Do Landscape Elements Interfere in Hovenia Dulcis Thunb. Invasions in Subtropical Forest Fragments?

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Research Article

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Abstract

Changes in characteristics of landscape adjacent to forest fragments due to anthropic actions result in increased invasion of non-native species and biodiversity loss. The aim of this study was to evaluate the invasion process of *Hovenia dulcis* (Thunb.) in forest fragments with different size and shape in order to relate the behavior of the invasion with landscape metrics. As a result, shape and size of the forest fragments do not influence the abundance of *H. dulcis*. However, a greater number of *H. dulcis* individuals are concentrated in the edge areas. The canopy, declivity and land use were not associated with the abundance of *H. dulcis*. The high abundance at the edge of forest fragments highlights the dynamics of the landscape in the study area that are marked by the agricultural matrix. The invasion process occurs regardless of the size and shape of the forest fragments.

Introduction

Human activities are among the main factors responsible for the invasion of non-native species, generating an increase in the number of disturbances in ecological communities (Guirado et al. 2006; Hobbs and Huenneke 1992; With 2004). In addition, biological invasions are considered a major global threat to environmental conservation (Millennium Ecosystem Assessment 2005; Pysek et al. 2012; Roiloa 2015), representing decreasing to the quality of ecosystem services (Foley et al. 2005, Harrison et al. 2014) and human well-being (Bennett et al. 2015).

Forest fragmentation is associated with the invasion of non-native species due to an increased availability of resources such as light and temperature, especially at the edges created between natural and modified areas (Denslow and Dewalt 2008; Fine 2002; Hobbs 2011). The main effects of fragmentation are related to the increase on fragment isolation, decrease of size, and increase on the susceptibility to external disturbances such as invasion by non-native species (Geneletti 2003). Among the main consequences of fragmentation are the fragment size and shape. Size and distance are directly related to biodiversity, while the edge effect is associated with the shape of the forest fragment and decreases as it advances into the interior of the fragment (Tabarelli et al. 2004).

Forest fragments in the southern region of Brazil show an increase in the abundance of *Hovenia dulcis* Thunb. (Rhamnaceae), a non-native tree species. The species was introduced on rural properties for use as wood, shading, energy production and wind breaks (Carvalho 1994). But actually, any propagation form of *H. dulcis* (among other species) is prohibited by law. The invasion by *H. dulcis* is associated with early-stage forest fragments, which are more susceptible due greater canopy opening, less diversity and lack of community structure (Dechoun et al. 2015; Lazzarin et al. 2015). On the other hand, advanced stages present invasion difficulty due to the floristic structure and fragment shading (Dechoun et al. 2015).

Studies carried out about pine invasion in South Africa highlight that landscape elements such as the size and shape of forest fragments are less explored, and therefore make it difficult to determine the landscape influence on the invasion of non-native species (Vilá and Ibánez 2011). In turn, Padilha et al. (2015) observed that the fragment size had little effect on the abundance of *H. dulcis*, but the occurrence of the species was associated with fragments with high light. In addition, a higher abundance of *H. dulcis* was associated with the proximity to the source of propagules (adult individuals) (Padilha et al. 2015).

Habitat invasion can also be determined by the spatial context (Fons 2014), where factors such as climate, topography and surrounding landscape are related to the habitat invasion (Vilà and Ibáñez 2011; Gassó et al. 2012; González-Moreno et al. 2013). The forest fragments in southern Brazil are mainly distributed in environments with greater declivity and with surrounding matrixes characterized by agricultural and urban uses (Decian et al. 2010). The objective of this study is to evaluate the invasion process of *Hovenia dulcis* in forest fragments with different sizes and shapes, and in edge and interior areas in order to relate the invasion dynamics with the different landscape metrics. The hypotheses evaluated in this study consist of verifying whether: I) The higher invasiveness of *H. dulcis* occurs in small, circular fragments and in edge areas; II) the landscape elements such as more open canopy and higher slope favors the *H. dulcis* invasion.

Materials And Methods

The study area comprises 16 forest fragments located in the South of Brazil (Figure 1). The economy of the study area is mainly centered on agriculture with the cultivation of soy, corn and wheat, and on livestock with poultry, swine and cattle (Decian et al. 2010). The climate is characterized as humid subtropical temperate (Cfa and Cfb according to the Köppen-Geiger classification), with an annual average temperature of 17 ± 1ºC, four well-defined seasons, and average annual precipitation ranging between 1900 and 2200mm, with regular pluviometric regime and the rains are well distributed during the year (Alvares et al. 2013). The geological and edaphic formation consists of basalt, the soil is predominantly composed of the Oxisol class, typical Aluminum-ferric Red Latosol (RLaf) (Streck et al. 2008). The region is part of the Atlantic Forest Biome, being characterized by Atlantic Forest with Araucarias and Seasonal Semi-deciduous Forest (Oliveira-Filho et al. 2015). The landscape is mainly anthropogenic in which native tree vegetation fragments are isolated in mosaics immersed in an agricultural matrix.

The forest fragments were selected from satellite images based on the following criterion: i) Location of the fragment within the topographic limits of study area; ii) Presence of *Hovenia dulcis* individuals; iii) Fragment size with two area classes, 10 — 100 ha and > 100 ha, with eight fragments selected for each area class; iv) fragment shape index with two classes (≤ 2 and> 2) according to the analysis obtained via Fragstats (forest fragmentation metrics) with four fragments selected, two of which were selected for the area class for each class shape (Supplementary Material Table SI).

