Spatial patterns of a tropical tree species growing under an eucalyptus plantation in South-East Brazil

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(With 5 figures)

Abstract

The objectives of this study were to evaluate the influence of propagules source and the implication of tree size class on the spatial pattern of *Xylopia brasiliensis* Spreng. individuals growing under the canopy of an experimental plantation of eucalyptus. To this end, all individuals of *Xylopia brasiliensis* with diameter at soil height (dsh) ≥ 1 cm were mapped in the understory of a 3.16 ha *Eucalyptus* spp. and *Corymbia* spp. plantation, located in the municipality of Lavras, SE Brazil. The largest nearby mature tree of *X. brasiliensis* was considered as the propagules source. Linear regressions were used to assess the influence of the distance of propagules source on the population parameters (density, basal area and height). The spatial pattern of trees was assessed through the Ripley K function. The overall pattern showed that the propagules source distance had strong influence over spatial distribution of trees, mainly the small ones, indicating that the closer the distance from the propagules source, the higher the tree density and the lower the mean tree height. The population showed different spatial distribution patterns according to the spatial scale and diameter class considered. While small trees tended to be aggregated up to around 80 m, the largest individuals were randomly distributed in the area. A plausible explanation for observed patterns might be limited seed rain and intra-population competition.

Keywords: colonisation, forest fragments, Ripley's K function, spatial distribution pattern, *Xylopia brasiliensis.*

Padrões espaciais de uma espécie arbórea tropical crescendo sob o dossel de um plantio de eucalipto no Sudeste brasileiro

Resumo

Os objetivos deste estudo foram avaliar a influência da fonte de propágulo e a implicação de diferentes classes de tamanho sobre o padrão de distribuição espacial de indivíduos de *Xylopia brasiliensis* Spreng. crescendo sob o dossel de um plantio experimental de eucalipto. Para isso, todos os indivíduos de *X. brasiliensis* com diâmetro à altura do solo (das) ≥ 1 cm foram mapeados em uma área de 3,16 ha no sub-bosque de um plantio de *Eucalyptus* ssp. e *Corymbia* spp., localizado no município de Lavras, MG. O maior e mais próximo indivíduo reprodutivo de *X. brasiliensis* foi considerado como fonte de propágulos. Foram utilizadas regressões lineares para avaliar a influência da fonte de propágulos sobre parâmetro populacionais (densidade, área basal e altura). O padrão de distribuição espacial das árvores foi avaliado por meio da função K de Ripley. O padrão geral demonstrou que a distância da fonte de propágulo teve forte influência sobre a distribuição espacial das árvores, principalmente as menores, indicando que quanto mais próximo à fonte de propágulos, maior a densidade e menor a altura das árvores. A população demonstrou diferentes distribuições espaciais de acordo com a escala analisada. Enquanto árvores menores tenderam a estar agregadas até uma escala de 80 m, os maiores indivíduos estavam aleatoriamente distribuídos na área. Uma explicação plausível para os padrões observados poderia ser a limitação espacial da chuva de sementes e a competição intraespecífica.

Palavras-chave: colonização, fragmentos florestais, função K de Ripley, padrão de distribuição espacial, *Xylopia brasiliensis.*

1. Introduction

The Brazilian Atlantic Rain Forest is considered one of the most threatened hotspots in the world (Myers et al., 2000). This important ecological area occurs as Humid Rain Forest in a narrow belt along the Atlantic Coast - from northeast to south Brazil – and becomes more deciduous the further inland due to a more seasonal climate. Floristic differences of this highly diverse forest on a large scale have been related to climatic gradients and edaphic factors (Oliveira-Filho and Fontes, 2000). Originally, this forest covered about 15% of Brazilian territory, but due to a historical deforestation process, this area has been reduced to a mosaic of different fragment sizes scattered across the landscape. In the state of Minas Gerais, forest fragmentation started in the second half of the 19th Century following selective logging, cattle raising, mining and fire (Oliveira-Filho et al., 1994)

Drawing upon this scenario, information about the ability of tree populations to cope with vegetation islands has become necessary for both forest fragment restoration and conservation. Having metapopulation theory (Levins, 1969) as the ecological framework, some studies have shown that some species are able to keep their dispersal movement among spatially isolated habitat fragments (e.g. Hewitt and Kellman, 2002). In this perspective, plant populations would be found as a source-sink system, where propagules from a good quality habitat (source) colonise a poor quality habitat (sink) (Dias, 1996) and the process of site occupancy would reflect the tree spatial pattern and the density variation over short distance in colonised areas (Condit et al., 2000). Seedling clumping and widely distributed adults would be the consequence of spatially limited seed dispersion and the density dependence process during recruitment (Condit et al., 2000; Hubbell, 2005).

