




Research Article

Climatic signals on phenological patterns among tree species in a subtropical forest community

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Abstract

The study of vegetative and reproductive phenophases of plants is critical for understanding aspects related to plant behavior in different environments. In the tropics, there is a gap of understanding related to plant phenology since the theoretical framework on the topic has been built from perspectives of the temperate region. Furthermore, there are few studies in tropical regions influenced by anthropic conditions, which may be important for understanding these issues in the face of future climate scenarios. This study aimed to describe the vegetative and reproductive phenology of trees in an urban subtropical forest community and to test the influence of climatic variables on the tree community. In an urban forest fragment in Rio Grande do Sul, Brazil, eight individuals of locally dominant species were monitored: *Allophylus edulis*, *Casearia sylvestris*, *Guarea macrophylla*, *Mimosa bimucronata*, *Myrsine coriacea*, *Myrsine umbellata*, *Schinus glandulosum*, and *Schinus terebinthifolia*. The monitoring occurred every two weeks, for two years, with the recording of the presence of leaf flushing, leaf shedding, flowering, and fruiting phenophases for each tree. The seasonality of the species was tested using the Rayleigh test. We described the common pattern of community phenological activity by a Principal Component Analysis. Finally, we correlated the common patterns of each phenophase in the community with climatic variables of total precipitation, average temperature, and day length. All species showed a non-uniform phenological pattern for the evaluated phenophases despite the variable intensity. We evidenced common patterns for the community only for the vegetative phenophases. The reproductive phenophases of flowering and fruiting present themselves independently among species in the community. Finally, we identified influences only of temperature and day length on the vegetative phenophases.

Key words: Atlantic Forest, climate, flowering, fruiting, leaf flushing, leaf shedding, seasonality

Introduction

Phenological studies have contributed to understanding the effect of climate on the seasonal life cycle of organisms (Garcia 2006; Forrest and Miller-Rushing 2010; Tang et al. 2016; Ponti and Sannolo 2022). In arboreal individuals, these studies mainly contribute to the description of the temporal variation of



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reproductive (i.e., flowering and fruiting) or vegetative (i.e., leaf flushing and leaf shedding) phenophases in a population or community level (Andreis et al. 2005; Polgar and Primack 2011; Garcia-Barreda et al. 2021). Furthermore, the influence of biotic interactions and environmental conditions (e.g., climate) that act on the physiological mechanisms of plants is a topic that has been widely explored (Almeida and Alves 2000; Ding and Nilsson 2016; Singh et al. 2016).

Temperate regions have been the focus of phenological studies for a long time because they present a well-defined thermal seasonality, where low winter insolation defines the dormant period of plants (Staggemeier et al. 2019). Recent advances in tropical dendrochronology have been breaking the paradigm that tropical trees generally lack seasonal growth rhythms (Quesada-Román et al. 2022; Zuidema et al. 2022). However, knowledge about the phenology of tropical and subtropical plants is still insufficient (Staggemeier et al. 2019; Davis et al. 2022). Thus, the theoretical framework on the topic has been built from a perspective that is contextually biased to temperate regions (Chambers et al. 2013; Davis et al. 2022). This paradigm makes it difficult to understand how tropical trees respond to climate change (Staggemeier et al. 2019; Davis et al. 2022).

Efforts to understand phenological patterns in tropical and subtropical regions face challenges, especially in the many distinct phenological patterns evidenced by the high diversity of species (Davis et al. 2022). Besides that, some knowledge gaps should be considered in future studies (Sakai and Kitajima 2018; Masson-Delmotte et al. 2021; Davis et al. 2022). First, most phenological studies in the southern hemisphere have temperature and day length as the only climatic variables tested (Chambers et al. 2013). Also, phenology studies in this region should cover a significant temporal scale, with more than one year of measurements (Sakai and Kitajima 2018; Davis et al. 2022). Furthermore, understanding the phenological cycles and patterns of organisms in areas influenced by anthropogenic conditions may reflect important interpretations from a conservation perspective, especially under future climate scenarios (Masson-Delmotte et al. 2021).

Urban forests are important components of urban landscapes as they provide environmental services such as reducing heat islands, preventing soil erosion, and improving air quality (Werner 2011). Furthermore, the existence of these ecosystems reflects a positive interaction for the maintenance and survival of animals and plants in urban landscapes (Jensen et al. 2021; Rigacci et al. 2021). In this sense, phenological studies of subtropical trees in urban forests can contribute to the understanding of plant behavior in environments influenced by anthropogenic conditions. Recent studies have been dedicated to understanding the effect of urbanization on trees and urban forests, identifying greater growth but lower longevity (Pretzsch et al. 2017) and in some cases delay in the onset of phenophase seasons (Li et al. 2022, in a temperate region). However, there is still a knowledge gap about the effects of urbanization on tree phenology in urban forests under subtropical conditions due to the absence of data series with sufficient spatial and temporal coverage (Chambers et al. 2013; Jochner and Menzel 2015).

This study aimed to (i) describe the annual vegetative and reproductive phenology of eight dominant tree species in an urban subtropical forest community, and (ii) test the influence of seasonal climate on the phenology of the community. The few studies of tree phenology in native forest environments in the South and Southeast regions of Brazil have shown responses related mainly to the seasonal cycle of day length (Morellato et al. 2000; Marques and Oliveira

2004; Marchioretto et al. 2007; Athayde et al. 2009; Rubim et al. 2010). Thus, we hypothesize that the climatic response of the tree community in this urban subtropical forest will be similar to previous studies for tropical regions, with a significant influence of day length on phenophases.

