PHENOLOGICAL BEHAVIOR OF THE INVASIVE SPECIES *Ligustrum lucidum* IN AN URBAN FOREST FRAGMENT IN CURITIBA, PARANA STATE, BRAZIL

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Abstract

Understanding the causes of biological invasions by exotic species is very important for biodiversity conservation, for which knowledge of their phenology is of paramount importance. The aim of this study was to characterize the phenology of *Ligustrum lucidum* W.T.Ait., its relations with the weather, and understand how its phenological behavior can facilitate its capacity of invasion in an urban Araucaria Rainforest fragment in Curitiba, Brazil. The evaluated phenophases were: young, mature and old leaves; flower buds and anthesis; unripe, mature and old fruits. The phenophases were correlated with climatic variables of maximum, medium and minimum temperature and precipitation using the *Spearman* correlation. The vegetative phenophases were observed throughout the whole study period, flowering predominated from October to January, and fructification from February to September. The only significant correlation between phenophases and climatic variables was represented by the relation between temperatures and fruiting, with negative correlations above 0.8 ($P < 0.01$). We concluded that rainfall did not influence the phenological behavior, and the temperature only influenced the ripening of fruits. Including flowering and fruiting, the species remained within at least one reproductive phenophase throughout the year. The prolonged period of fruiting can be an important advantage that facilitates the invasion of *L. lucidum* in the Araucaria Rainforest.
Keywords: Alien species; phenophases; rainfall; temperature.

Resumo

Comportamento fenológico da espécie invasora Ligustrum lucidum em um fragmento florestal urbano em Curitiba, Paraná, Brasil. Compreender as causas de invasões biológicas por espécies exóticas é muito importante para a conservação da biodiversidade, podendo a fenologia ser uma relevante ferramenta para esse fim. O objetivo deste estudo foi caracterizar a fenologia de *Ligustrum lucidum* W.T.Ait., suas relações com o clima, e entender como seu comportamento fenológico pode facilitar sua capacidade de invasão em um fragmento urbano de Floresta com Araucária em Curitiba, Brasil. As fenofases avaliadas foram: folhas jovens, maduras e velhas; botões florais e antese; frutos imaturos, maduros e velhos. Usando a correlação de Spearman, as fenofases foram correlacionadas com as variáveis climáticas temperatura máxima, média, mínima e precipitação. As fenofases vegetativas foram observadas ao longo de todo período de estudo, a floração predominando de outubro a janeiro e a frutificação entre fevereiro e setembro. A única correlação significativa entre fenofases e as variáveis climáticas foi representada pela relação entre temperaturas e frutificação, com correlação negativa acima de 0,8 ($P < 0{,}01$). Conclui-se que as chuvas não influenciaram o comportamento fenológico e a temperatura apenas influenciou o amadurecimento dos frutos. Incluindo floração e frutificação, a espécie mantém pelo menos uma fenofase reprodutiva durante todo o ano. O período prolongado de frutificação pode ser uma importante vantagem que facilita a invasão de *L. lucidum* na Floresta com Araucária.
Palavras-chave: Espécie exótica; fenofases; precipitação; temperatura.

INTRODUCTION

Invasive species are defined as those species which, when established in new territories proliferate, disperse and persist to the detriment of species native to the particular ecosystem, and thus cause changes in ecological processes (GISP, 2005). In the modern day, these species constitute one of the most important ecological problems and are considered the second leading cause of global environmental change, affecting the conservation of biodiversity and ecosystem services (FERRERAS *et al*., 2008).

There are some characteristics that lead plants species to become invasive, such as: rapid growth rate, high production of fruits, easy dispersion of seeds, high longevity of the seeds and germination rate, early maturation, long flowering and fruiting periods, a general pioneering habit and absence of natural enemies (GENOVESI; CARNEVALI, 2011).

Due to the high level of modification in the remaining Atlantic forest, it is quite common that native species are forced to share their niches with invasive species. This leads to the necessity for information about the reproductive behavior of invasive species, which can be used to support methods for their control (CHRISTIANINI, 2006).