Within forest fragments, the tree spatial pattern generally demonstrates strong variation over short distances and in different tree size classes due to the combination of dispersal and recruitment limitations (Hubbell, 2005). Therefore, studies taking into account the spatial pattern of trees must consider the employment of a method sensitive to the spatial scale as well as different phases of tree life-span.

Considering the implication of propagule source position and variations in competition during the life-span of a tree, in this study we have addressed the following questions: i) is the distribution of trees correlated with the propagules source distance? ii) do the spatial pattern of trees differ among different size classes?

The strategy for tackling theses questions was to focus our efforts on mapping a population of *Xylopia brasiliensis*, a very common Annonaceae in highly-drained deep soils in semi-deciduous tropical forests in southeast Brazil, growing in a sink habitat, considered in this study the understory of a 30 year-old plantation of *Eucalyptus* spp and *Corymbia* spp., surrounded by a matrix composed of different elements.

2. Materials and Methods

2.1. Area description

The current study was carried out in the understory of a 3.16 ha experimental plantation of *Eucalyptus* spp. and *Corymbia* spp. established in the early 70's, situated in the Federal University of Lavras (UFLA). This plantation is located in the municipality of Lavras, SE Brazil (21° 13' 17'' S and 44° 57' 47'' W), at about 900 m above sea level (Figure 1). The climate is Cwa, following the Köppen classification, with a mean annual rainfall of 1343.3 mm and mean annual temperature of 19.3 °C. The rainfall is concentrated from November to February (Brasil, 1992). The study area is surrounded by a matrix composed of different elements, such as pasture, agriculture, native fragment forest and university buildings. The nearest block of natural vegetation is a 4.64 ha montane semi-deciduous forest about 40 m away (Figure 1).

2.2. Species description

Xylopia brasiliensis Spreng. is a very common annonaceae in highly drained deep soils in semi-deciduous tropical forest in SE Brazil. Its ecological guilds classification is unclear: while some authors have classified it as light demanding (Lorenzi, 1992), others have as moderate shade demanding (Oliveira-Filho et al., 1996). The fruits are bird dispersed and produced from September to November (Lorenzi, 1992). This species has a great potential to be used in degraded area restoration, mainly in steeper sites (Klein, 1966) and its wood could be used in civil construction and in masts of sailing ships. Due to its ornamental aspect, *X. brasiliensis* could also be used in urban area gardens and parks (Lorenzi, 1992).

2.3. Study design and data analyses

The understory of the *Eucalyptus* spp. and *Corymbia* spp plantation was considered as a sink because we had reason to believe, based on field observation, that there was not any reproductive individual of *X. brasiliensis* in the area. Thus, all standing living trees of *X. brasiliensis* with diameter at soil height (dsh) ≥ 1 cm were measured

Figure 1. Image of the Satellite Ikonos (resolution 1.5 × 1.5 m) showing the position of the propagules source in a fragment of tropical semi-deciduous forest (a) and the experimental plantation where the individuals of *Xylopia brasiliensis* were sampled (b).

