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ORIGINAL ARTICLE – Conservation of nature

Phenology and Tree Radial Growth of *Schinus terebinthifolius* in a Subtropical Forest

Jaçanan Eloisa de Freitas Milani [1,4]
Rodrigo de Andrade Kersten[2]
Tomaz Longhi - Santos[1]
Franklin Galvão[1]
Erika Amano[3]
Carlos Velozzo Roderjan[1]
Maria Raquel Kanieski[1]

Abstract

During a period of 5 years, we monthly monitor the phenology and the stem diameter increment of 12 of *Schinus terebinthifolius* trees. Dendrometer bands were used for it. This study was aimed to answer the following questions: (i) Are there conflicting demands for resource allocation in different phenophases? (ii) In which period does the stem diameter increment occur? (iii) Which phenophases are more likely related to stem radial growth? The phenological observations were carried out using the Activity Index. In order to identify patterns in phenology and diameter increment over the assessment period (2010-2015), we performed an analysis of seasonal decomposition, followed by Pearson's correlation analysis. Apparently, there is no conflicting demand for resources, but an optimized distribution of them, regulated mainly by the allocation of nutrients derived from leaf senescence, as well as, temperature rise and photoperiod. Higher diameter growth rates occurred from December to March which coincided with the flowering period.

Keywords: Demand, Flowering, Increment, Plasticity, Resources.

1. INTRODUCTION

The relationship between plant phenology and growth in both tropical and subtropical forests in South America has been very little explored (O'brien et al., 2008), and also scientific knowledge of alluvial environments is even more scarce. In addition, understanding the dynamics of alluvial environments in different biomes remains a major challenge in ecology. In the Brazilian Atlantic Forest, the remaining fragments are mostly small, isolated and composed of disturbed secondary vegetation, comprising less than 50 ha (Ribeiro et al.,2009). The landscape connectivity favors biological processes for the survival of populations and interactions among species (Metzger et al., 2009). Actually, forest corridors are considered the best-known factors to reduce the negative effects of fragmentation (Lees and Peres, 2008). In this context, riparian vegetation, currently protected under laws and regulations by means of "Areas of Permanent Protection", (APPs) plays a very important role in the preservation of such ecosystems. Therefore, further studies on the ecological aspects of riparian vegetation are required for the establishment of environmental conservation strategies as they will benefit future generations.

Tree growth is controlled by endogenous factors such as the plant genotype (Anderson *et al.*, 2012) and physiological processes (Pallardy, 2006), as well as exogenous factors which are regulated by the availability of water and light (Gričar, 2013). Growth can usually be measured by repetitive measurements of the tree dimensions, which is most commonly performed by monitoring the stem diameter increment (Turner, 2001). These factors play a fundamental role on the growth of trees, which are linked to plant phenology and are evaluated by their phenological behavior (Morellato et al., 2000).

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[1]Universidade do Estado de Santa Catarina, Lages, SC, Brasil.
[2]Universidade Federal do Paraná, Setor de Ciências Agrárias, Departamento de Ciências Florestais, Curitiba, PR, Brasil.
[3]Pontifícia Universidade Católica do Paraná, Escola de Ciências da Vida, Curitiba, PR, Brasil.
[4]Universidade Federal do Paraná, Departamento de Botânica, Setor de Ciências Biológicas, Curitiba, PR, Brasil.

In tropical forests, climate temperature, light, and rainfall are the factors that most regulate fluctuations in primary and secondary growth of the plants and may be related to small environmental changes, such as rainfall variations and day length. (O'brien et al., 2008 Borchert *et al.*, 2005, Marques and Oliveira, 2004 Wright and Van Schaik, 1994). In temperate forests, climatic conditions, especially low temperatures, are the main factors that control the dynamics of tree growth (Morel *et al.*, 2015).

The relationship between phenology and growth of some tropical forest species has been evaluated and reported by Worbes (1995) O'Brien *et al.* (2008) Yáñez-Espinosa et al. (2010), among others. However, no study has been found relating between phenology and growth in alluvial or hydromorphic soil environments, which main characteristic is temporarily water-saturated soil, caused by shallow water tables.