Methods

Study area

The study was conducted in fragments of urban forest located at Universidade do Vale do Rio dos Sinos (Unisinos), São Leopoldo, Rio Grande do Sul, Brazil (29°45'39"S, 51°9'8"W). The total area of the fragments is 5 ha, and they were divided into 20 plots of 100 m², randomly distributed in the fragments (Fig. 1).

The climate is classified as Humid Subtropical (Cfa), characterized by at least one month with an average temperature above 22 °C (Alvares et al. 2014). The average temperature in the hottest month (January) is 24.5 °C; the coldest month (July) records an average of 14.3 °C, marking winter; the annual average temperature is approximately 19.4 °C (BDMEP 2023). Precipitation is abundant throughout the year, with an annual average of 1,324 mm (BDMEP 2023). Regarding day length, December has the longest day, with 14 hours and 3 minutes, while the shortest day occurs in June, with a duration of 10 hours and 17 minutes (Fig. 2).

The vegetation type in the region is classified as Semideciduous Seasonal Forest (Teixeira et al. 1986). In a phytosociological survey carried out between

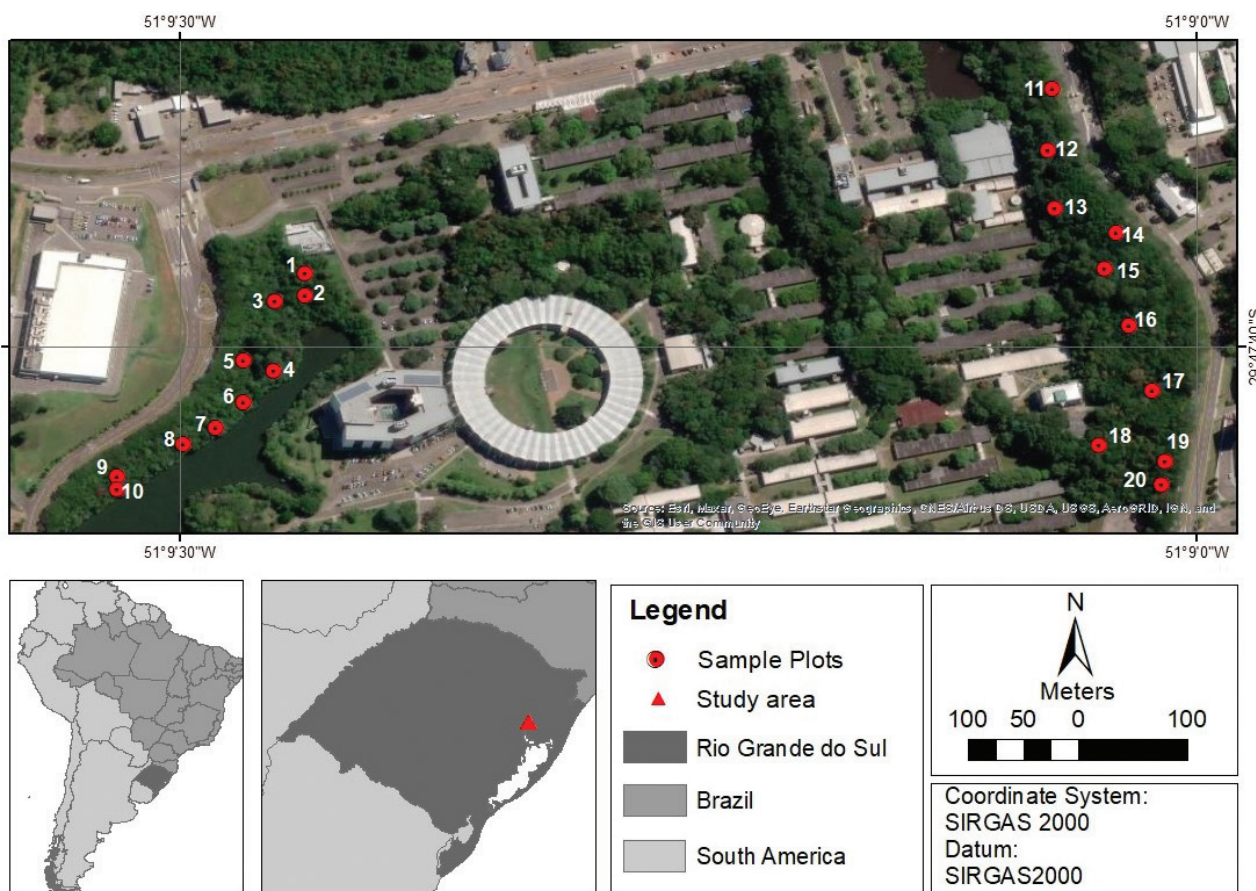


Figure 1. Location of the study area and sample plots in forest fragments in the state of Rio Grande do Sul, Brazil.