With a high level of anthropic pressure on natural communities, phenology studies are of increasing importance, and, especially in the context of climate change (CHEN and XU, 2012), they become a basis for the conservation of native species and control of invasive plants. As such, phenological differences between native and invasive species can define the success of these species (WOLKOVICH *et al*., 2013). The establishment of invasive species can be associated with disturbances or changes in the environment as well as the different phenological strategies between the species.

Ligustrum lucidum W.T.Aiton – Oleaceae, is popularly known as Glossy privet and was introduced from China to Brazil for use in urban tree planting programs. Considering its good adaptation to different environments, the species has dispersed very quickly, invading several natural areas in southern Brazil and Argentina (GISP, 2005; HUMMEL *et al*., 2014).

With fruits typically dispersed by birds (FERRERAS *et al*., 2008), this species spreads quickly in different environments. This coupled with its rapid growth and shade tolerance, makes the species highly competitive (GISP, 2005; HOYOS *et al*., 2010), exerts strong pressure and damages the structure of some native forests ecosystems (ARAGÓN and GROOM, 2003; HOYOS *et al*., 2010; HUMMEL *et al*., 2014).

The aim of this study was to evaluate the phenology of *Ligustrum lucidum* and understand how its phenological behavior contributes to its invasiveness in an urban Araucaria Rainforest fragment in Curitiba, Parana, Brazil. A secondary aim was to verify if the climatic variables of precipitation and temperature influences the phenological behavior of the species.

MATERIAL AND METHODS

This study was conducted in the Polytechnic Center of the Federal University of Parana (25º26’52,80” S e 49º14’09,23” W), in Curitiba, Parana state, at 914 meters altitude. According to the climatic classification of Koeppen, the study area is under influence of the Cfb climate, mesothermal humid subtropical, without a dry season, with mild summers and the possibility of frosts in winter. Curitiba is located in the first Paraná plateau and its geological composition is characterized by the Guabirotuba formation (MAACK, 2012).

The study area was situated in a fragment of Araucaria Rainforest of 55,000 m^2, in an undulated relief, with Hydromorphic soils and Cambisoils. In one phytosociological study in the area a high structural expression of the invasive species *Ligustrum lucidum* was found (REGINATO *et al*., 2008). As illustrated by GISP (2005), this is a tree species with simple and opposite leaves that produces numerous small and globose dark purple fruits, arranged in terminal panicles.

We selected ten mature individuals under similar environmental conditions, with height between 10-12 m and diameter at breast height between 24.2-47.4 cm. The presence or absence of phenophases was recorded monthly during 12 months, and classified as young, mature or old leaves, with reproductive phenophases classified as flower buds, anthesis, unripe, mature and old fruits. Phenophases were analyzed using the qualitative method, by the simple presence or absence, and also by the semiquantitative method that ranks the phenophase in five categories of intensity. This ranking scale ranges from 0 to 4, where 0 is absence; 1 represent 1-25%; 2 represent 26-50%, 3 represent 51-75% and 4 represent 76-100%. These semiquantitative data were used to calculate the intensity index of the phenophases for each month using the formula proposed by Fournier (1974): $I=[(\Sigma i).(4n)^{-1}].100$, where I = intensity index of a given phenophase; Σi = sum of the intensity indexes of each sampled tree; n = number of sampled trees.

Meteorological data of precipitation (mm) and minimum, medium and maximum temperatures (ºC) for the study area were obtained from SIMEPAR (Parana Meteorological System), registered in a meteorological station situated 400 meters from the studied area. The *Spearman* correlation was used to analyze the relation of the meteorological variables with the observed phenophases.

In order to verify the occurrence of phenophases throughout the study period, as wellconcentration (r) and seasonality, were used circular statistical analysis with support of the software ORIANA 3 (KOVACH, 2004). With regard to the concentration, (r) values closer to 1 indicates high concentration of a phenophase in a given period. The seasonality was tested by the Rayleigh test (z), where the phenophases that showed the mean average angle (p) <0.05 were considered seasonal (ZAR, 1999).