Plant resource allocation is typically associated with growth and reproduction, which might represent conflicting demands by plants (Barbour et al., 1999). Furthermore, resource allocation in plants appears to be related to three key processes: (1) resources are simultaneously allocated to produce energy, growth and self-maintenance throughout the growing season, (2) most of the resources are allocated up to the beginning of the growing season and only later that such resources are allocated to reproduction, (3) the reproduction is shifted to the period of higher nutrient availability for the plants (Bazzaz et al., 2000).

According to these issues, this study was developed based on the premise that a given effort in plants is divided between growth and reproduction in a competing manner, in which resource allocation has to achieve optimal trade-offs on each of the processes. More specifically, the present study seeks to answer the following questions: (i) Are there conflicting demands for resource allocation in different phenophases? (ii) Do reproductive phenophases cause decrease in the stem diameter increment? (iii) In which period does the diameter increment occur? (iv) Which phenophases are more likely related to stem radial growth?

2. MATERIALS AND METHODS

2.1. Characterization of the study area

The study was performed in a fragment of Alluvial Araucaria Forest, within the Brazilian Atlantic Forest geographical coordinates 25º34'02,5" S and 49º20'53,5" W, in the Municipality of Araucaria, in the State of Parana, Brazil (Figure 1).

According to the classification of Köppen, the study area climate is humid subtropical mesothermal (Cfb), with a mean annual rainfall between 1,300-1,500 mm, without dry season and frequent frost occurrences in the winter. From January 2010 to December 2015, the monthly average temperature ranged from 12.2 °C in July (the coldest month) to 28.2 °C in February (the hottest month) (Figure 2). During the study period the average temperature was 17.7 °C.

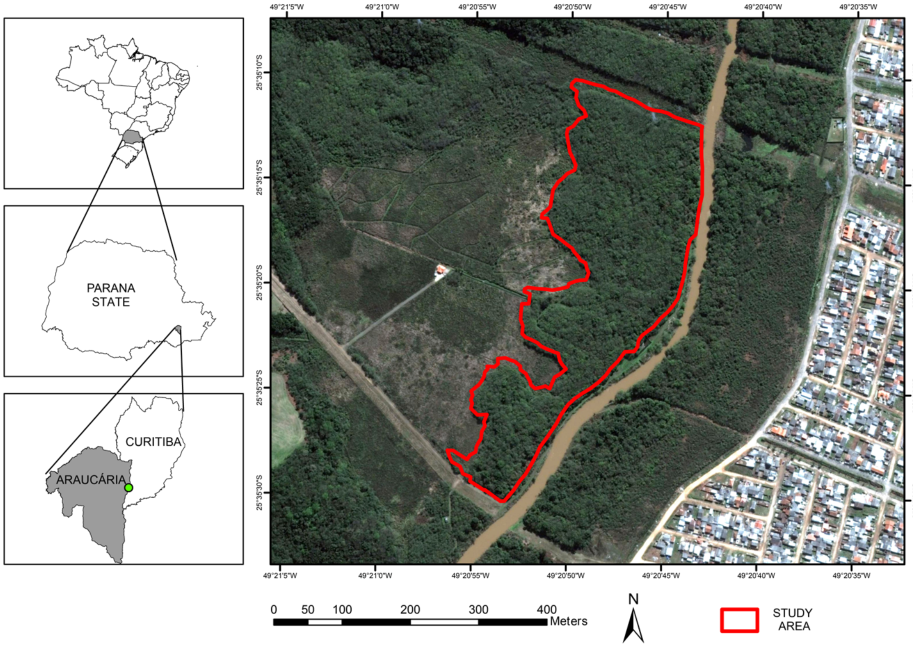

Figure 1. Location of the study area.

