INTERANNUAL VARIATION IN THE PHENOLOGICAL BEHAVIOR OF TWO NATIVE TREE SPECIES IN ALLUVIAL FOREST

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Resumo

Variação interanual no comportamento fenológico de duas espécies arbóreas nativas em floresta aluvial. Foi avaliado o comportamento fenológico vegetativo (folha senescente, folha madura e brotação) e reprodutivo (botão, antese, fruto imaturo e maduro) durante 5 anos de Gymnanthes klotzschiana (Euphorbiaceae) Blepharocalyx salicifolius (Myrtaceae), em um fragmento de Floresta Ombrófila Mista Aluvial no Sul do Brasil, pelo índice de intensidade, buscando responder: (i) Os eventos fenológicos seguem um padrão anual ou há variação ao longo do período? (ii) Quais variáveis meteorológicas, entre temperaturas (mínimas, médias e máximas) e precipitação, influenciam nas fenofases? Os dados fenológicos foram correlacionados com as variáveis meteorológicas de precipitação, temperatura mínima, média e máxima do período do estudo. Foram detectadas variações da intensidade das fenofases entre os anos analisados. Correlações com as temperaturas foram identificadas para algumas fenofases durante o período de estudo. As espécies apresentaram comportamento fenológico semelhante nas fenofases vegetativas, porém foram detectadas variações na intensidade das fenofases entre os anos analisados, podendo ser respostas das variações anuais de temperatura e precipitação. Com os dados de correlações obtidos entre as fenofases e as variáveis meteorológicas, foi possível concluir que diferentes sinais meteorológicos são sentidos pelas plantas para expressar suas fenofases. Ao que tudo indica, há uma tendência de a temperatura ser um importante fator que regula a fenologia das plantas, mas que o período de monitoramento também influencia esses fatores.
Palavras-chave: temperatura; mudanças climáticas; precipitação.

Abstract

The vegetative (senescent leaf, mature leaf and budding) and reproductive (bud, anthesis, unripe fruit and ripe fruit) phenological behavior of *Gymnanthes klotzschiana* (Euphorbiaceae) and *Blepharocalyx salicifolius* (Myrtaceae) were evaluated for 5 years in a fragment of Alluvial Mixed Ombrophilous Forest in southern Brazil, by the intensity index, seeking to answer the following questions: (i) Do phenological events follow an annual pattern or is there variation over the period? (ii) Which meteorological variables, among temperatures (minimum, mean and maximum) and precipitation, influence the phenophases? Phenological data were correlated with precipitation and minimum, mean and maximum temperatures of the study period. Variations in the intensity of the phenophases were detected between the years analyzed. Correlations with temperatures were identified for some phenophases during the study period. The species showed similar phenological behavior in vegetative phenophases, but variations in the intensity of the phenophases were detected between the years analyzed, which may be responses to annual temperature and precipitation variations. With the obtained data of correlation between the phenophases and the meteorological variables, it was possible to conclude that different meteorological signals are felt by the plants to express their phenophases. It seems that there is a tendency for temperatures to be an important factor that regulates plant phenology, but that the monitoring period may also influence these factors.
Keywords: temperature, climate change, precipitation.

INTRODUCTION

The interest for phenological patterns in the world has intensified in recent years, partly due to the global climate change scenario (IPCC, 2014), associated with the fact that phenology has become an important tool to assess possible climate change (JOCHNER, 2016; MORELLATO *et al.*, 2016) and for being an important record of the evolutionary history of many species (STAGGEMEIER *et al.*, 2015). Phenology can be understood as the key process that can link climate change to the persistence of populations and the composition of communities (VISSER, 2010; FU YONGSHUO H., 2018).

The factors that influence the phenological behavior of the species are widely known in the Northern Hemisphere, especially regulated by photoperiod and temperature, whereas in tropical regions, the seasonal variation of precipitation has been indicated as the main trigger for the phenological behavior of the species (GONÇALVES *et al.*, 2018)

In subtropical regions, phenology is not fully understood because these regions do not have a marked climatic seasonality, with no periods of water deficit, and sometimes the photoperiod (BORCHERT *et al*., 2005; MARQUES *et al*., 2004) or small changes in temperature are the inducers of phenological behavior.

Some species shape their phenology to ensure their permanence in a given ecosystem, so that the calendar of their life cycle is synchronized with the climate (ALBERTO *et al*., 2013). Predictive annual cues (photoperiod) and social cues (abundance of food and precipitation) are conditions that allow good adjustment of phenophases for the appropriate time, in a given place and for each season (VISSER *et al*., 2010).