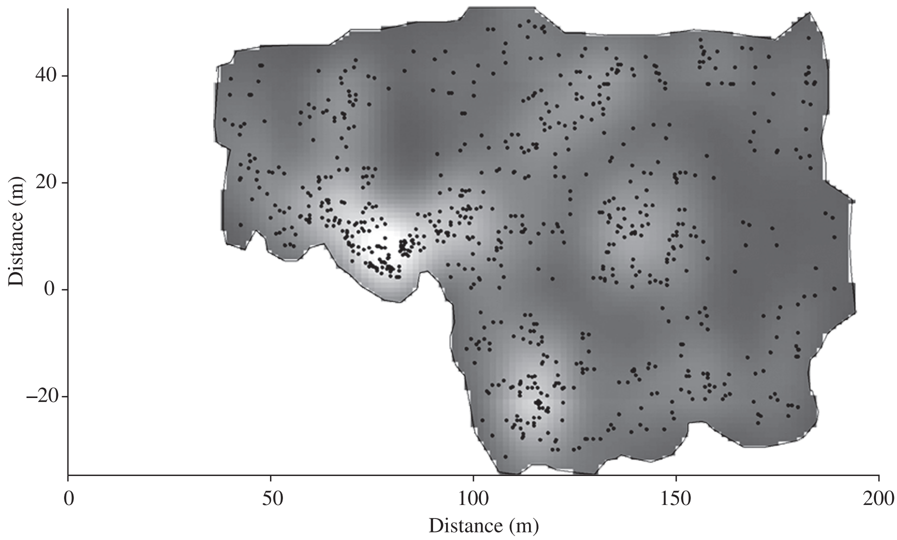

Figure 2. Spatial distribution of individuals of *Xylopia brasiliensis* growing under the canopy of an experimental plantation of eucalyptus, municipality of Lavras, SE Brazil. The origin of the graphic represents the propagules source. Shaded areas represent sites with lower density.

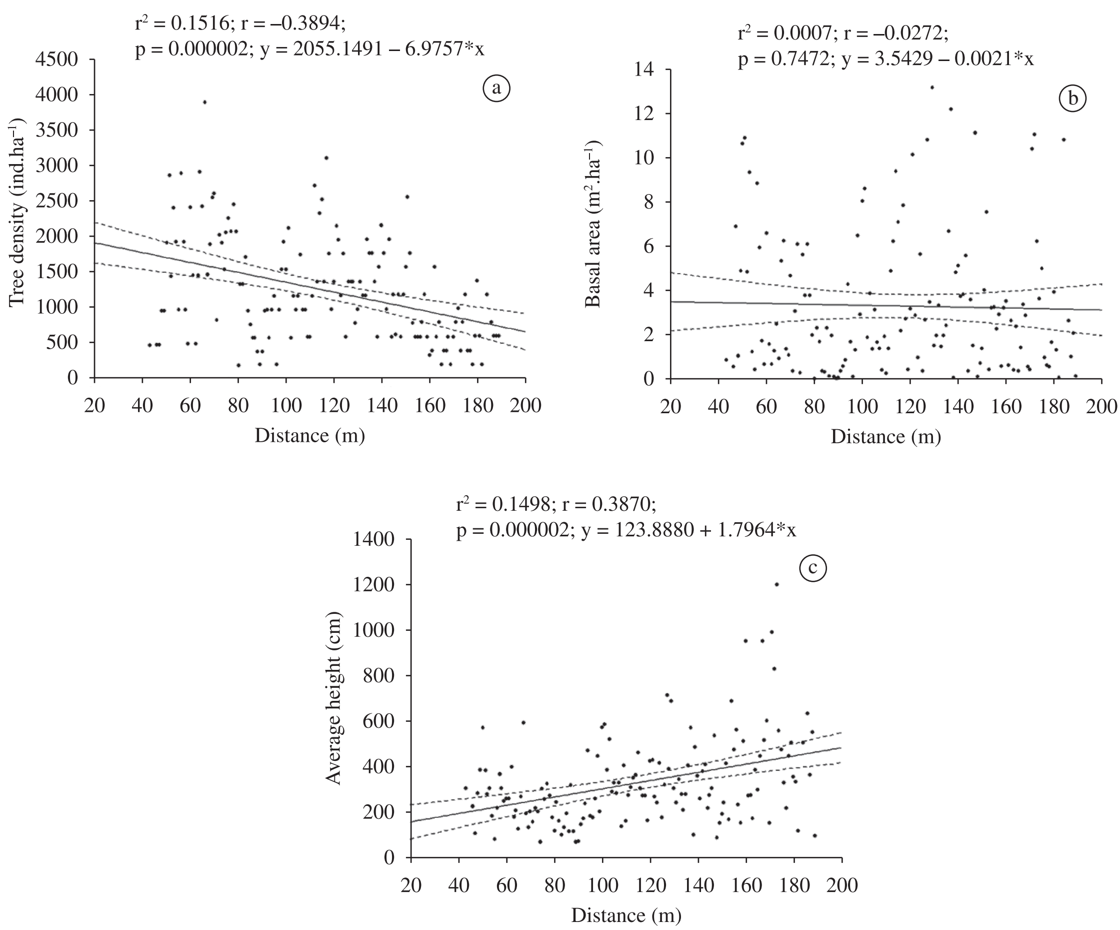

Figure 3. Linear regressions between the distance from the propagules source and the density (a), basal area (b) and average height (c) of the individuals of *Xylopia brasiliensis* under the canopy of an experimental plantation of eucalyptus, in the municipality of Lavras, SE Brazil.