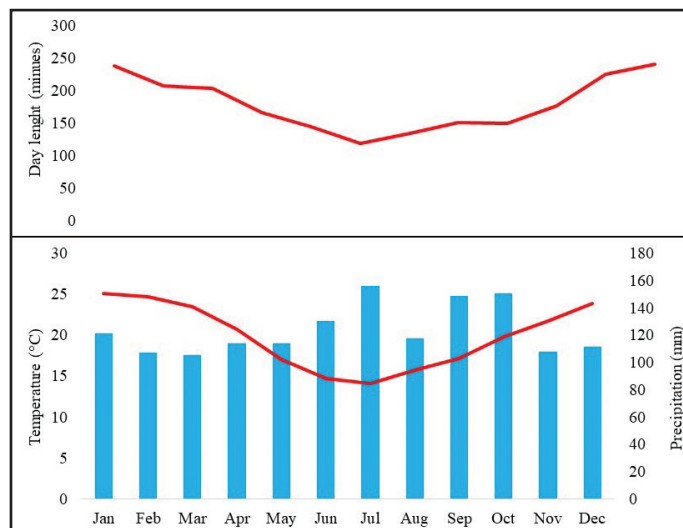


Figure 2. Monthly variation in mean day length, mean total precipitation, and mean temperature in the study region from 1990 to 2022 (BDMEP 2023).

2015 and 2017, 469 tree individuals belonging to 60 species were recorded (Olmedo et al. 2018). Of these, most (37) are native to the Semideciduous Seasonal Forest. Among the native species, most are characterized by being pioneer species, such as *Guarea macrophylla*, *Casearia sylvestris*, *Myrsine umbellata*, and *Mimosa bimucronata*. Furthermore, seven species that are exotic to the Atlantic Forest were identified, four of which were classified as invasive: *Hovenia dulcis*, *Ligustrum sinense*, *Pinus elliottii*, and *Syzygium cumini*. It should be noted that urban forest plots are under the same management influence, with pruning on their edges and little intervention in the interior. No other management treatments, such as irrigation or fertilization, are carried out in the environment.

Phenology description

Based on a phytosociological survey in the same study sites (Olmedo et al. 2018), we selected the eight most frequent and abundant species from the sample: *Allophylus edulis* (A.St.-Hil., Cambess. & A. Juss.) Radlk., *Casearia sylvestris* Sw., *Guarea macrophylla* Vahl, *Mimosa bimucronata* (DC.), *Myrsine coriacea* (Sw.) R.Br., *Myrsine umbellata* Mart., *Schinus glandulosum* (L.) Morong, and *Schinus terebinthifolia* Raddi. For each species, we randomly selected eight individuals from the plots, distributed as equitably as possible among them, totaling 64 individuals. Considering the minimum of five individuals per species recommended for phenological studies in the tropics, the number of individuals evaluated is within the suggested average (Frankie et al. 1974). Between January/2016 and December/2017, we monitored all individuals every two weeks, recording the presence and absence of leaf flushing, leaf shedding (vegetative phenophases), flowering, and fruiting (reproductive phenophases). This two-year sampling totaled 48 visits to the trees for monitoring the phenophases.

We tabulated the presence and absence data of the phenophases observed during the 48 samplings for the 64 trees in binary form. We then evaluated the seasonality of all phenophases using circular statistics (Zar 1996; Morellato et al. 2000). To do this, we first converted the dates into angles of 15°. For example, we assigned values recorded in the first half of January to angle 0°, while values

recorded in the second half of December were assigned to angle 345°. For each phase, we estimated the mean angle (μ), from which we tested the null hypothesis ($\alpha = 0.1$) of random distribution (i.e., uniform distribution throughout the year), using the Rayleigh test. Thus, phenophases with p -values < 0.05 in the Rayleigh test indicate non-uniform data, i.e., occurring in specific periods. In addition, the degree of seasonality (r) has results ranging from 0 (evenly distributed over the year) to 1 (concentrated at one time of year). If considered seasonal, i.e., when the r value is above 0.6, we estimate in which period of the year the peak of the population phenophase occurs, that is, at what time most individuals present the phenophase. These analyses were performed in R software using the “circular” (Agostinelli and Lund 2022) and “overlap” (Ridout and Linkie 2009) packages.

To describe the activity pattern of the tree community, for each phenophase, we performed a Principal Component Analysis (PCA) based on Spearman’s correlation (a suitable method for non-normally distributed data with occurrence peaks, such as phenology data) between the activity index series of each species. We then applied a significance test for the two principal axes of the analysis considering a tolerance limit $\alpha = 0.05$ (Pillar 1999). For the phenophases that did not show significant PCA axes, we considered that the community behavior was independent among species, with each contributing individually to the community. Thus, the presence of a common pattern of activity for the phenophase in the tree community implies the presence of at least one common axis for species activity. The analyses were performed with MULTIV software version 3.85 (Pillar 2006).

Correlation with climate variables

We obtained climate data regarding mean precipitation, mean temperature, and day length from the Meteorological Database of the Brazilian Institute of Meteorology (BDMEP 2023) for the Porto Alegre meteorological station, located approximately 40 km from the study area. The data were obtained for the period from January 2016 to December 2017, corresponding to the phenophase monitoring period. In the two years of study, the average precipitation was 141 mm/year and the average temperature was 21 °C/year. In general, the meteorological records were similar for the two study years (Fig. 3).