Therefore, long-term studies with repeated evaluations in individuals over several years may reveal heterogeneity and specific responses to the climate. However, some individuals may be more plastic than others in their phenology. Regarding the duration of phenological studies in tropical forests, it is important to point out that the sampling effort in studies of this nature, which address at least reproductive phenology, is generally low, as they last two years or less – studies of less than two years correspond to more than 72% of all the phenological studies conducted (MENDOZA *et al.*, 2016).

However, studies with longer periods of observations can help to better understand variations in phenological behavior over the years and identify what are the real climatic signals detected by plants. In Brazil, only three studies were conducted with duration of 10 years or close to this: Alencar *et al.* (1979) in the Amazon Forest, from 1965 to the present; Morelatto *et al.* (2013) in the Cerrado in Itirapina, São Paulo, from 2004 to the present; and a study already completed by Engel and Martins (2005), from 1982 to 1992, in Espírito Santo.

Also, understanding how alluvial vegetation, partly within Permanent Preservation Areas (PPA) currently protected by law, plays a very important role for the preservation of these ecosystems. Therefore, further studies on the ecological aspects of riparian vegetation are needed to establish environmental conservation strategies, as they will benefit future generations, and phenology is a key point, especially of species such as *Gymnanthes klotzschiana* Müll.Arg and *Blepharocalyx salicifolius* (Kunth) O. Berg, which are indicator species of these environments.

G. klotzschiana, popularly known in Portuguese as “branquilho”, is almost exclusive to the alluvial plains of southern Brazil, where it often becomes the dominant species, forming about 60 to 80% of the continuous stratum of canopy of these formations (REITZ, 1988; BARBIERI; HAIDEN, 2009). Its morphological description refers to a tree 10 to 15 meters tall, with simple alternate, discolor, elliptical-lanceolate leaves, which fall in winter (BARDDAL *et al*., 2004). Its flowers are hermaphrodite, gathered in ears, and its fruits are capsules of loculicidal dehiscence that explode when ripe, expelling the seeds, in a type of dispersal called ballistic. *B. salicifolius* is very abundant mainly in gallery forests, as well as in pine tree sub-forests, and is found in moist and compact soils, of gentle slopes and very slow drainage, as well as in depressions (REITZ, 1988). It grows in various environments or stages of vegetation, from open grasslands to forests with developed understory, being particularly frequent in moist soils of riparian forests (DENARDI, 2005). According to its morphological description, it is a tree 15 to 20 meters tall, with diameter of 20-40 cm, trunk usually rectilinear and cylindrical, with thick bark and cracks in the longitudinal direction of dark brown color; it has simple and opposite leaves, small and white flowers, with numerous stamens; its fruits are orange when ripe (REITZ, 1988).

In this context, this study aimed to evaluate the phenological behavior of two native tree species in a fragment of Alluvial Mixed Ombrophilous Forest, over 60 months, to answer the following questions: (i) Do phenological events follow an annual pattern or is there variation over the period? (ii) Which meteorological variables, among temperatures (minimum, mean and maximum) and precipitation, influence phenophases?

MATERIAL AND METHODS

Study area

This study was conducted in a forest fragment of approximately 9 ha, located in the municipality of Araucária, Paraná, Brazil, between the geographic coordinates 25º34'02.5" S and 49º20'53.5" W and at an altitude of 920 m. Its vegetation is a remnant of Alluvial Mixed Ombrophilous Forest, belonging to the Atlantic Forest biome. The study area has soil of alluvial-colluvial origin, formed by sediments of fine particles, called *Gleissolo Háplico* (Entisol) (BARDDAL *et al.*, 2004). Soils with this constitution are considered poorly drained or very poorly drained under natural conditions (EMBRAPA, 2012).

Collection of phenological data

Every month, 12 individuals of *Gymnanthes klotzschiana* and 10 individuals of *Blepharocalyx salicifolius*, indicator species of alluvial environments, the former a pioneer and the latter a late secondary, were monitored. The number of monitored individuals met the premise of Fournier and Charpantier (1975), who suggested sampling between five and ten individuals, thus considering a good sampling size for each species in phenological studies. The monitored trees are located inside permanent plots in the study area. Vegetative (mature leaf, senescent leaf and budding) and reproductive (bud, anthesis, unripe fruit and ripe fruit) phenophases were monitored. Data collection consisted of using the Intensity Scale proposed by Milani (2013), which ranges from 0 to 100%, where (0) absence, (1) 1% to 25%, (2) 26% to 50% and (3) 51% to 100 (%), observing vegetative and reproductive phenophases. Phenological observations were carried out from July 2011 to August 2016. In the survey period, the two species were collected and registered in EFC herbarium under number *Gymnanthes klotzschiana* Müll.Arg. EFC 12129 and *Blepharocalyx salicifolius* (Kunth) O.Berg. 10732 EFC

Weather information

The average annual precipitation is 1,407 mm and the average temperature is 16.4 ºC, according to data from the climatological normal of 1960-1991, available at the Climatological Database of Brazil. For verification and updating of these data, the database of INMET (National Institute of Meteorology) was consulted.