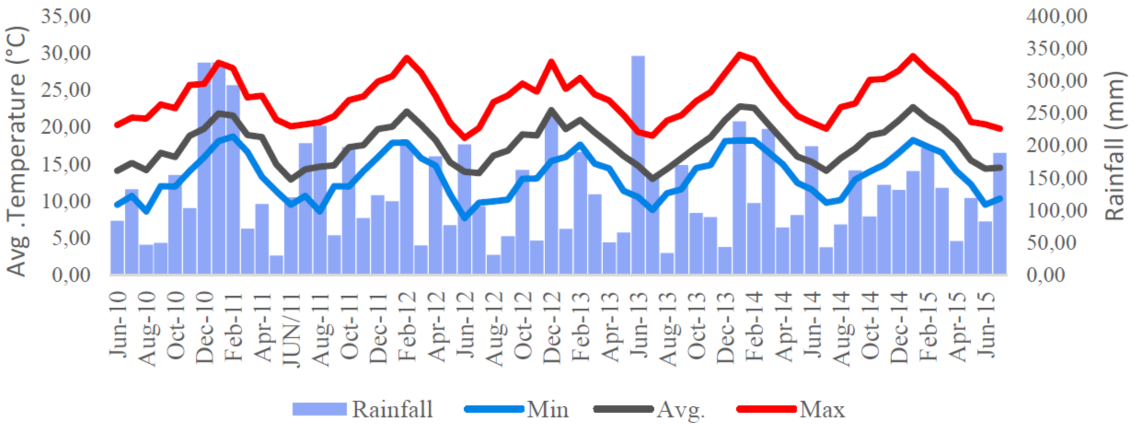

Figure 2. Climate chart, data provided by SIMEPAR Weather Station. Average monthly temperatures (minimum, average, maximum) (lines) and monthly rainfall values (blue bars) between 2010-2015.

The soil in the study area is composed of fine-grained sediments, classified as Gleysol (Barddal et al., 2005) and poorly drained under natural conditions according to Brazilian soil classification system (Embrapa, 2013).

Schinus terebinthifolius (Anacardiaceae), also known as aroeira or pink pepper, it's another important tree species in the remnant as it's a pioneer in wide dispersion, found in almost all Brazilian States and ecosystems, from the Restingas of Rio Grande do Sul State up to the dry forests of Rio Grande do Norte State (Flora of Brazil, 2016). *S. terebinthifolius* is commonly found in river banks, streams and wet meadows. However and interestingly, it also occurs in dry land with low nutrient availability. Unlike Araucaria *Araucaria angustifolia* (Bert.) O. Kuntze, a notable species within mixed rainforests of Brazil, it is intolerant to hydromorphic soil, but it does not occur in such areas.

S. terebinthifolius shows great phenotypic plasticity based on its ability to successfully grow in diverse habitats in different places, not only in South America but also in Central and North America. Moreover, in the United States, this species has been introduced as an ornamental plant but it has become a major threat to ecosystems and it was then listed among invasive species (Williams et al., 2007).

2.2. Phenological behavior

It was randomly selected 12 individuals of S. terebinthifolius, which had their phenological behavior monthly monitored using binocular. The phenological vegetative and reproductive stages were registrated based on the Activity Index (Newstrom et al., 1994), which considerates the presence-absence of a particular phenophase, on a scale of 0 (absence) to 1 (presence).

2.3. Stem diameter increment

All specimens were mounted with dendrometer bands (Mariaux, 1977 Worbes, 1995) made of stainless steel with an accuracy of ± 0.20 mm, which were fixed at breast height (1.30 m) for continuous measurements of tree radial increment. Data were subsequently converted into tree stem diameters.

The monitoring of diameter increments and phenophase cycles were carried out concurrently for a 60-month period, between June 2010 and July 2015.

2.4. Data analysis

In order to identify the phenology behavior and the diametric increment throughout the assessment period, it was used the seasonal decomposition, considering the behavior of the month pattern for the variables (12-month period), into the additive model used (Collado et .al, 2017). The method divides time series into three components: trend-cycle, seasonality, and irregularity (Cleveland et al., 1990). Our approach was focused only on the seasonality. The variables analyzed were: tree budding, leaf senescence, mature leaf, flowering, fruiting and diameter increment. By applying this technique, the annual average is transformed into zero and the seasonal indices (positive or negative) show the balance throughout the year. Negative numbers do not necessarily indicate the absence or loss but values below average.