We correlated the climate variables only with the phenophases that presented a common pattern of frequency for the community since we aimed to understand the community responses to climate. Thus, we tested all significant axes of the Principal Component Analysis with the climatic variables using Spearman correlation considering the significance test by randomization for a tolerance limit $\alpha = 0.05$. Studies that aim to assess the influence of climatic variables on the phenological activity of trees have been using correlation analysis in different regions of the world (Azevedo et al. 2014; Liang et al. 2016; Pancharoen et al. 2021) These analyses were performed using the MULTIV software version 3.76b (Pillar 2006).

Results

Phenology description

All species showed non-uniform phenological patterns for the evaluated phenophases, with $p < 0.001$. However, not all presented a Rayleigh value (r) greater than

0.6, indicating that they have a more distributed occurrence of the phenophase throughout the study period and it is not possible to estimate its peak. The values of the Rayleigh test are shown in Table 1, and, in Fig. 4, it is possible to observe the dynamics of the phenophase activity for each species throughout the experiment.

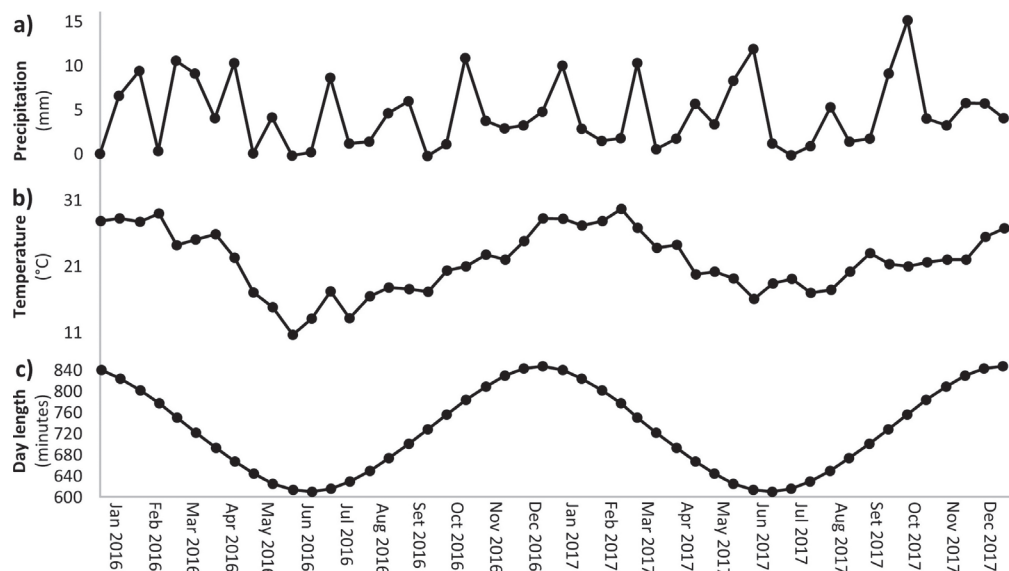


Figure 3. Variation of environmental conditions (mean precipitation (a), mean air temperature (b), and day length (c)) every two weeks in the region during the study period. Each point represents the average values of the variable for each fortnight.

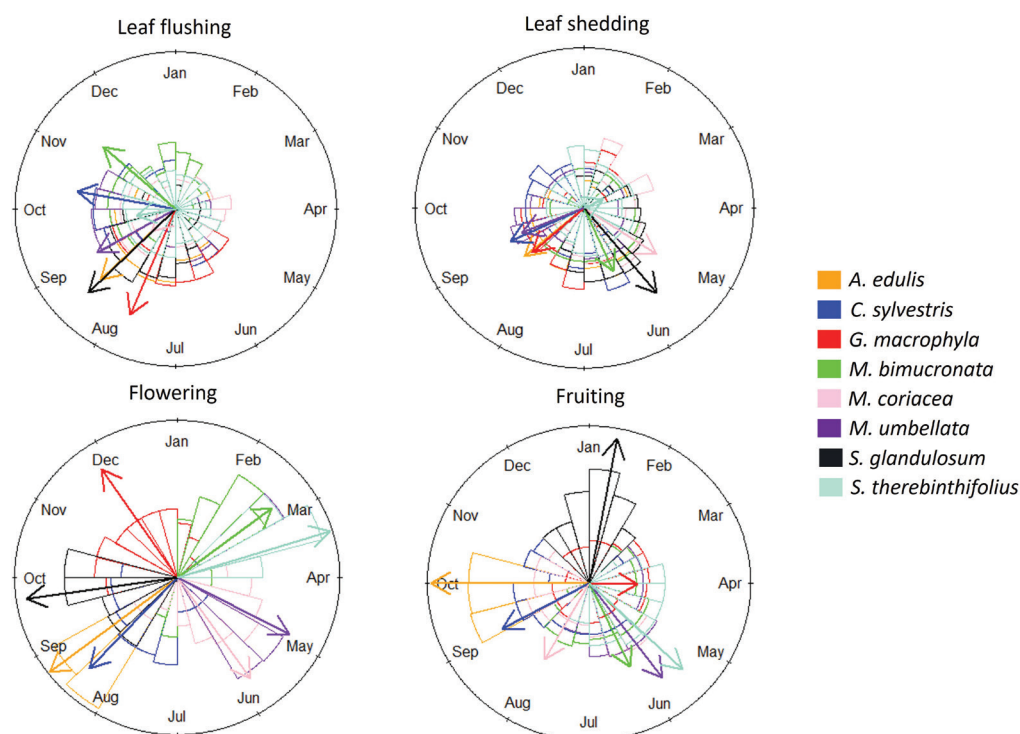


Figure 4. Results of the circular statistics for each phenophase. The different colors in each graph represent the results for each species. The frequency of occurrence of the phenophase in the population, considering the two years of study, is informed by the triangles, in which the larger their size, the more individuals are presenting the phenophase. On the other hand, the arrows represent the common period of occurrence for individuals of each species, and the larger the size of the arrow, the more individuals in the respective population are presenting the phenophase in the period of the year indicated in the graph.