During the study period, from 2011 to 2016, the average annual precipitation, considering the period between August and July of each year, was 1,629.6 mm in 2011-2012, 1,555.8 mm in 2012-2013, 1,414.2 mm in 2013-2014, 1,537.4 mm in 2014-2015 and 2035.8 mm in 2015-2016, the latter being an atypical year, with precipitation 480 mm above the average of the last 30 years. The monthly averages of minimum, mean and maximum temperatures showed variations of approximately 1 ºC over the five years studied. The lowest average temperatures were observed in June 2016 (6.9 ºC) and July 2013 (7.9 ºC). The highest average temperatures were recorded in January 2014 and January 2015, 29.8 and 29.6 ºC, respectively, according to data obtained from the meteorological station of the Paraná Environmental Technology and Monitoring System - SIMEPAR, 35 km away from the study area (Figure 1 and Table 1).

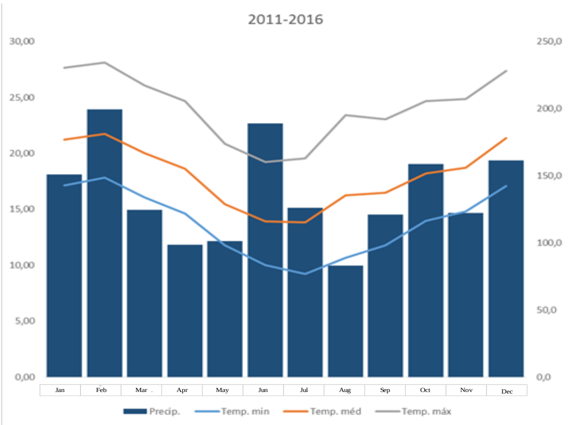


Figure 1. Precipitation and temperatures, along the period from August/2010 to July/2016 for the region of Curitiba. Source: SIMEPAR (2017).

Figura 1. Precipitação e temperaturas, durante o período de agosto/2010 a julho/2016 para a região de Curitiba. Fonte: SIMEPAR (2017).

Table 1. Data of meteorological variables for the study period.

Tabela 1. Dados das variáveis meteorológicas para o período de estudo.

Year	Precipitation (mm/year)	Minimum temperature (ºC)	Mean temperature (ºC)	Maximum temperature (ºC)
2011-12	1,629.6	8.78	17.31	29.40
2012-13	1,555.8	7.93	17.91	28.85
2013-14	1,414.2	8.60	18.04	29.80
2014-15	1,537.4	9.50	18.18	29.60
2015-16	2,035.8	6.95	18.46	28.09
Mean	**1633,6**	**13.7**	**17.97**	**24.12**

Source: the author (2017).