Based on such indices, generated by analyzing seasonal decomposition, we used test Pearson's correlation analysis to identify the relationship between the phenological variables and the increment. Data were tested at 95% confidence level. All statistical analyses were made with Statgraphics.

3. 3. RESULTS

3.1. Phenology

Schinus terebinthifolius showed a pattern of continuous leaf production, more intensively from September to April. It was observed an annual cycle of phenophases, but not necessarily with the same intensity. Generally, there was little variation relating to leaf production, maintenance, and replacement among the study years (Figure 3).

The Flowering occurred from October to February, with a peak of blooming in December and January. The flowering period coincided over the 5-year survey, except for intensity variation among years. Fruiting was observed from January to March, simultaneously with the flowering period. However, March showed the highest fruiting incidence.

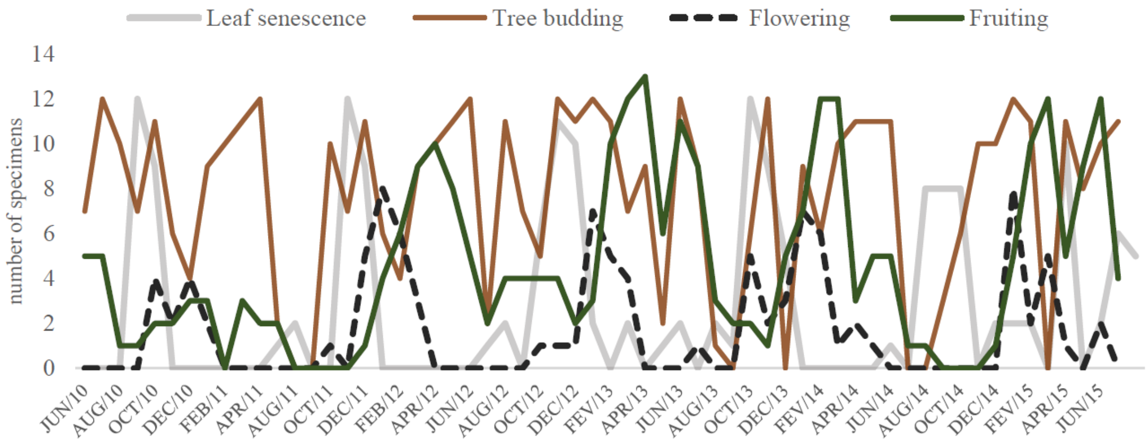

Figure 3. Vegetative and reproductive phenological behavior of *Schinus terebinthifolius* in hydromorphic soil environment for a 5-year period.

3.2. Diameter increment

The average monthly increment of tree diameter was 0.54 mm within the 60- month assessment, and the species cumulative diameter growth occurred from November to February (Figure 4). Overall, the monthly increment ranged from -1.08 to 2.25 mm. However, our findings showed that stem radial growth rates were significantly lower in August. The resumption of growth coincided with photoperiod increase.

The resumption of growth occured after August, maily between November and February. Nevertheless, it does not mean that throughout the other months the species trees ceased to grow in diameter, but the growth rates were lower (Figure 5).

Apparently, *S. terebinthifolius* showed concurrent periods of flowering and higher diameter growth rates. As to the fruiting, it began in the half of the highest increment period (Figure 6).