(dsl and height) and mapped along a transect crossing the understory plantation toward its longest length. The propagules source was selected in a 4.64 ha fragment of tropical semi-deciduous montane forest about 40 m from the study area. Although the presence of more than one reproductive tree of *X. brasiliensis* in the fragment of natural forest and the fact that the seed shadow in the understory plantation may be a mosaic of multiple genetic sources, for the sake of simplicity and statistical analysis, we assumed the closest and the largest reproductive individual of *X. brasiliensis* in relation to the study area as the propagules source.

The influence of the propagules source location on the individuals' spatial distribution was evaluated using simple linear regressions between population parameters (density, basal area and average height) and the distance to the propagules source. The basal area was represented by the sum of sectional area at soil level of each individual. The spatial patterns for the total population and for each sample represented by the tree diametric class (class 1 = 1-2 cm, class 2 > 2-4 cm, class 3 > 4-8 cm, class 4 > 8-16 cm and class 5 > 16 cm) was analysed using Ripley K-function, also known as the reduced second order moment, where confidence envelope intervals were created through 500 permutation of complete spatial randomness using the total number of individuals sampled (Ripley, 1981; Câmara et al., 2001).

All analyses were done using R version 2.0.1 (R Development Core Team, 2004) and the library Splancs (Rowlingson and Diggle, 2004). In the Splancs function *Khat*, a boundary is used for implementing an edge correction for the non-recording of cases outside the study region (Rowlingson and Diggle, 1991).

3. Results

The survey totalled 778 trees with a total basal area of 2.11 m^2 (Figure 2). The effect of propagules source distance, determined by the linear association force among the studied variables, was stronger over density ($r = -0.5152$, $P = 0.0000$) than over basal area ($r = -0.2140$; $P = 0.0061$) and average height ($r = 0.1503$; $P = 0.0555$) (Figure 3). The nature of the correlation coefficient signal (r) indicates the association directions and P value indicates the probability of the r value is due