RESULTS

According to figure 1, during the period of study it was observed that the highest average values of maximum temperature were 29.1º C and 30.4º C in February and January, respectively. The lowest means of minimum temperature were 11.5º C (June) and 9.8º C (July). Precipitation occurred in every month, however it was not regular during the year. The highest value was observed in March, with 225.4 mm, with the lowest values detected in April and July – 73.2 mm and 42.6 mm, respectively.

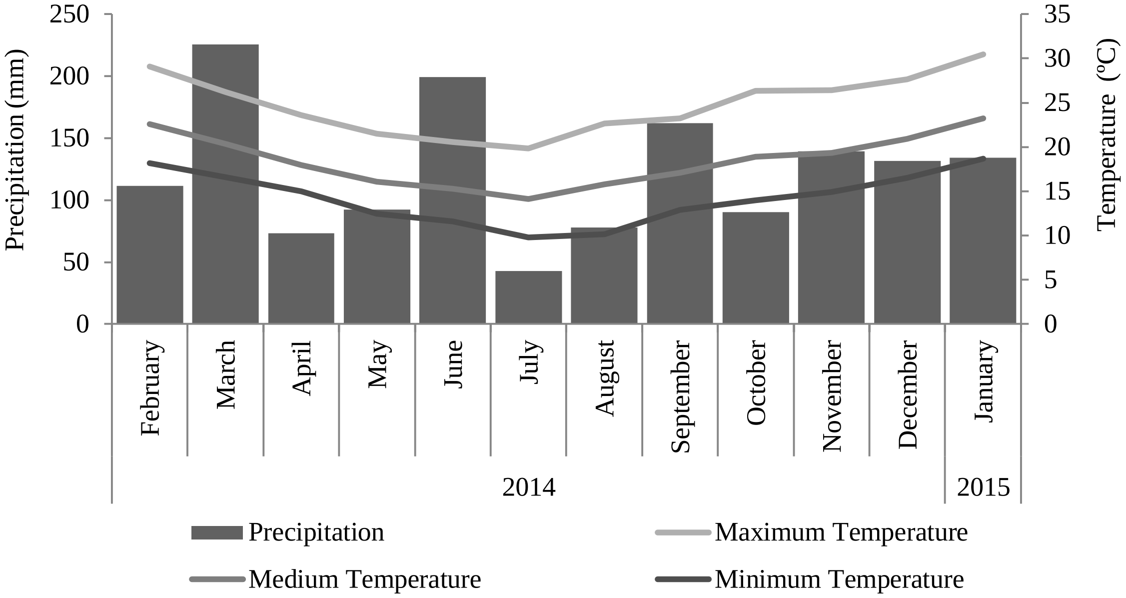

Figure 1. Meteorological variables (accumulated precipitation and temperature means) registered in Curitiba during the period of study (Source: Parana Meteorological System – SIMEPAR).
Figura 1. Variáveis meteorológicas (precipitação acumulada e médias de temperatura) registradas em Curitiba durante o período de estudo (Fonte: Sistema Meteorológico do Paraná – SIMEPAR).

There was no significant correlation between any of the studied phenophases and precipitation, indicating that this variable did not affect the phenological behavior of *L. lucidum* (Table 1).

Table 1. Spearman correlation coefficients for each meteorological variable and the phenophases of *L. lucidum.*
Tabela 1. Coeficientes de correlação de Spearman para cada variável meteorológica e fenofases de *L. lucidum.*

Phenophases	**Precipitation**	**Maximum temperature**	**Medium temperature**	**Minimum temperature**
Young leaf	- 0.02	- 0.04	- 0.24	- 0.31
Mature leaf	0.20	- 0.06	- 0.17	0.27
Old leaf	- 0.06	- 0.52	- 0.48	- 0.39
Flower buds	0.19	0.25	0.09	0.04
Anthesis	- 0.22	0.13	0.03	- 0.01
Unripe fruit	- 0.18	0.29	0.47	0.53
Mature fruit	- 0.27	- 0.77**	- 0.62*	- 0.56
Old fruit	- 0.08	- 0.82**	- 0.83**	- 0.83**

* = significant at the 0.05 level of probability; ** = significant at the 0.01 level of probability.