Data analysis

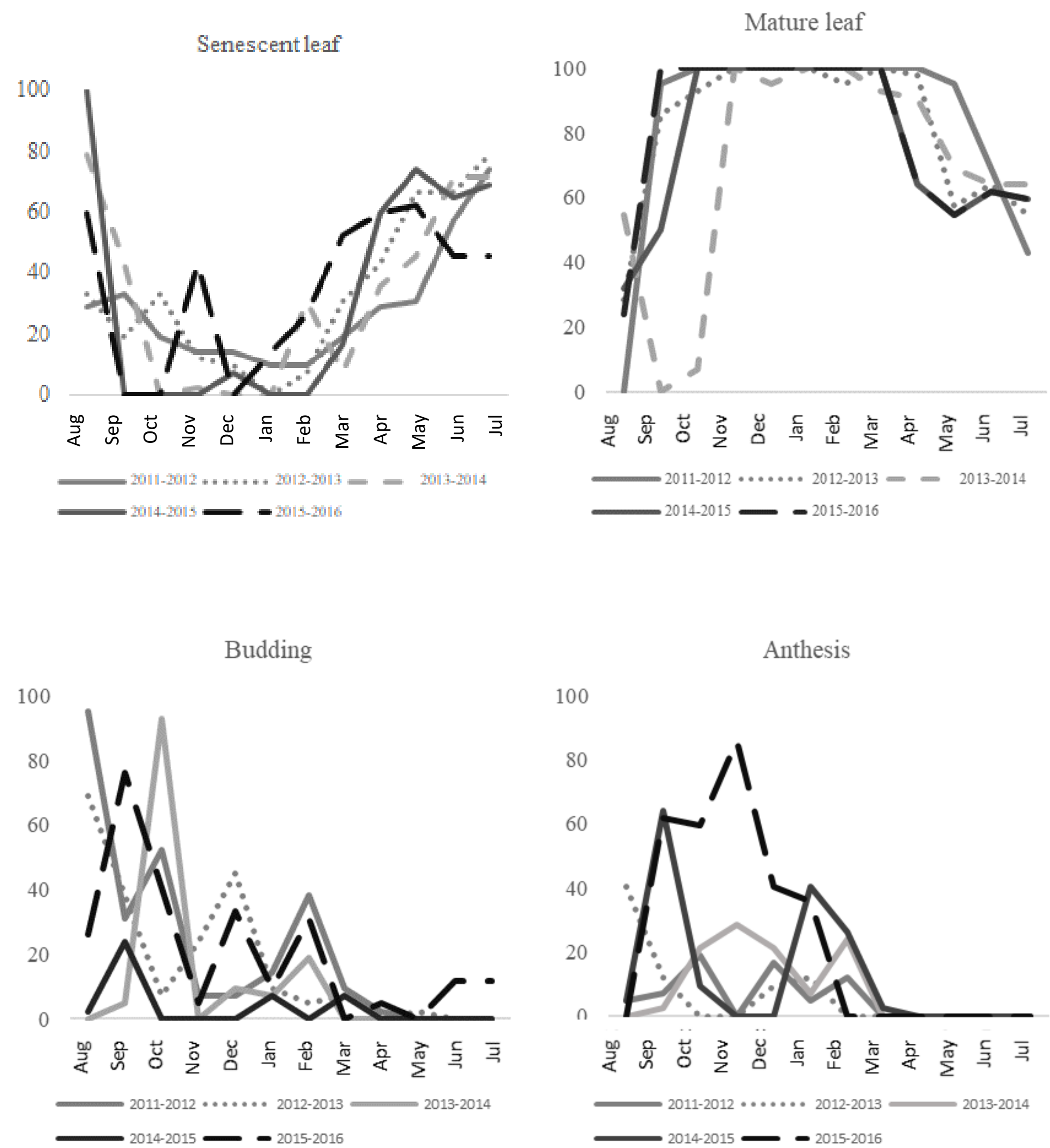
Spearman's coefficient at significance level of $p < 0.005$ was used to verify which meteorological variables most influence the phenological events. Correlations of phenophases with the variables from August 2010 to August 2016 were tested. Correlation analyses were performed using Statgraphics software.

RESULTS

The species responded differently over the period (Figure 2 and Figure 3). *G. klotzschiana* had a phenological behavior with greater variation, while *B. salicifolius* showed a more regular behavior of its phenophases.

The phenophases that varied the most in *G. klotzschiana* were anthesis and unripe fruit, and mature leaf was the phenophase with the lowest variation. For *B. salicifolius*, variations were detected in budding and anthesis phenophases, and fruiting was almost perfectly regular over the period. Both species renewed their leaves during the year, but in *G. klotzschiana* this renewal lasted longer, about six months.

Fruiting phenophases followed the trend observed for flowering. The fruiting period was longer in *G. klotzschiana*, resulting from the also longer flowering. In the five years analyzed, the most discrepant variation was the low intensity of phenophases in the 2012-2013 period.