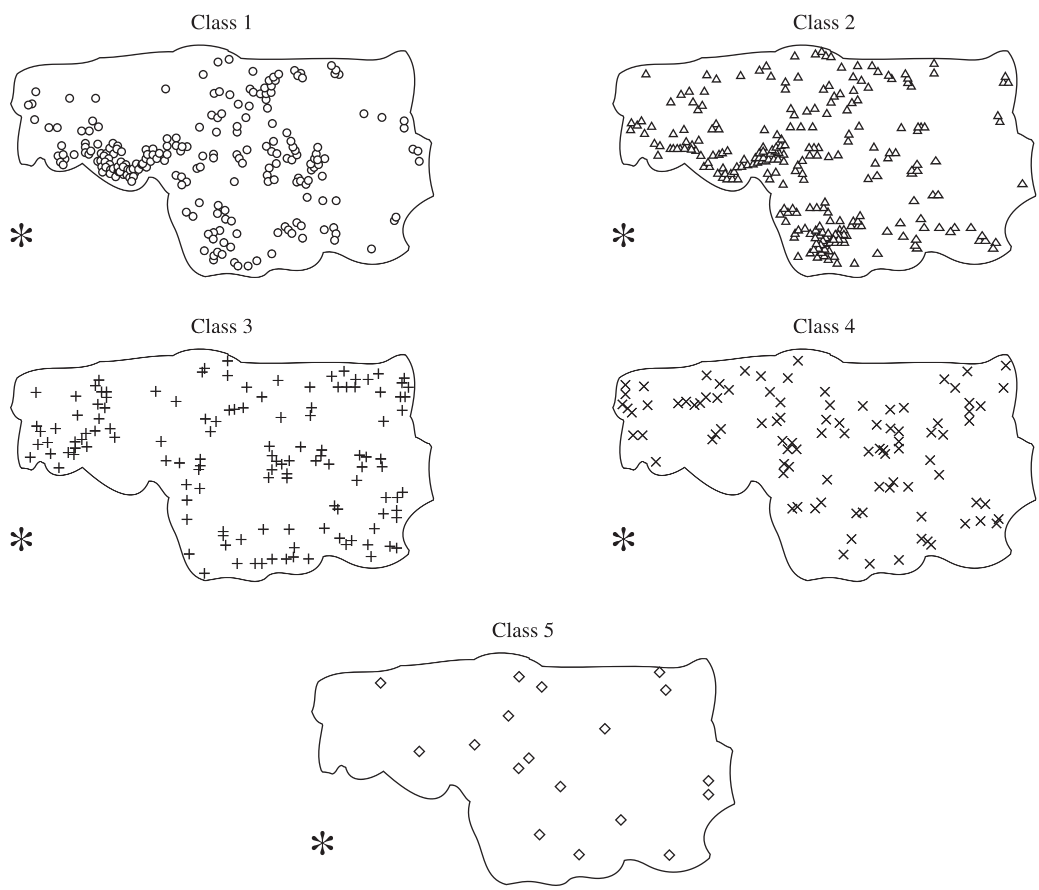

Figure 4. Spatial distribution of individuals of *Xylopia brasiliensis* in different diameter class (Class 1: 1-2 cm; Class 2: >2-4 cm; Class 3: >4-8 cm; Class 4: >8-16 cm and Class 5: >16 cm) growing under the canopy of an experimental plantation of eucalyptus, municipality of Lavras, SE Brazil. The propagules source location is represented by a "star".

to the randomness, showing the significance or not of the relation among the variables.

In summary, the linear associations indicated that the closer the distance from the propagules source, the higher the density and basal area and the lower the average height of individuals of *X. brasiliensis* (Figure 3), suggesting a high density of small trees close to the propagules source. Furthermore, the total basal area was dominated mostly by the sum of a large number of small trees than by the large trees. While small trees, belonging to diametric class 1 and 2, are concentrated mainly at the edge close to the propagules source, the large trees (diametric class 4 and 5) are sparsely distributed in the area (Figure 4).

The K-function indicated that the spatial pattern of the population individuals varied according to both the spatial scale and the diametric class (Figure 5). The spatial pattern of trees belonging to diametric class 1 and 2 was predominantly aggregated up to a distance of around 80 m. This pattern revealed the occurrence of high-density patches in the area, reflecting the high concentration of small trees close to the propagules source, as affirmed above. Since the total population was made up mostly of small trees, the total population spatial pattern was similar to that observed for diametric class 1 and 2. The individuals belonging to diametric class 3 were considered aggregated in a small spatial scale, up to around 10 m, and were randomly distributed when a large spatial scale was considered. The individuals belonging to class 4 and 5 were predominantly randomly distributed in the study area (Figure 4), seemingly showing no relation with the distance from the propagules source (Figure 5).

4. Discussion

Notwithstanding the small distance considered between the habitat source and sink (40 m), the results suggested that small blocks of Atlantic forest could be an important source of propagules. Based on our observation of small trees spatial clustering and the influence of