There was a significant correlation at 0.01 level between the maximum temperature and the phenophases of mature and old fruits (Table 1). The coefficients are negative and high, showing that the fruiting occurs when the temperatures are lower. A significant and negative correlation was also found between average temperatures and the phenophases mature (0.05) and old fruits (0.01).The phenophase old fruit also presented significant correlation with the minimum temperature at 0.01 level. These correlations indicate that the temperature influences the maturation of the *L. lucidum* fruits, but apparently has no influence on the vegetative and floral phenophases.

The intensity index calculated for the phenophases (Figure 2) demonstrate that individuals maintained the leaves during the entire period of study. The budding began in June and continued until January. The production of new leaves and presence of old leaves was constant along the entire period.

Flowering phenophases were only recorded in four months. During June, July and August it was found that one individual showed bud and anthesis unlike the other individuals observed.

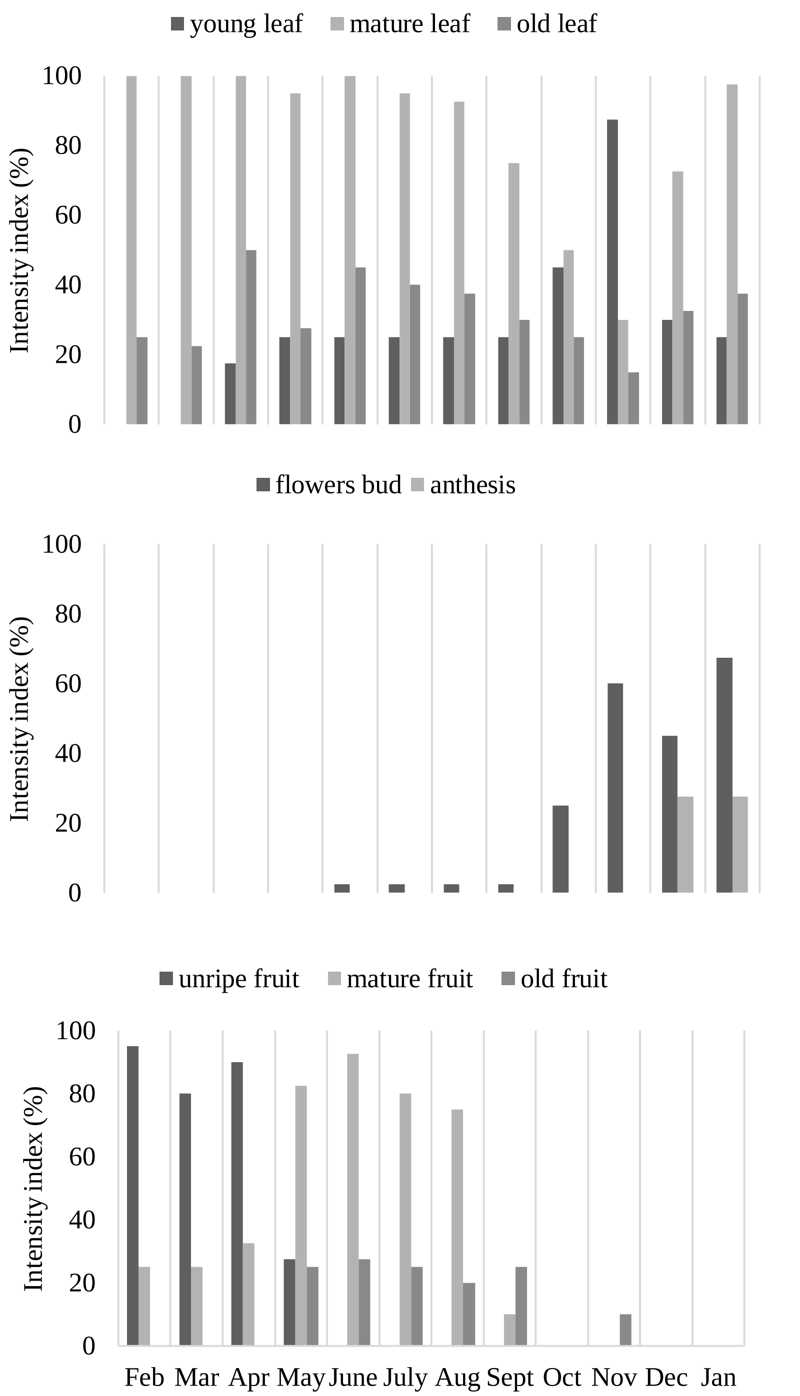

Figure 2. Fournier intensity index for *Ligustrum lucidum* individuals evaluated from February 2014 to January 2015 in Curitiba, Brazil.