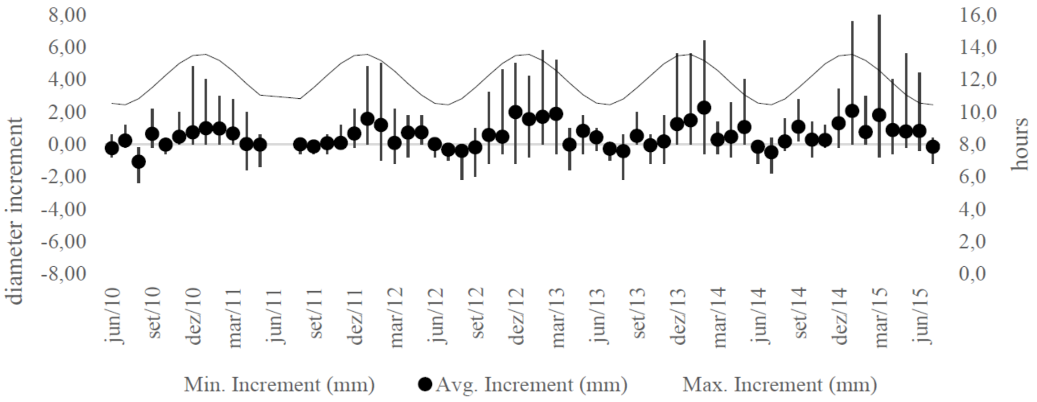

Figure 4. Relationship between photoperiod and the average diameter increment of *Schinus terebinthifolius* in hydromorphic soil environment within a 5-year period.

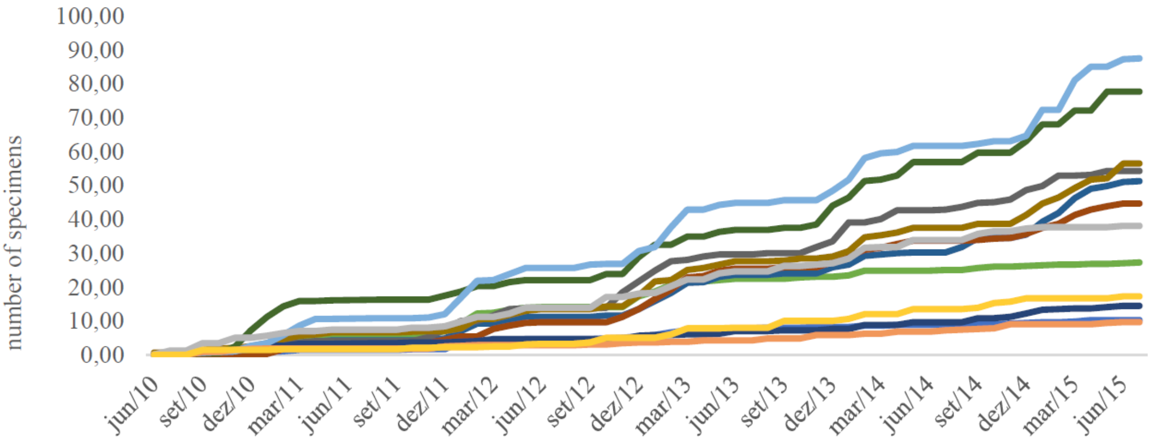

Figure 5. Cumulative diameter growth of 12 specimens of *Schinus terebintifolius* in hydromorphic soil environment for a 5-year period.

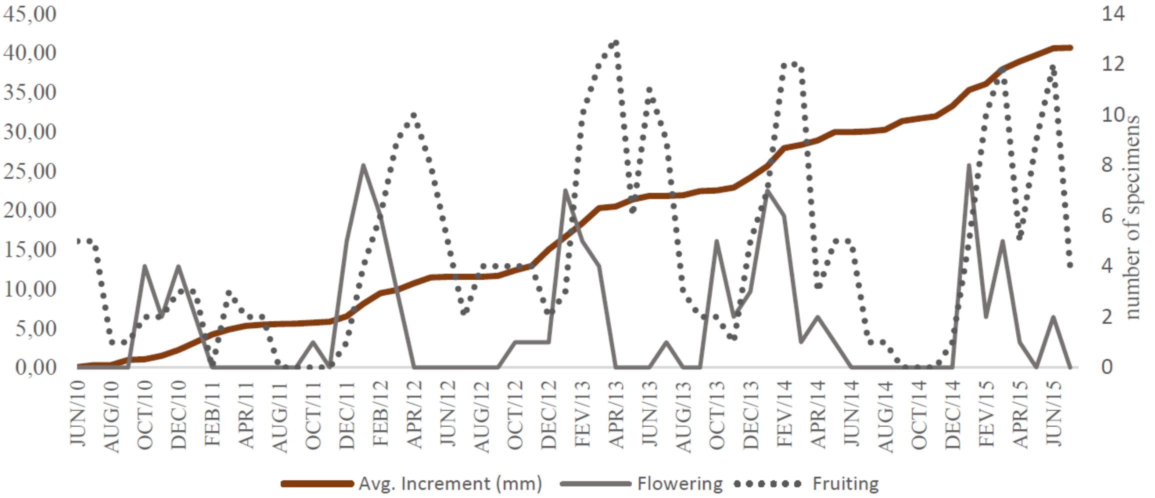

Figure 6. Growth and reproductive phenology of *Schinus terebinthifolius* in hydromorphic soil environment.