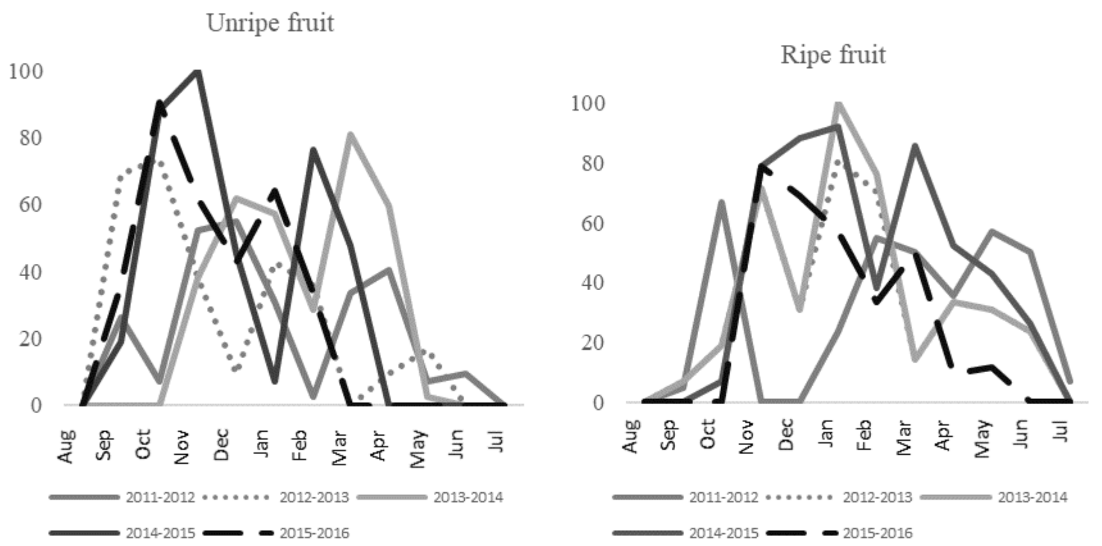
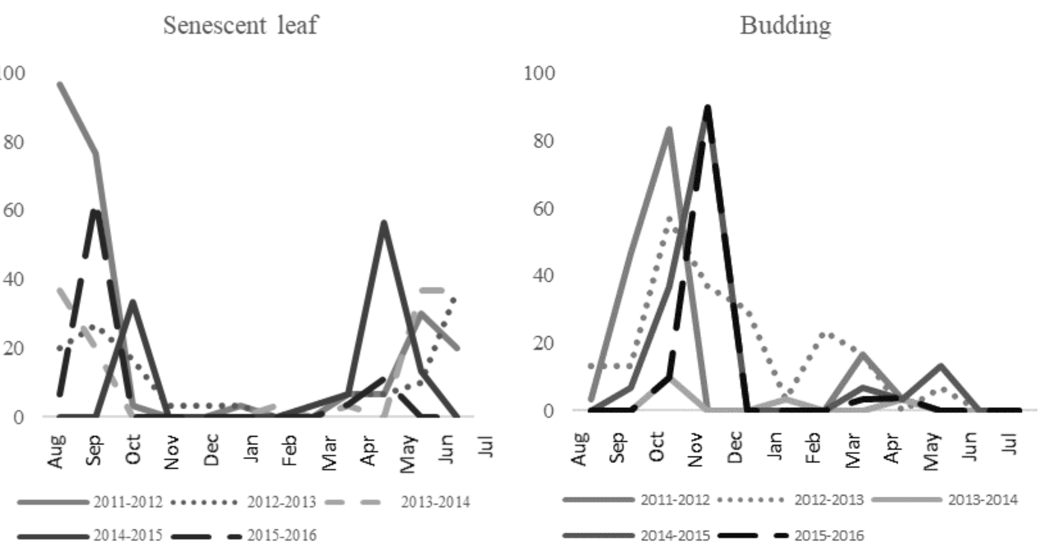


Figura 2. Comportamento fenológico anual de G*ymnanthes klotzschiana* em fragmento de Floresta Ombrófila Mista Aluvial.

Figure 2. Annual phenological behavior of *Gymnanthes klotzschiana* in a fragment of Alluvial Mixed Ombrophilous Forest.

Source: the author (2017).