Figura 2. Índice de intensidade de Fournier para indivíduos de *Ligustrum lucidum* avaliados no período de fevereiro de 2014 a janeiro de 2015 em Curitiba, Brasil.

Unripe and mature fruits were observed from February until September. During the first four months of observations, all individuals presented unripe fruits. The species showed presence of mature fruits for eight months and the old fruits occurred from May to November. In addition, it was observed that the fruiting coincides with the end of summer, extending through the fall and decreasing in late winter (Figure 3).

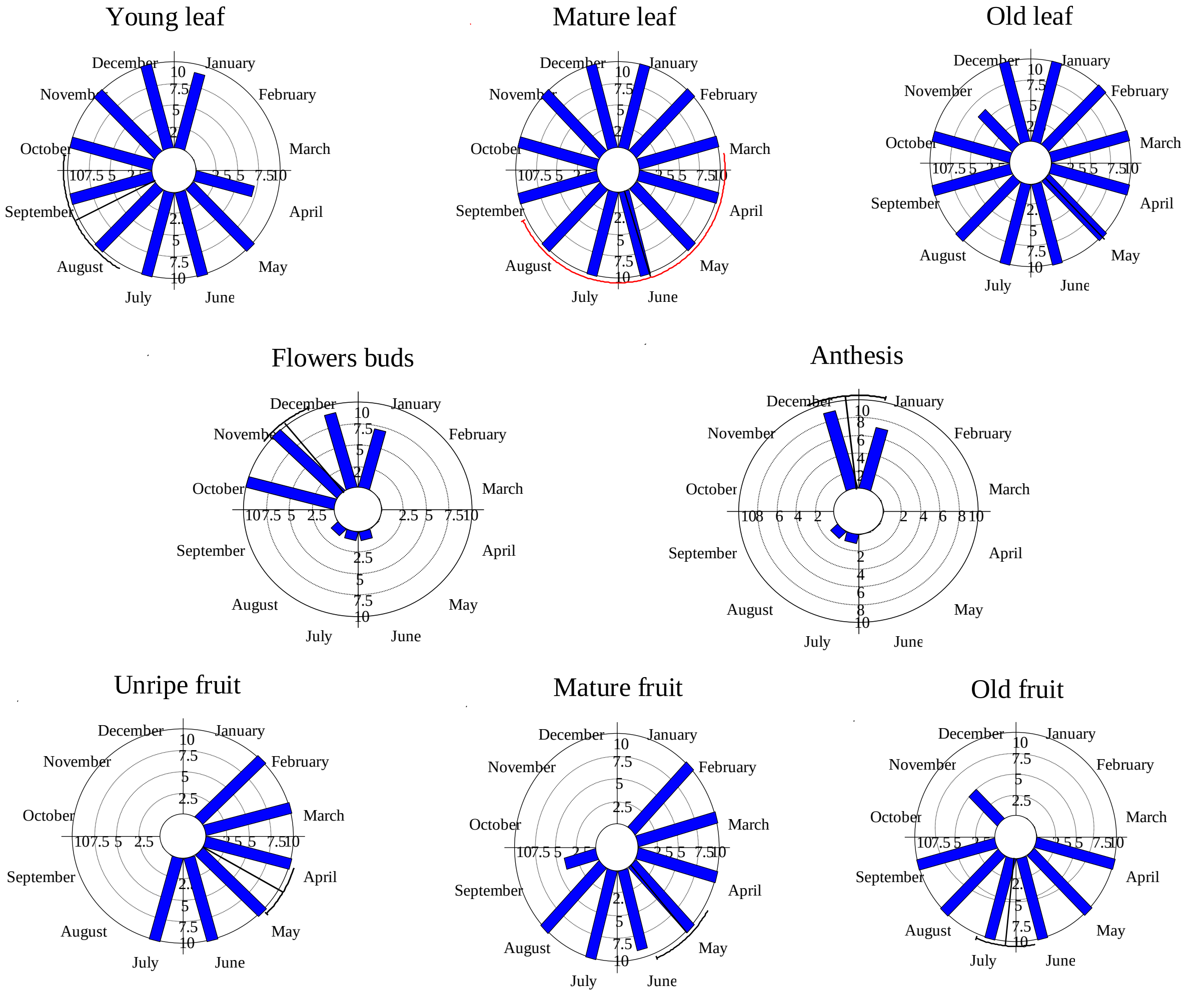

Figure 3. Circular histograms generated on Oriana version 3.0 for phenophases of individuals of *L. lucidum* evaluated from February 2014 to January 2015 in Curitiba, Brazil.

Figura 3. Histogramas circulares gerados no Oriana versão 3.0 das fenofases de indivíduos de *L. lucidum* avaliados no período de fevereiro de 2014 a janeiro de 2015 em Curitiba, Brasil.

With the statistics obtained through the circular histograms (Table 2), it was observed that the vegetative phenophases were not concentrated, as indicated by the very low (r) coefficients. Both vegetative phenophases and reprodution are seasonal, except, for the mature and old leaves.

Table 2. Statistics generated on Oriana version 3.0 for phenophases observed in *L. lucidum* individuals evaluated from February 2014 to January 2015, in Curitiba, Brazil.

Tabela 2. Estatísticas geradas no programa Oriana versão 3.0 para fenofases observadas em indivíduos de *L. lucidum* avaliados no período de fevereiro de 2014 a janeiro de 2015 em Curitiba, Brasil.

Variables	**Young leaf**	**Mature leaf**	**Old leaf**	**Flowers buds**	**Anthesis**	**Unripe fruit**	**Mature fruit**	**Old fruit**
Observations	96	120	119	37	20	40	74	51
Concentration (r)	0.23	0	0.01	0.73	0.80	0.85	0.49	0.65
Rayleigh test (z)	5.25	-	0.01	19.83	12.68	28.64	17.42	21.66
Rayleigh test (p)	0.01	-	0.99	0.00	0.00	0.00	0.00	0.00

DISCUSSION