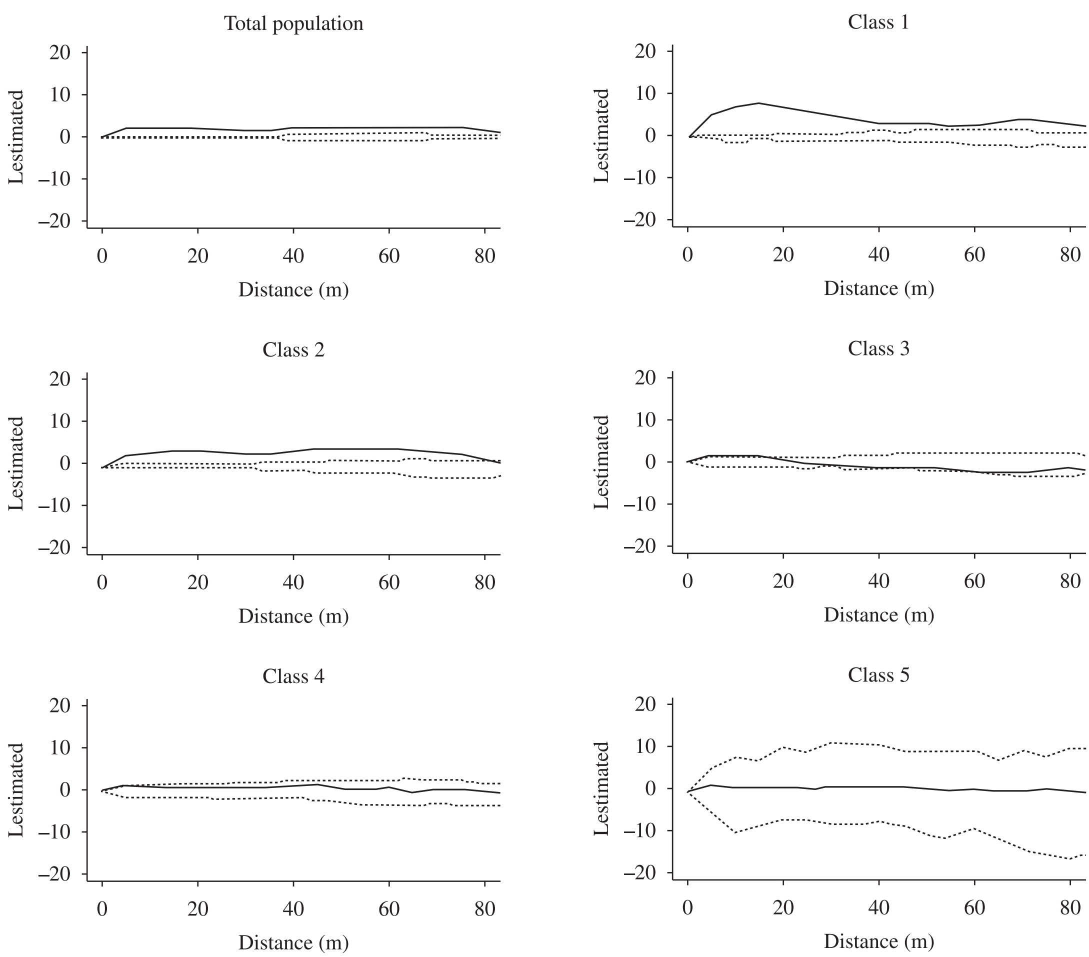

Figure 5. Ripley K function (estimated L) in different scales for the individuals of the total population, Class 1 (1-2 cm), Class 2 (>2-4 cm), Class 3 (>4-8 cm), Class 4 (>8-16 cm) and Class 5 (>16 cm) under the canopy of an experimental plantation of eucalyptus, in the municipality of Lavras, SE Brazil. Positive values indicate aggregation, negatives indicate regular distribution and the continuous lines inside of the dotted ones indicate randomly.

the propagules source over tree density, the propagules dispersion seemed to be very irregular in the area.

The same pattern of small tree spatial aggregation, indicating a strong variation over a short distance, has been found by many studies in tropical forests (Alvarez-Buylla and Martínez-Ramos, 1992; Hubbell et al., 1999; Nicotra et al., 1999). According to Stoyan and Penttinem (2000), this pattern could arise from irregular seed dispersion resulting in a high density of small trees in the neighbourhood of the propagules source, as demonstrated in this study by the strong negative association between tree density and distance from the propagules source. Despite not being tested in this study, the combination of small scale micro environmental changes (Stoyan and Penttinem, 2000), due to edge and gap formation, and specific micro environment requirements (Alvarez-Buylla and Martínez-Ramos, 1992; Hubbell et al., 1999; Nicotra et al., 1999) of *X. brasiliensis* might also be crucial factors.

Contrary to that observed for small trees, a random spatial distribution and a large space between individuals were observed for the largest individuals (diametric class 4 and 5). This pattern has been regularly found in tropical forest and has been suggested as a key factor for the co-existence of tree species, leading to high diversity in this environment (Janzen, 1970; Connell, 1971; Gravin and Peart, 1997).

The changes from aggregated to a random spatial pattern during tree life-span, could indicate the existence of a density dependence factor playing an important role for seedlings (Gavin and Peart, 1997), such as herbivory (Janzen, 1970; Connell, 1971), competition or predation (Sousa and Mitchell, 1999).

The present study demonstrated that in SE Brazil even small forest fragments areas could be an important source of propagules for colonisation of new areas. Therefore, the preservation of native forest blocks should be considered for the sake of biodiversity conservation and restoration of degraded areas.

The propagules source distance was an important element in determining the spatial distribution mainly of small individuals of a *X. brasiliensis* population. The spatial patterns observed changed according to both the spatial scale analysed and diametric class size, reinforcing the importance of employment of methods that take into account different spatial scales.

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