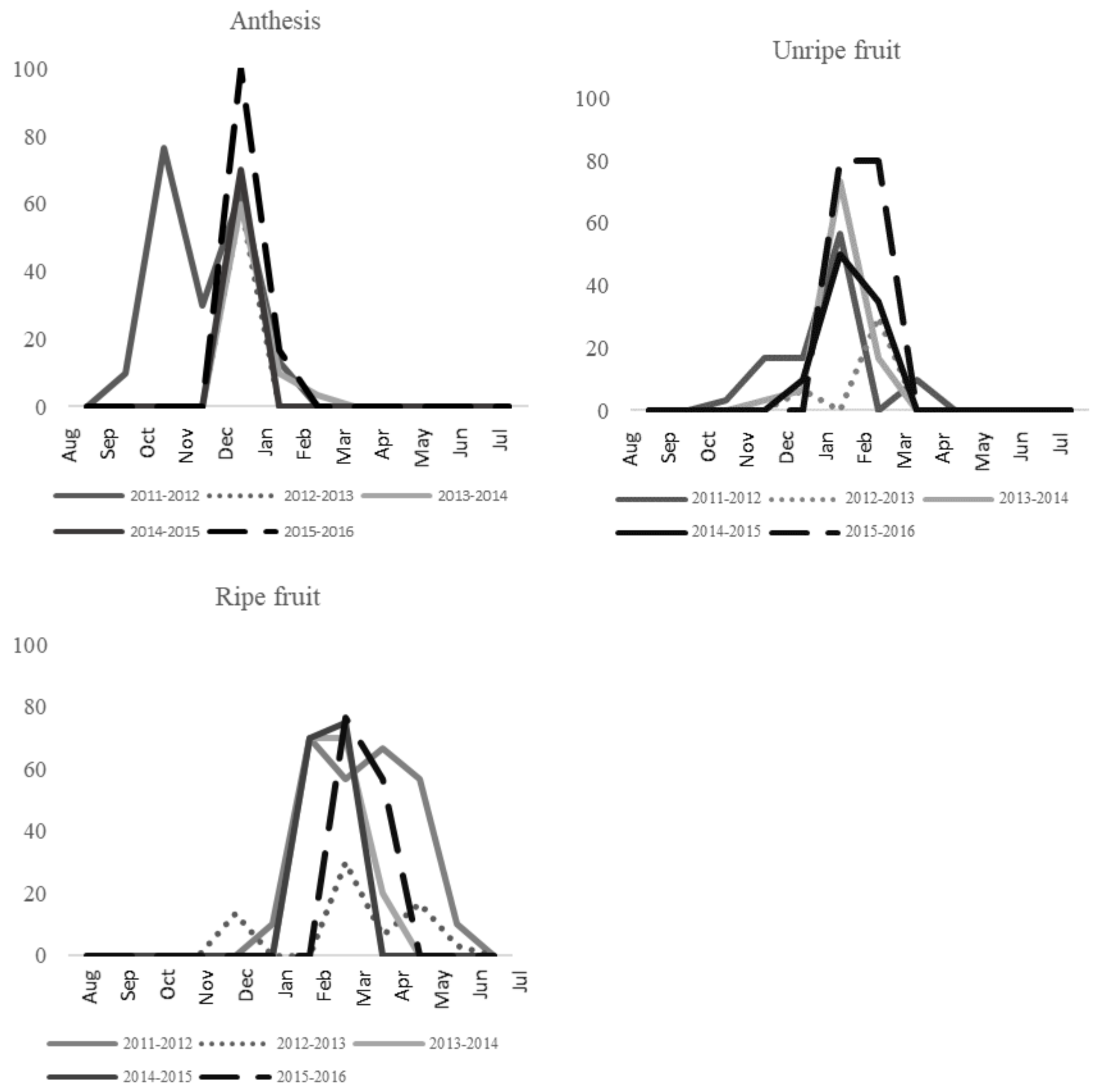


Figure 3. Annual phenological behavior of *Blepharocalyx salicifolius* in an Alluvial Mixed Ombrophilous Forest fragment.

Figura 3. Comportamento fenológico anual de *Blepharocalyx salicifolius* em fragmento de Floresta Ombrófila Mista Aluvial.

The correlations of meteorological variables with phenophases indicated a similar significant effect of the tested variables on the two species during the period from 2011 to 2016 (TABLE 2). During this period, no correlations with precipitation were detected for any of the species.

Table 2. Spearman's correlation between environmental variables and phenophases of the species monitored between August 2011 and July 2016: Tmin (minimum temperature), Tmean (mean temperature) Tmax (maximum temperature) and P (precipitation).

Tabela 2. Correlação de Spearman entre as variáveis ambientais e as fenofases das espécies monitoradas entre agosto de 2011 a julho de 2016: Tmin (temperatura mínima), Tmean (temperatura média) Tmax (temperatura máxima) e P (precipitação).

Phenophase	**Tmin (ºC)**	**Tmean (ºC)**	**Tmax (ºC)**	**P (mm)**
Gymnanthes klotzschiana				
Mature leaf	0.7484	0.7196	0.6767	*Ns*
Senescent leaf	-0.6624	-0.6866	-0.6680	*Ns*
Budding	N*s*	*Ns*	*Ns*	*Ns*
Anthesis	0.3639	0.3827	0.3676	*Ns*
Unripe fruit	0.6003	0.5858	0.5662	*Ns*
Ripe fruit	0.6040	0.5413	0.4676	*Ns*
Blepharocalyx salicifolius				
Mature leaf	0.4310	0.4150	0.3832	*Ns*
Senescent leaf	-0.5676	-0.5473	-0.4799	*Ns*
Budding	*Ns*	*Ns*	*Ns*	*Ns*
Anthesis	0.4133	0.4362	0.4264	*Ns*
Unripe fruit	0.4554	0.4536	0.4642	*Ns*
Ripe fruit	0.2569	N*s*	N*s*	*Ns*

Source: the author (2017).
Note: n sample: (60). assuming a significance probability of 95%.

The forces of associations between the species and the phenophases were moderate to strong for the phenophases mature leaf and senescent leaf in *G. klotzschiana.* For *B. salicifolius*, the same phenophases had lower correlation values. In both species, no correlations of budding with the meteorological variables were detected. The ripe fruit phenophase of *B. salicifolius* was correlated only with minimum temperature, unlike *G. klotzschiana*, whose ripe fruit phenophase was also correlated with mean and maximum temperatures.

When analyzed separately, differences in correlation values were verified in each year of the study. Correlations with precipitation were detected when the years were analyzed individually. The phenophases mature leaf, senescent leaf and unripe fruit were correlated with this variable in the year 2015-2016 for *G. Klotzschiana*. Also for this species, the minimum temperatures were not correlated with budding and anthesis, but showed correlations with other phenophases, especially between the years 2013 and 2016. Mean and maximum temperatures showed correlations with similar values and years (TABLE 3).