The correlation values found between phenophases and temperature, especially for fructification, can express an affinity for this climatic variable, which can be an indication of phenotypic plasticity. According to Godoy *et al*. (2006), the phenotypic plasticity of invasive species plays an important role in reproductive success, as this plasticity allows the plants to respond to local environmental cues, inducing them to express phenotypes that allow them to develop in a wide range of environments.

With similar objectives to those of the present study (including native species and also the invasive *L. lucidum* in an alluvial forest), Milani (2013) reported that the temperature showed a significant influence on fruiting of native and exotic species. The author points out that this affinity with temperatures can be favorable to the colonization, because this exotic species has no limitations with respect to temperature, even in an environment characterized by low temperatures.

Furthermore, the temperature showed significant correlation with the reproductive phenophases of *Ligustrum lucidum*, and the same influence of temperature on phenological phases can be observed in the study of Yu *et al.* (2014) in the temperate forests of China. Those results were observed through phenological variables, with growth and development of trees highly influenced by the average temperature of the spring and summer, although the start of the growing season was negatively correlated with rainfall.

The absence of a correlation between phenophases and rainfall reflects the results of Marques *et al*. (2004), which affirm that precipitation, by having a great variation during the year, would not be a good predictor of phenological annual cycles of Araucaria Forest, where *L. lucidum* is established. Conversely, in the study of Pezzini *et al*. (2014) on the phenology of the in seasonally dry tropical forests of Southeastern Brazil, a high influence of seasonality on vegetative phenophases of many native species was observed.

The vegetative behavior of *L. lucidum* allows its classification as evergreen, according to the classification of Bordiert (1994). The behavior of evergreens can be a strategy to achieve maximum photosynthetic efficiency throughout the year Larcher (2006), ensuring supply energy and resilience to adverse conditions. For this reason, it is possible to justify the absence of significant correlation of the vegetative phenophases with climatic variables.