Table 1. Rayleigh test results for each phenophase and species. Rayleigh test values ≥ 0.6 (marked with an asterisk) indicate the existence of a concentration of the phenophase in some specific period of the year. The p-value indicates the uniformity of the data. Phenophase peaks represent the period in which the individuals in the population have concentrated phenophase and are described only for species with $r \geq 0.6$.

Phenophase	Species	Rayleigh Test (<i>r</i>)	<i>p</i> -value	Phenophase peak
Leaf flushing	<i>A. edulis</i>	0.6474*	<0.001	Late August/Early September
	<i>C. sylvestris</i>	0.6243*	<0.001	Late October
	<i>G. macrophylla</i>	0.73*	<0.001	Early August
	<i>M. bimucronata</i>	0.6019*	<0.001	Late November
	<i>M. coriacea</i>	0.2039	<0.001	
	<i>M. umbellata</i>	0.5613	<0.001	
	<i>S. glandulosum</i>	0.7599*	<0.001	Late August/Early September
	<i>S. terebinthifolius</i>	0.2477	<0.001	
Leaf shedding	<i>A. edulis</i>	0.4644	<0.001	
	<i>C. sylvestris</i>	0.4803	<0.001	
	<i>G. macrophylla</i>	0.4127	<0.001	
	<i>M. bimucronata</i>	0.4324	<0.001	
	<i>M. coriacea</i>	0.5144	<0.001	
	<i>M. umbellata</i>	0.3987	<0.001	
	<i>S. glandulosum</i>	0.6839*	<0.001	Early June
	<i>S. terebinthifolius</i>	0.1237	<0.001	
Flowering	<i>A. edulis</i>	0.9914*	<0.001	Early September
	<i>C. sylvestris</i>	0.7911*	<0.001	Late August/Early September
	<i>G. macrophylla</i>	0.8285*	<0.001	December
	<i>M. bimucronata</i>	0.7332*	<0.001	Early March
	<i>M. coriacea</i>	0.7856*	<0.001	June
	<i>M. umbellata</i>	0.7781*	<0.001	May
	<i>S. glandulosum</i>	0.9343*	<0.001	Early October
	<i>S. terebinthifolius</i>	0.9839*	<0.001	Late March
Fruiting	<i>A. edulis</i>	0.9773*	<0.001	October
	<i>C. sylvestris</i>	0.6106*	<0.001	September
	<i>G. macrophylla</i>	0.3019	<0.001	
	<i>M. bimucronata</i>	0.5904	<0.001	
	<i>M. coriacea</i>	0.5538	<0.001	
	<i>M. umbellata</i>	0.7526*	<0.001	June
	<i>S. glandulosum</i>	0.9335*	<0.001	Late January
	<i>S. terebinthifolius</i>	0.7953*	<0.001	Late May/Early June

For leaf flushing, only *M. coriacea*, *M. umbellata*, and *S. terebinthifolia* had *r* lower than 0.6, while the others are characterized by concentrating this phenophase in a particular fortnight, predominantly at the end of winter (*A. edulis*, *G. macrophylla*, and *S. glandulosum*) and during spring (*C. sylvestris* and *M. bimucronata*). Leaf shedding was the phenophase that presented a more distributed occurrence throughout the year for most species. That is, although all species are seasonal for this phenophase, they are characterized by leaf shedding in a more distributed way throughout the year, occurring over several fortnights, except for *S. glandulosum*, which has its peak at the end of autumn.

Flowering was concentrated at one time of year for all species; however, they did not present a common pattern at the community level, with flowering peaks scattered throughout the year. On the other hand, regarding fruiting, three species (*G. macrophylla*, *M. bimucronata*, and *M. coriacea*) did not have the phenophase concentrated in a small period of the year. The others presented a peak of occurrence, but, as with flowering, in varying periods throughout the year.

The patterns of each phenophase considering the whole tree community were described by the significant axes of the PCA (Fig. 5). Axis 1 of the PCA of leaf flushing described most of the variation in the data (43%) and was the only significant axis for this phenophase ($p = 0.02$). Therefore, the common frequency pattern for leaf flushing in this tree community is described by axis 1. All species were positively related to the first axis, with community leaf flushing occurring from June to November in the first year of study and May to December in the second year.