3.3. Seasonal decomposition

The estimated seasonal indices shown in Table 1 represent the effect of each season over the species radial growth as well as the respective magnitudes of events. Our results showed that the phenophases assessed during the time series were seasonal related and occurred in the same period of each year. In general, the phenology index values were lower on the second semester, and phenological activities were significantly more intense between January and April of each year.

Tree budding began in November, month in which we also recorded high rates of senescent leaves. Therefore, the rates of mature leaves only increased from December onwards. Although the budding peaks occur almost alternately in the subsequent months, the mature leaf rates remained high, likely due to no leaf fall in such period. Reproductive phenophases occurred from December to April of each year, but the flowering was more intense between December and March. Also, it was observed that the diameter increment coincided with the flowering period.

Resource allocation for stem radial growth was higher in January and lower in July. Furthermore, based on the data of seasonal decomposition shown in Table 1, we observed an even distribution of resources for both diameter increment and flowering.

In fact, the correlation test Pearson proved the direct relationship between diameter increment and flowering ($p = 0.81 < 0.005$). Such strong correlation indicates that the flowering season also marks the beginning of the diameter increment period.

Table 1. Seasonal indices of vegetative and reproductive phenophases as well as diameter increment of *Schinus terebinthifolius*. The four major values are shown in bold and the four lower ones are underlined.

	Leaf budding	Mature Leaf	Senescent Leaf	Flowering	Fruiting	Radial increment
July	-4.13	1.04	**1.13**	-1.45	-0.51	-0.87
August	-4.52	-2.20	-0.14	-1.74	-2.12	-0.78
September	-5.00	-2.19	**4.01**	-1.75	-2.78	-0.29
October	-0.66	-2.19	**5.41**	-0.04	-2.93	-0.41
November	**2.86**	-1.70	**3.88**	-1.05	-3.29	-0.38
December	0.66	0.79	-1.69	**0.43**	-2.46	**0.66**
January	**2.34**	0.79	-2.27	**5.66**	-0.09	**1.03**
February	-1.37	**1.47**	-1.95	**3.53**	**3.56**	**0.96**
March	1.29	**1.45**	-2.62	**0.78**	**4.90**	**0.29**
April	**2.68**	**1.06**	-2.32	-1.22	**2.47**	0.00
May	1.44	0.62	-1.63	-1.47	1.49	0.27
June	**4.42**	**1.05**	-1.82	-1.68	**1.76**	-0.49

4. DISCUSSION

4.1. *Phenology*

Plant development and survival have been often quantified and compared with conventional measurements based on individual characteristics (Mckown et al., 2013). As seasonal or cycle events occur in plants, several ecophysiological relationships are established (Ackerly, 2004 Pau et al., 2011) and might be studied, because they interfere with the plant resource reorganization for both growth and development efforts.

Our findings showed phenological patterns relating to vegetative and reproductive phenophases, which occurred in overlapping periods. *Schinus terebinthifolius* presents a pattern of intermittent budding and frequent periods of leaf senescence. This species is not deciduous and has leaves during the whole year, in spite of a higher leaf fall between September and November.

Thus, in environments with low climate seasonality and without defined dry season, leaf fall and continuous budding would be the most advantageous strategies for such plant species, by allowing senescent leaves to remain attached to branches until the uptake and transport of nutrients (Jackson, 1978). It would also contribute to the maintenance of photosynthetic rates along the whole year (Wagner et al., 2016).