However, it was observed that flowering occurs predominantly at the end of the year, between October and January, whereas between February and October the formation and maturation of fruits occurs. These variations in periods of flowering or fruiting were explained by Lyons and Mully (1992), as a reflection of the density of trees, which can act to advance or delay the blossoming of some individuals of the species. This difference may result in selection for faster growth and early flowering.

According to Bleasdale (1997), the flowering is an essential point for the survival of many plants. Also studying *L. lucidum* in the Araucaria municipality, Milani (2013) reported results that corroborates with our results, where the reproductive phenophases bud flower and anthesis occurred from August to December and from October to January, respectively. In addition, a similar result was found in the study of Descanio *et al*. (1994), who studied the environmental performance of native forests and *L. lucidum* forests on River Plate in Argentina, and observed that the exotic species had flowers from November to March, representing 92% of the total flowering frequency of the different studied species.

A study by Bleasdale (1997) reported that fruiting depends on environmental factors, and the results found in the present study are similar to that described. Bleasdale (1997) noted that the phenology of species is primarily controlled by the temperature, followed by the moisture in regions with well-defined seasons.

The long fruiting period was highlighted by Staggemeier *et al.* (2007). Their study evaluated the phenology of native species of the Atlantic forest, suggesting that low seasonality offers few restrictive conditions for the development and the ripening of fruits throughout the year. This is extremely advantageous for invasive species, such as *L. lucidum,* and its divergent behavior with regard to native species can be an advantage due to less competition for the dispersers (EMER; OLIVEIRA; ALTHAUS-OTTMANN, 2012).

In Córdoba, Argentina, Ferreras *et al.* (2008) observed that the development of the fruits of *L. lucidum* happens from March to May and its maturation occurs from May to the end of September. Over this period, the native species presented only few ripe fruits, this being one of competitive advantage for invasive species as it thus becomes the main source of food for dispersers (in this case the birds), and so increases its capacity to spread.

In the study of Descanio *et al*. (1994), it was observed that the fruits of *L. lucidum* represented 88% of forest reproductive structures throughout the year. The constant presence of fruits was also acknowledged in this study which again suggests that the fruiting regularity and abundance are favorable to the invasion success of this species.

A study by Hoyos *et al.* (2010), to investigate the invasion of *L. lucidum* in a native forest of Cordoba, Argentina, found fruit production over the coldest months, while native species provided fruits usually in the warmest months. In the present study *L. lucidum* has produced at least one reproductive phenophase throughout the whole year. This result indicates that the species is always investing in reproduction efforts, the dispersal of genetic material and colonization of new areas.

The dispersal of *L. lucidum* is zoochoric (ARAGÓN, GROOM, 2003; GISP, 2005), which can be favorable for the successful invasion of this species in the Araucaria Rainforest (REGINATO *et al*., 2008), as well as others environments (DESCANIO *et al.*, 1994; FERRERAS *et al*., 2008; HOYOS *et al*., 2010; HUMMEL *et al.*, 2014). The continuous fruit production has been a strategy for maintaining resources to seed dispersers, so, *L. lucidum* can take advantage of this behavior overcoming native arboreal species. This was also pointed by Hummel *et al*. (2014), who found that the abundant seed production and efficient zoochoric dispersal are important factors that can be facilitate the development of *L. lucidum*. In fact, species of *Ligustrum* can form dense groups that drive out the native vegetation, quickly dominating the lower strata, which results in reduction in the diversity of species and changes in the community structure (GISP, 2005).

CONCLUSIONS

- Temperature influences the fruiting patterns of *Ligustrum lucidum* and may be a variable that can be used to predict the fruit ripening behavior, a finding which can be used to support start time of control programs. It was found rainfall had no significant correlation with any of the investigated phenophases.
- The species is characterized as evergreen given that the mature leaves were observed in the whole year. The predominant flowering of *L. lucidum* lasted four months starting in October and remaining until January. The predominant fruiting period proved to be longer, from February to September, including unripe, mature and old fruits.
- The prolonged period of fruiting, eight months, can be an important advantage that facilitates the invasion capacity of *L. lucidum* in the Araucaria Rainforest environment.

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