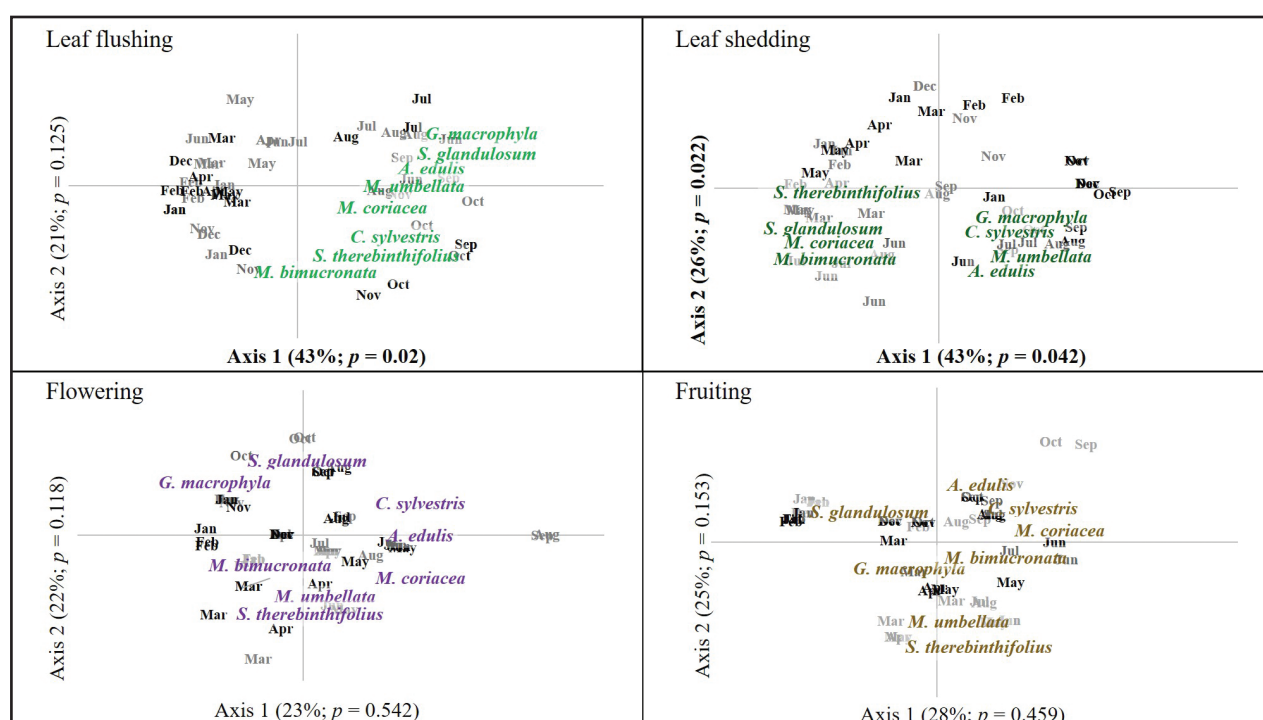


Figure 5. Ordination analysis (Spearman correlation) of the activity index of each phenophase over the two years of study. Species are positively or negatively associated with axes 1 and 2, and those with values near the axis line are weakly related to the main variation of the axis. Months in black represent the first year of sampling and months in gray, the second year of sampling. Significant axes ($p \geq 0.05$) were marked.

For leaf shedding, the first two axes of the PCA were considered significant (axis 1 with $p = 0.042$ and axis 2 with $p = 0.022$); thus common patterns of this phenophase are described by them. Axis 1 described most of the variation in the data community (43%) and two distinct patterns were identified: *A. edulis*, *C. sylvestris*, *G. macrophylla*, and *M. umbellata* related positively and *M. bimucronata*, *M. coriacea*, *S. glandulosum*, and *S. terebinthifolia* negatively to this axis. In this sense, the first group of species in the community is characterized by presenting the phenophase occurring from July to October in both years. The second group has this phenophase anticipated in relation to the first, occurring from March to July in the first year and in May in the second year. Axis 2 of leaf shedding (26% of

explanation) represented the common variation among all species in the community, indicating occurrence between March and October in both years.

For the reproductive phenophases (flowering and fruiting), no axis of the Principal Component Analyses was found to be significant. Thus, the species have independent patterns of flowering and fruiting, which is also confirmed by the arrows of the circular statistic analysis (Fig. 4). In this, one can see that the species have flowering and fruiting periods at different times.

Correlation with climate variables

The significant axes of the PCA (Fig. 5) of each phenophase, described in the previous section, were related to climatic variables of temperature, day length, and precipitation corresponding to the study period. Thus, it was possible to assess the influence of climate on the dynamics of reproductive and vegetative phenophases of the tree community of this forest. Only correlations with temperature and day length were identified (Table 2).

Table 2. Spearman correlation between the climatic variables of precipitation, temperature, and day length and significant axes of the PCA of each phenophase ($p \geq 0.05$ are marked).

		Precipitation		Temperature		Day length	
		Spearman cor.	p-value	Spearman cor.	p-value	Spearman cor.	p-value
Leaf flushing	Axis 1	-0.034525	0.796	-0.57824	0.001	-0.386	0.007
Leaf shedding	Axis 1	0.0029858	0.985	0.065525	0.648	0.36776	0.001
	Axis 2	0.22024	0.137	0.73554	0.011	0.65307	0.001

Axis 1 for leaf flushing linked all species positively on the axis and showed negative correlations with temperature ($r = -0.57$; p -value = 0.001) and day length ($r = -0.38$; p -value = 0.007). In this sense, this axis, which represents the highest percentage of explanation of community variation for this phenophase, indicates that all species produce leaves in hot conditions and high intensity of sunlight per day.