Tabela 3. Resultados da correlação de Spearman para as fenofases vegetativas e reprodutivas de *Gymnanthes klotzschiana*.

Table 3. Spearman's correlation results for the vegetative and reproductive phenophases of *Gymnanthes klotzschiana*.

	Gymnanthes klotzschiana				
	Period	**Tmin (ºC)**	**Tmean (ºC)**	**Tmax (ºC)**	**P (mm)**
Mature leaf	2011-2012	*Ns*	*Ns*	*Ns*	*Ns*
	2012-2013	*Ns*	*Ns*	*Ns*	*Ns*
	2013-2014	0.8184	0.8113	0.7655	*Ns*
	2014-2015	0.7798	0.7876	0.7954	*Ns*
	2015-2016	0.8486	0.7845	*Ns*	0.7060
Senescent leaf	2011-2012	*Ns*	*Ns*	*Ns*	*Ns*
	2012-2013	*Ns*	*Ns*	*Ns*	*Ns*
	2013-2014	-0.7619	-0.8184	-0.8148	*Ns*
	2014-2015	-0.6816	-0.7034	-0.7686	*Ns*
	2015-2016	*Ns*	*Ns*	*Ns*	-0.7244

Budding	2011-2012	*Ns*	*Ns*	*Ns*	*Ns*
	2012-2013	*Ns*	*Ns*	*Ns*	*Ns*
	2013-2014	*Ns*	*Ns*	*Ns*	*Ns*
	2014-2015	*Ns*	*Ns*	*Ns*	*Ns*
	2015-2016	*Ns*	*Ns*	*Ns*	*Ns*
Anthesis	2011-2012	*Ns*	*Ns*	*Ns*	*Ns*
	2012-2013	*Ns*	*Ns*	*Ns*	*Ns*
	2013-2014	*Ns*	0.6021	*Ns*	*Ns*
	2014-2015	*Ns*	*Ns*	*Ns*	*Ns*
	2015-2016	*Ns*	*Ns*	*Ns*	*Ns*
Unripe fruit	2011-2012	*Ns*	*Ns*	*Ns*	*Ns*
	2012-2013	*Ns*	*Ns*	*Ns*	*Ns*
	2013-2014	0.7831	0.7831	0.7614	*Ns*
	2014-2015	0.6163	0.6671	0.7034	*Ns*
	2015-2016	*Ns*	*Ns*	*Ns*	0.7726
Ripe fruit	2011-2012	*Ns*	*Ns*	*Ns*	*Ns*
	2012-2013	*Ns*	*Ns*	*Ns*	*Ns*
	2013-2014	0.6494	0.6270	0.5934	*Ns*
	2014-2015	0.6902	0.6338	0.5986	*Ns*
	2015-2016	0.7976	0.7106	*Ns*	*Ns*

Source: the author (2017).

For *B. salicifolius*, a smaller number of correlations was identified between the years individually, and the mature leaf phenophase was correlated only with the temperatures of the year 2012-2013. With regard to vegetative phenology, senescent leaf was the phenophase in which correlations were detected in three consecutive years – this phenophase was the only one to show correlation with precipitation, exclusively in 2014-2015 (Table 4).

Tabela 4. Resultados da correlação de Spearman para as fenofases vegetativas e reprodutivas de *Blepharocalyx salicifolius*.

Table 4. Spearman's correlation results for vegetative and reproductive phenophases of *Blepharocalyx salicifolius*.

	Blepharocalyx salicifolius				
	Period	**Tmin (ºC)**	**Tmean (ºC)**	**Tmax (ºC)**	**P (mm)**
Mature leaf	2011-2012	Ns	Ns	Ns	Ns
	2012-2013	Ns	Ns	Ns	Ns
	2013-2014	0.7644	0.7195	0.6970	Ns
	2014-2015	Ns	Ns	Ns	Ns
	2015-2016	Ns	Ns	0.7186	Ns
Senescent leaf	2011-2012	-0.8216	-0.8216	-0.7716	Ns
	2012-2013	-0.8593	-0.7809	-0.6704	Ns
	2013-2014	-0.6409	-0.7163	-0.6748 <	Ns
	2014-2015	Ns	Ns	Ns	-0.5926
	2015-2016	Ns	Ns	Ns	Ns
Budding	2011-2012	Ns	Ns	Ns	Ns
	2012-2013	Ns	0.6244	0.7619	Ns
	2013-2014	Ns	Ns	Ns	Ns
	2014-2015	Ns	Ns	Ns	Ns
	2015-2016	Ns	Ns	Ns	Ns
Anthesis	2011-2012	Ns	Ns	Ns	Ns
	2012-2013	Ns	Ns	Ns	Ns
	2013-2014	0.7251	0.7343	0.7343	Ns
	2014-2015	Ns	Ns	Ns	Ns
	2015-2016	0.5913	0.5913	Ns	Ns

