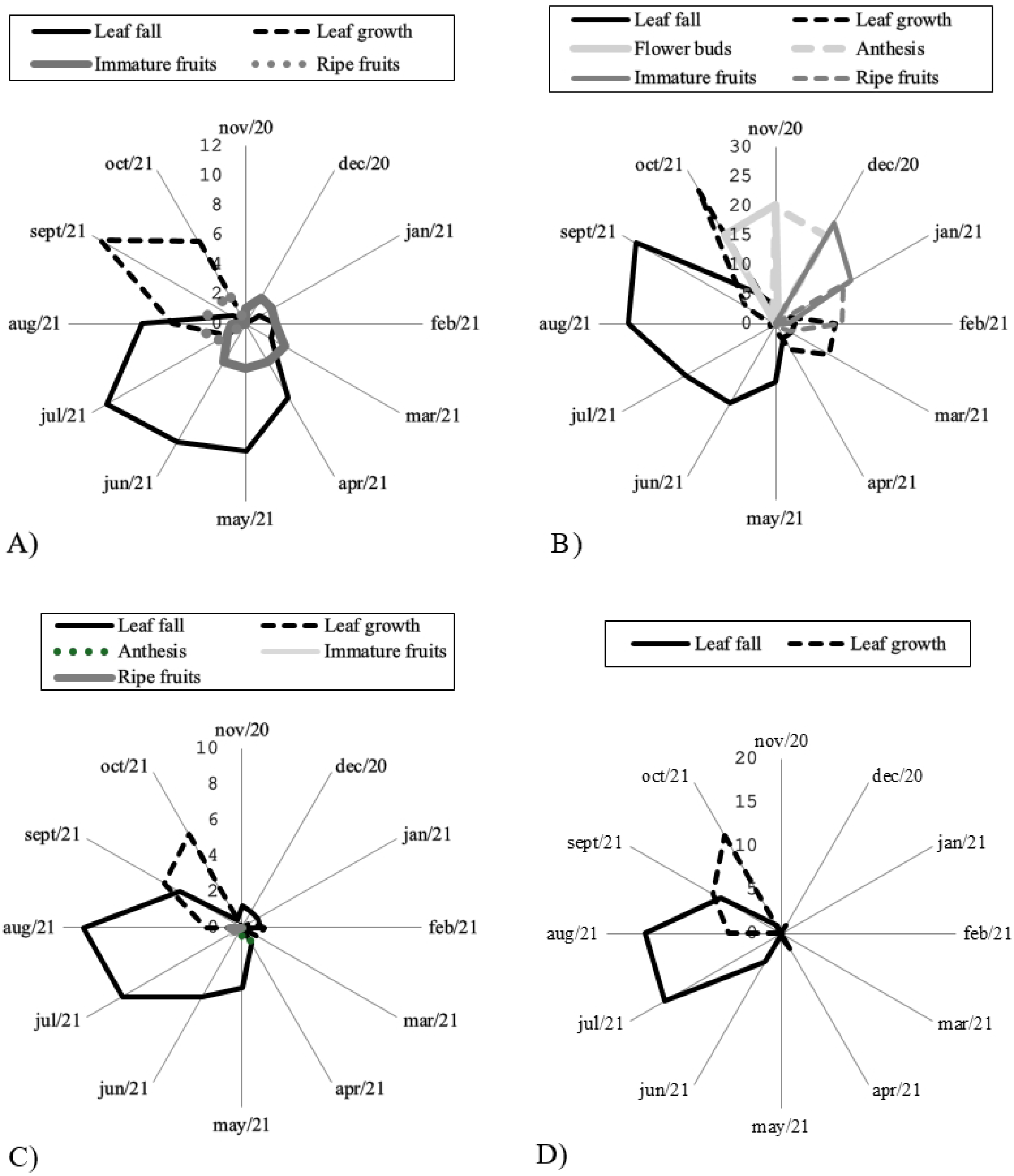
Source: authors (2021)

Leaf growth occurred during the months of the rainy season, with high humidity and low wind speeds, whereas the individuals of *C. fissilis* had their leaf growth during the final months of the dry season beginning in the second half of August, with a peak in at the end of September lasting until October. For the species *C. floribundus*, leaf growth occurred from February to May at medium intensity, and again in October with peak intensity. For *M. nyctitans*, leaf growth was present between January and March at low intensity and then started again in August with greater intensity, with equivalent peaks in the first half of September and later, in the first week of October. In *M. villosum* leaf growth started in the second half of August, peaked in the first half of October, decreasing in intensity at the end of October (Figure 2).

Flowering was present at high intensity in individuals of the species *C. floribundus* during the months of the rainy season, whereas in the species *M. nycitans* it had low intensity with only one individual flowering at the end of the rainy season and the beginning of the dry season in April. In *C. floribundus*, the production of flower buds already started with a peak of intensity in November and lasted the whole month, the anthesis of the flowers started in the second half of November with a peak, lasting until December (Figure 2).

Fruiting occurred in distinct periods and progressions in the three species that presented this phenophase. In *C. fissilis*, fruiting occurred for almost the entire monitoring period, starting in November with immature fruits until July, with the peak intensity of presence of immature fruits in March. Fruit maturation and seed dispersal in individuals of the species occurred from the second half of July to October, with a peak of intensity in August. In *C. floribundus*, immature fruits were present in December, already at their peak, lasting until February, and fruit maturation began in January, peaking in the second half of that month, lasting until March. Fruiting in only one individual of *M. nyctitans* began in May and in July fruit maturation occurred (Figure 2).

Figure 2. Fournier Intensity from Nov/2020 to Oct/2021. A) *C. fissilis*; B) *C. floribundus*; C) *M. nyctitans*; D) *M. villosum*.