For leaf shedding, the axis that represented the greatest variation in the data divided the species into two distinct groups and was positively related to day length ($r = 0.37$; p -value = 0.001). Thus, the most representative behavior in the community for this phenophase is characterized by species that show leaf shedding under conditions of high (*G. macrophylla*, *C. sylvestris*, *M. umbellata*, and *A. edulis*) or low (*S. terebinthifolia*, *S. glandulosum*, *M. coriacea*, and *M. bimucronata*) day length. However, the second axis, which linked all species negatively to it, was positively related to temperature ($r = 0.73$; p -value = 0.011) and day length ($r = 0.65$; p -value = 0.001). Thus, the species in general do not show leaf shedding under conditions of very high temperatures and day length.

Discussion

The tree species evaluated in this work are common in the early stages of ecological succession (Cappelatti and Schmitt 2009), and some have been widely used in agroforestry systems (*A. edulis* and *M. bimucronata*) and forest restoration programs (*A. edulis* and *S. terebinthifolia*) in the Atlantic Rainforest,

especially in Rio Grande do Sul (Silva et al. 2019; Chemello et al. 2023; Domingues et al. 2023). Therefore, the results of this study provide knowledge about the ecology and both reproductive and vegetative phenological variation, as well as important information for sustaining future public policy programs for seed collection and promotion of plantations of these species and for the extraction of non-timber forest products, influencing the economy of small families (Domingues et al. 2023). Therefore, promoting knowledge about phenological data, especially through field observations in a natural environment, provides accurate information that can aid in future projections about species behavior (Tang et al. 2016; Zurell et al. 2020; Ponti and Sannolo 2022).

The leaf-flushing phenophase showed high seasonality values for most of the community, except for *M. coriacea*, *M. umbellata*, and *S. terebinthifolia*, which resulted in a low seasonality pattern with a more uniform expression of the phenophase throughout the years, although it is still classified as seasonal. This result corroborates the fact that these species are not classified as perennials and, therefore, their vegetative cycle is expected to be less regular compared to perennial plants (Bencke 2005; Bauer et al. 2012; Milani 2013). Tropical species may have different strategies regarding leaf-flushing, mainly related to defense against herbivore attacks (Corlett 2009; Yoneyama and Ichie 2019). Leaf-flushing activity throughout the year may be related to more resistant leaves and higher photosynthetic capacity and, on the other hand, sprouting occurring over a longer period may indicate some chemical influence against herbivore attack (Yoneyama and Ichie 2019). In this sense, the studied community may show distinct patterns against herbivore attacks related to variations in sprouting.

On the other hand, for leaf shedding, most species showed low seasonality. Similar results have been found in other locations for *A. edulis* (Milani 2013), *C. sylvestris* (Marchioretto et al. 2007), *G. macrophylla* (Bencke and Morellato 2002), *M. coriacea* (Bauer et al. 2012), and *M. umbellata* (Bencke 2005). Therefore, the community, regarding leaf shedding, can be considered slightly deciduous. This may be explained by damage associated with leaf and branch falls caused by winds and storms, which are common in the region (Janzen 1980). In this sense, future phenological studies related to the vegetative activity of tree species in the tropics should consider the frequency of these events throughout the observation period. Only *S. glandulosum* differed from this pattern of low seasonality, showing a concentration of its phenophase at the beginning of winter, corroborating what was found in other studies (Bencke 2005) and the fact that leaf deciduousness is considered a survival strategy for unfavorable periods, such as the cold winter months (Chabot and Hicks 1982).

Flowering was the phenophase with the best-defined seasonal pattern for all species. *A. edulis* and *C. sylvestris* had their flowering peak in early spring, a pattern recognized for these species (Andreis et al. 2005; Bencke 2005). Most other species flowered in autumn and winter, as already observed for *M. bimucronata* (Bencke 2005), *M. coriacea* (Bauer et al. 2012), and *S. terebinthifolia* (Milani 2013). It is also worth noting that no species showed flowering in January or July, months with extreme climatic conditions of temperature and day length, which may be associated with less favorable times for pollinators or even for the physiology of fertilization (Lieberman 1982; Alencar 1994). Climate extremes tend to be more pronounced in urban areas (Qian et al. 2022), which may further potentiate their effects in our study location.

The fruiting peak of most species occurred in early winter or spring, with most species showing little marked seasonality. Fruit production in tree communities occurring during long periods of the year has been recorded in other studies, and the period between years can be highly variable (Spina et al. 2001). The fruiting period is strongly related to the dispersal strategy of the species (Freire et al. 2013). Among the species in this study, only *M. bimucronata* presents autochoric dispersal, with dispersal occurring in the autumn and winter months in agreement with the literature (Carvalho 2004). In other studies in Atlantic Forest environments, especially in pioneer secondary forests, the zoochory is also more common than autochory (Negrini et al. 2012; Freire et al. 2013). In this sense, it is worth noting the strong influence of fauna, especially avifauna, on the fruiting of the species in this study since disturbances in these groups can directly impact the seasonality of this phenophase (Negrini et al. 2012). Among the species that presented this well-defined phenophase, *A. edulis* and *C. sylvestris* are highlighted, both corroborating observations in other localities of the Atlantic Forest (Bencke 2005; Athie and Dias 2011). Finally, it is also important to note that plant age is related to the seasonality of fruiting events (Schorn 2003). This factor was not considered in this study, but, for future studies, it may be important to include this information.