Unripe fruit	2011-2012	Ns	Ns	Ns	Ns
	2012-2013	Ns	Ns	Ns	Ns
	2013-2014	0.7572	0.8030	0.8030	Ns
	2014-2015	Ns	Ns	Ns	Ns
	2015-2016	Ns	Ns	Ns	Ns
Ripe fruit	2011-2012	Ns	Ns	Ns	Ns
	2012-2013	Ns	Ns	Ns	Ns
	2013-2014	Ns	Ns	Ns	Ns
	2014-2015	Ns	Ns	Ns	Ns
	2015-2016	Ns	Ns	Ns	Ns

Source: the author (2017).
Note: n sample: (60). Assuming a significance probability of 95%.

DISCUSSION

Comparatively, the species seem to have a similar behavior with regard to their vegetative phenology over the five years, being two semideciduous species with senescence and budding of leaves occurring between August and February for *G. klotzschiana* and August to December for *B. salicifolius,* concomitantly. The onset of leaf senescence in the species, in general, occurs in early autumn and extends until winter, which is an expected behavior for subtropical forests, as reported in the studies conducted by Antoneli and Thomaz (2012), Scheer *et al.* (2009) and Pinto and Marques (2003). This strategy seems to function as a mechanism to withstand temperatures that are negative or near 0 °C, which are frequent in the region, ensuring an escape from physiological drought (drought caused by intense cold) (LARCHER, 2006), typical at this time of year and even the effect of frosts.

G. klotzschiana has its reproductive phenophases varying more over the years, unlike *B. salicifolius.* Species living in the same environment and receiving the same environmental stimuli may show different phenological behavior, as is the case of the species monitored in the present study. The variation in the phenology of these species is an advantageous strategy, being an important mechanism for the maintenance of coexisting species, reducing competition for biotic resources, such as pollinators, and abiotic resources, such as radiation (RATHCKE; LACEY, 1985). The largest difference between the species was found in the anthesis phenophase, as *G. klotzschiana* had two flowering peaks that together extend from August to March, with varying intensity between the observed years. In *B. salicifolius*, flowering followed the same period (November to January) in four of the five years observed, compatible with the rainy season. Staggemeier, Diniz-Filho, & Morellato (2010) observed the same flowering behavior in reproductive events in 70% of Myrtaceae species evaluated in a phenology study in tropical forest in Brazil. Thus, it is possible to infer that the species have niches for their flowering, since flowering should occur when the plants are able to accumulate sufficient resources and when pollination is efficient to maximize seed production (LINDER, 2020).

The results of correlation between phenophases and environmental variables of the species monitored between August 2011 and July 2016 showed that both species had no correlation with precipitation. However, when the correlation between the phenophases and each year was tested individually, some correlation with this variable was observed in *G. klotzschiana* and *B. salicifolius* virtually only in the year 2015 – 2016. For the temperatures (minimum, mean and maximum), the phenophases had forces of association detected. In regions that do not have a marked climatic seasonality, with no periods of water deficit, the preponderant factor in phenology is no longer precipitation; rather, the photoperiod or small changes in temperature become the inducers of phenological behavior (BORCHERT *et al*., 2005; MARQUES; ROPER; SALVALAGGIO, 2004, MILANI, 2017).

Between the years, variations in the forces of associations tested with phenophases were observed, causing a phenophase to be correlated with a given variable in one year but not in another, and these variations were observed basically with temperatures and fruiting. In this study, this includes not only high temperatures, but also cold shocks from subtropical frosts, which affect flowering events, fruit maturation and even seed production (COOK *et al.*, 2012; CORTÉS-FLORES *et al*., 2013; STAGGEMEIER AND MORELLATO, 2011).

Although variations in phenology may have natural causes, or non-climatic factors, climatic factors may be responsible for some of these trends, and human-induced climate or atmospheric change is the most consensual explanation for many scientists (HUGHES, 2000). Changes in the life cycle of organisms (phenology) are one of the most widely used early warning indicators in climate change, but they are still poorly understood for the tropics (MENDOZA *et al*., 2016).

The results indicate that the same species may have different phenological behavior between the years in which they are evaluated, highlighting the need for phenological studies to be long, regardless of phytogeographic unit, since local microclimatic changes can alter the intensity of phenological events of the species.

CONCLUSIONS

- The species show similar phenological behavior during the years, but variations in the intensity of phenophases were detected between the years analyzed.
- The meteorological variables minimum, mean and maximum temperatures influenced the phenophases in both species when correlated together and individually (year by year). Precipitation was not correlated with the phenophases.

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