Source: authors (2021)

Discussion

The studied phenophases had correlations with the climatic variables, indicating that the period and intensity of expression of vegetative and reproductive behaviors were influenced by the variation in climate marked by double seasonality in the study region (APARECIDO, SOUZA, 2021). The correlations found, as well as studies that investigate the influence of climate oscillations on the behavioral responses that plants present, allow the better understanding how these relationships shaped the evolution of behavioral strategies in plants in their habitats, and investigate through this how these behaviors and relationships may be affected by climate change (MORELLATO *et al*., 2016).

In the semideciduous forest, where there is low precipitation, humidity and temperature during the dry season correspond to the period of greater intensity of leaf fall (MORELLATO *et al*., 1989). As found in this study, leaf fall was influenced by dehydration provided by dry winds and water deficit due to low precipitation during the cold and dry season months. In forest ecosystems, such as those included in the Atlantic Forest domain, where the soils are chemically poor, litter constitutes the main nutrient supply route through the decomposition of organic matter that is deposited on the soil surface (CÂMARA, 2020). The leaf fall presented during the monitoring period in this research indicates that the greatest contribution to the supply of litter with leaf deposition occurred during the dry season.

In species with anemochoric dispersal syndrome, such as *C. fissilis*, *M. nyctitans* and *M. villosum*, leaf fall is possibly associated with increased evolutionary success in seed and fruit dispersal (NOVAES *et al*., 2020). Therefore, the defoliation of the canopy allows the wind to pass freely through the treetops, increasing the dispersion radius. Especially the species *C. fissilis*, which started fruit opening and seed dispersal after the peak of leaf fall, with fruit opening correlated with the increase in wind speed in the study region, increasing dispersion by anemochory.

Leaf growth of individuals of the species *C. fissilis* occurred in the last months of the dry season, correlated with water deficit, low humidity and high wind speed. This may be related to the ecology of the species, which despite external conditions, expresses its leaf growth behavior shortly after dispersal, since the end of a phenophase may be intrinsically linked to the beginning of the next, given the biological and ecological dependence between them (LIUTH, TALORA, AMORIM, 2013). Furthermore, there are also possible indications for the species that the conditions and resources of the rainy season will come after this season.

The species *C. floribundus* flourished in the rainy season in synchrony among the individuals monitored. Synchronous reproduction between individuals of a species allows cross-pollination between them, increasing the genetic variability of the population's descendants (BOGDZIEWICZ *et al*., 2020). Pollination of this species is carried out mainly by anemophilia and myophily. However, during the rainy season, wind rates were lower than during the dry season in the study region. Therefore, myophilia is possibly enhanced in the rainy season, because although the abundance of some dipteran and insect species has a low correlation with seasonal change in forest environments, the greatest activity of these organisms occurs during the rainy season (FERRAZ, GADELHA, AGUIAR-COELHO, 2010); since the activity of insects is regulated by physiological factors, which in turn are largely affected by the environment (NASCIMENTO; NASCIMENTO, 2012). As it is the case of some species, which significantly reduce their flight and foraging activity when exposed to a rate of less than 40 % of relative humidity (FERRAZ, GADELHA, AGUIAR-COELHO, 2010).

Fruiting by autochory after flowering in *C. floribundus* caused dispersion during the rainy season, in which the climatic conditions of that season may represent the ideal conditions for seed germination and recruitment of young individuals, in view of the availability of resources in this period (PENHALBER, MANTOVANI, 1997). In addition, fruit dispersal during the rainy season possibly enhances the secondary dispersal of this species by ant genera that are more active in this season (FAGUNDES *et al*., 2009).

On the other hand, the species *M. nyctitans* and *M. villosum*, which, respectively, did not have significant representation in reproduction, and did not develop reproductive behavior, may represent a reproductive variation that has a supra-annual character, considering that adult individuals capable of reproduce were monitored. This possible reproduction strategy allows these species to deal with environmental variability and maximize their chances of reproduction in different conditions, as well as allowing the allocation of resources for vegetative growth (KUMARI, HAMAL,, SHARMA, 2020).

However, species with supra-annual patterns require monitoring over a longer period of time so that species patterns can be described and understood. Individuals of the *C. fissilis* species had biomass loss and gain correlated negatively with precipitation, a factor that influenced both the gain of some individuals and the loss of biomass of others, which may be related to the different intensities of water deficit linked to the edaphic variations and topographical attributes in the soil of the studied forest fragment (STAHL *et al*., 2013). Another possible alternative to biomass loss during the wet season may be associated with the reallocation of resources from the trunk to reproduction, taking into account flowering and the long period of fruit formation. The gain during the dry season may be associated with the interruption of evapotranspiration due to leaf loss, as well as the no need to keep the fruits already dispersed (LUNDGREN, DES MARAIS, 2020).

Although significant relationships between biomass loss and gain were not found among other species, long-term studies on the interplay between climate and biomass dynamics are increasingly relevant in the context of climate change. Such studies provide critical insights into species' strategies for resource allocation and adaptation to seasonal climate variations. Additionally, they contribute to understanding carbon stock dynamics, which could significantly impact the balance and rates of carbon fluxes.

Conclusion

Phenological events, such as budding and leaf fall, as well as reproductive behavior, reflect specific adaptations to environmental conditions, highlighting the role of the rainy and dry seasons in regulating these biological processes. This understanding reinforces the intricate relationship between seasonal cycles and species adaptations, contributing to a deeper comprehension of the autoecology and population dynamics of these species. By elucidating these processes, the study provides knowledge for the conservation of biodiversity in the Atlantic Forest biome.

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