We evidenced a common pattern of activity frequency among the species of the tree community only for the vegetative phenophases. The occurrence of independent reproductive phenophases among species in the community can be explained by the fact that flowering and fruiting are strongly dependent on factors such as age, pollination, dispersal, and competition, which can have their effects at different times of the year among species (Frankie et al. 1974; Alencar 1994; Forrest and Miller-Rushing 2010; Ding and Nilsson 2016; Viana et al. 2020; Garcia-Barreda et al. 2021). The common species pattern between vegetative and reproductive phenophases has also been found in other studies conducted in the subtropical region (Marchioretto et al. 2007; Athayde et al. 2009). However, it is worth noting that the occurrence of common patterns among species, that is, for the tree community, is little explored in phenological studies. Thus, we emphasize that new studies should seek to test these patterns beyond the description by species, aiming to better understand the leaf and reproductive phenology of tree communities in the subtropical region.

The vegetative phenophases were the only ones that showed a common pattern among the species in the community; therefore, their responses to climate were evaluated. We only found influences of temperature and day length, corroborating the few studies carried out in the subtropical region (Marques and Oliveira 2004; Bencke 2005). The leaf flushing activity in the community was negatively related to day length and temperature conditions. The production of vegetative structures usually occurs by avoiding less favorable climatic periods (Schaik et al. 1993; Ding and Nilsson 2016), which corroborates the results of this study since no species showed leaf flushing during the months with higher temperatures and longer days.

For leaf shedding, we evidenced two distinct patterns in the community related to a group of plants that present the phenophase during periods of lower day length and others in periods of higher day length. Leaf shedding in periods of longer days may be related to the change in the nutritional characteristics of the soil caused by the production of litter in early spring (Morellato and Leitão-Filho 1992; Santos and Fisch 2013). This change causes influence on the physiological aspects of the

plant and, consequently, can affect the phenological patterns of the community (Costa et al. 2007; Cardoso 2009). We also evidenced a pattern for all species in the community regarding leaf shedding, which was characterized by a negative influence of temperature and day length. Responses of leaf shedding to day length are expected in the tropical region (Wright and Van Schaik 1994), but they have also been related to water changes (Marques et al. 2004; Marques and Oliveira 2004). This contrasts with our study, where we did not identify a significant relationship with precipitation. In this sense for this forest community, we evidenced inverse climatic correlations between leaf flushing and leaf shedding, as also evidenced by other studies with other species in southern Brazil (Viana et al. 2020).

In general, the phenological activity of the species in this urban subtropical forest environment in relation to natural forest environments was similar. We confirmed the hypothesis of our study since the phenophases of the tree community were mainly related to day length. However, some distinct patterns were observed, especially in the times of occurrence of the phenophases. Changes (delays or advances) in the typical period of phenophases have been observed in trees in urban conditions (Liang et al. 2016; Li et al. 2022), which synergistically with other factors may be affecting some species of the studied community. Future studies involving genetic factors in the physiology of these species are essential for a better understanding of plant ecology (Ding and Nilsson 2016; Singh et al. 2016). This knowledge, in addition to other surveys at larger temporal and local scales, is fundamental even for understanding the response of the tree community under future climate change scenarios (Polgar and Primack 2011).

Conclusion

During the two years of monitoring, we increased our knowledge about the ecological variation of vegetative and reproductive activities of eight common native species in secondary forests. We conducted high resolution phenological monitoring for eight tropical species; three of them (*Mimosa bimucronata*, *Schinus glandulosum*, and *Schinus terebinthifolia*) have few or no studies for southern Brazil. In addition, in this work we address phenology at a community scale in contrast to the species scale, which is usually analyzed. We found that the tree community presents common patterns of phenological activity for the vegetative phenophases, in contrast with the reproductive ones, which seem to present independent patterns among species in the community. We showed that climate seasonality is also a significant factor for vegetative phenology in this urban forest community in southern Brazil, especially considering variations in day length, as evidenced in other studies in the tropics. Finally, we emphasize that this study can serve as a basis for future comparisons regarding differences in the phenology of trees growing in urban and natural environments. In this sense, we contribute to further studies about the influence of urbanization on the phenology of tropical species.

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

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Author contributions

Gabriela Morais Olmedo performed all the statistical analyses of the data obtained in the field and wrote the manuscript, together with Mateus Raguse-Quadros who obtained the data in the field. Guilherme Taboada Conrado also participated in the field data collection, wrote and organized the first version of the manuscript. Juliano Morales de Oliveira idealized the project and coordinated the activities. All authors participated in the writing and reviewing of the final document.

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Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.

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Supplementary material 1

Distribution of the sampled trees in the study site

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Data type: table (docx. file)

Explanation note: Distribution of the sampled trees in the study site. Trees were mapped in 20 plots (100 m², each), randomly placed in two forest fragments at Unisinos. For each species, 8 individuals from those mapped were randomly selected for observation. Two individuals of *Mimosa bimucronata* entered senescence during the study (plot 8 and 10) and were replaced by others (plot 3), which were also randomly selected (*).

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