As reported in this study, the process of leaf senescence and later leaf fall occurring over the high rainfall months of October, November, December, January and February is crucial to satisfy plant nutrition needs, either by the nutrient redistribution prior to leaf fall or the nutrition intake derived from decomposition of soil organic matter (Bazzaz and Ackerly, 1992). Plant nutrition demand may be achieved by photosynthesis and nutrient intake, as well as the recycling of products degraded by senescent leaves (Gregersen et al,. 2008). Reallocating resources from leaf fall seems to play a major role, so that phenophases and radial growth can be more efficient relating to this species.

Flowering periodicity over tropical regions varies a lot. However, if a species has a longer flowering period which coincides with leaf renewal cycle, it might also be beneficial to the reproductive success of the species, by adjusting to extreme climate conditions (drought or precipitation excess), lack of pollinators or a strategy of protection against herbivore attack (Pallardy, 2006).

The high correlation between flowering and stem diameter increment in this study corroborates that the reproductive phenophase may trigger tree radial growth. This behavior has also been reported to other tropical species, to which phenological events may occur simultaneously (Lieth, 1974) as far as radial growth is concerned. In a study performed in the Amazon rainforest, Schöngart et al. (2002) has reported that the radial growth coincides with the beginning of budburst. According to Bordiert (1994), stem diameter increment in tropical forests is associated with budding and the beginning of flowering. It also corroborates Yáñez-Espinosa et al. (2010), to whom budburst and flowering are directly linked to radial growth while assessing phenology and growth periodicity of perennial trees within subtropical forests.

4.2. *Stem diameter increment*

The average growth rate of 4.94 mm/year observed in *S. terebinthifolius* is typical for tropical forest species, to which annual radial growth ranges from 0.5 to 6 mm, reaching up to 15 mm (Turner, 2001). Our findings showed that the radial growth varied over the course of five years. Such variations might be due to environmental seasonalities of temperature or soil water availability. It is worth mentioning that the study area is in a flood plain covered by an alluvial forest, where shortage of available water is not a limiting factor, unless severe climate events (drought or floods) occur. Consequently, rainfall did not show to be a key factor for diameter growth, although it might play an important role since S. *terebinthifolius* had the highest diameter increment rates under conditions of higher water availability (Figure 3) associated with photoperiod and higher temperatures.

Moreover, studies focused on tree rings as indicators of growth of subtropical species have indicated that lower temperatures are limiting factors for radial growth (Oliveira et al., 2010 Longhi-Santos, 2013). During autumn and winter seasons, low temperatures induce a direct metabolic depression (dormancy), while increase in temperature induces significant tree-ring growth.

It is important to point out that over a 5-year period**,** there were significantly lower increment rates in August of each year, resulting in bark reduction due to lower moisture content (Kanieski *et al.,* 2013). August is the driest month of the year in the study area, with lower rainfall (Figure 1). Such bark reduction was verified on the dendrometer bands prior to the season of higher growth as well as temperature and rainfall rise.

Plant dynamics, in terms of resource allocation demands, might be conflicting to favor a phenological activity over another (Begon *et al.*, 2006) and, in turn, it may endanger such activities. However, based on the data of seasonal decomposition, this phenomenon was not observed in the present study. On the other hand, we observed that both reproduction and growth occurred at the same time range during a 5-year period (Table 1).

According to our findings, it seems that the flowering event triggers the resumption of higher radial growth of *S. terebinthifolius*. The stem diameter increment of this species is also associated with temperature rise, photoperiod and volume of rainfall.

5. CONCLUSION

Considering *Schinus terebinthifolius*:

Apparently, there was no conflicting demand for resources, but an optimized distribution of them, regulated mainly by the allocation of nutrients derived from leaf senescence, temperature, and photoperiod (*question I*).

Reproductive phenophases did not cause a reduction in the diametric increment *(question II).*

The monthly increment of the specie diameter growth occurred from November to February (*question III*).

Schinus terebinthifolius allocated its resources for growth and reproduction simultaneously when growing on a hydromorphic soil. Diameter increment was intrinsically related to the flowering phenophase (*question IV)*.

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CORRESPONDENCE TO

Jaçanan Eloisa de Freitas Milani
Universidade Federal do Paraná,
Av. Luiz de Camões, 2090, CEP: 88.520-000, Lages, SC, Brasil.
e-mail: jacanan.milani@gmail.com

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