The form of a fragment is obtained by Shape, from which a lower value indicates fragments of simple formats, meaning those which are beneficial for conservation. Values close to 1 indicate fragments with shapes that resemble a square, and as the value increases, it indicates fragments with elongated shapes

(Oliveira Rodrigues 2011). A radius distance of 50 meters was arbitrarily established to calculate metrics related to the shape, edge and size using the methodology proposed by Murcia (1995); Young and Mitchell (1994); Metzger (2009). The shape and size (Hectares) analysis of the forest fragments used for the study was performed using the FRAGSTATS v4.2.1 program.

After selection with the aid of the MapInfo 8.5 and Idrisi Selva 17.0 software designed in Geographic Coordinate System (GMS) and Datum WGS 84, the selected fragments were verified in the field to verify if they met the established criterion. Thus, 10 plots with a minimum distance of 30 meters were established for each fragment, with 5 plots in the edge area and 5 plots in the interior area of the fragments with a size of 5 x 5m ($25m^2$). A distance of 50 meters from the beginning of the fragment's edge was stipulated for the interior area, as adopted by Murcia (1995).

Data collection

H. dulcis individuals classified were according to the shoot height in three different classes. Class I corresponds to adult individuals taller than 2.5 meters; Class II corresponds to young individuals between 0.5 to 2.5 meters in height; and Class III to individuals classified as seedlings with height < 0.5 meters. All *H. dulcis* individuals in the different classes counted were in all sampled plots according to the criteria above.

Landscape elements were collected in the plots such as open canopy and slope, and then the forest fragment use and coverage of the surrounding land (500 meters) was later classified through Geographic Information Systems.

Canopy opening was assessed using tree hemispheric photographs were obtained in the center of each plot in a perpendicular shot (90º) using a Sony DSC30 high resolution digital camera, coupled to a 180º Rainox fisheye lens in order to assess the canopy discontinuity. The images were subsequently analyzed using a Gap Light Analyzer (GLA) program (Frazer et al. 1999), determining the canopy discontinuity percentage (%). Slope data processed were using MapInfo Professional 8.5 and Idrisi Selva 17.0 software, generating a Numerical Terrain Model (NTM) for the entire study region and then selecting the average slope value for the edge and interior areas of the evaluated forest fragments.

Data analysis

The characteristics of the selected fragments (size, shape and the edge/interior area), together with the abundance of *H. dulcis* (class I, II and III) were analyzed using Split-plot paired measures analysis of variance (ANOVA) to assess whether the invasiveness of *H. dulcis* is associated with small fragments (shape > 2) and with edge areas. Furthermore, linear regressions performed were to assess whether landscape elements (canopy opening and slope) influence *H. dulcis* invasion. It is noteworthy that only adult *H. dulcis* individuals used were for the canopy opening analysis, as young individuals and seedlings were not found in all evaluated plots.

All tests performed were in the R statistical program using the vegan package (R Core Tean 2018; Oksanem et al. 2018).

Results

Landscape metrics

A total of 1,708 *H. dulcis* individuals were sampled distributed among the 16 fragments. From this total, 299 individuals were adults (class 1), while 1,409 were young individuals and seedlings (Class II and III). Of these, 1,438 *H. dulcis* individuals are located in the edge areas (84.20%), and 270 individuals in the interior areas of the forest fragments (15.80%).

The relative abundance of adult *H. dulcis* individuals (Class I) was not influenced by size or shape of the forest fragments (Table 1). The edge and interior areas of the fragments differ in the relative abundance of class I individuals, with higher abundance observed in the edge area of the forest fragments (Table 1 and Figure 2A).

The relative abundance for young *H. dulcis* individuals (Class II) and seedlings (Class III) does not differ in relation to size or shape of the forest fragment (Table 1). However, a difference was observed in the relative abundance of both class (II and III) between the edge and interior area of the fragments, being higher in the edge (Figure 2B and C).

Table 1

Split-plot analysis of variance (ANOVA) results of Relative abundance of adult, young and seedlings *Hovenia dulcis* individuals in forest fragments in relation to size, shape and edge-interior.

H. dulcis classes	Landscape metrics	F	*p*	GL
Class I	Size	0.453	0.503	1;24
	Shape	0.358	0.555	1;24
	Edge-Interior	39.482	<0.005	1;24
Class II	Size	1.038	0.318	1;24
	Shape	0.142	0.709	1;24
	Edge-Interior	18.880	<0.005	1;24
Class III	Size	0.270	0.608	1;24
	Shape	0.257	0.616	1;24
	Edge-Interior	6.336	<0.005	1;24
Class I corresponds to adult individuals taller than 2.5 meters; Class II corresponds to young individuals between 0.5 to 2.5 meters in height; and Class III to individuals classified as seedlings with height < 0.5 meters.				

Landscape elements

Regarding the analyzed landscape elements, it is observed that the canopy opening and slope do not influence the relative abundance of *H. dulcis* for all the evaluated classes (Table 2).

Table 2

Linear regressions result of the H. dulcis individual’s abundance to the landscape elements (GL: 1;30).

Landscape elements	*H. dulcis classes*	F	*p*	R^2
Slope	Class I	1.593	0.216	0.018
	Class II	1.070	0.309	0.002
	Class III	2.911	0.098	0.058
Open canopy	Class I	3.585	0.068	0.076
Class I corresponds to adult individuals taller than 2.5 meters; Class II corresponds to young individuals between 0.5 to 2.5 meters in height; and Class III to individuals classified as seedlings with height < 0.5 meters.				

Discussion

The size and shape of the forest fragments were not associated with the abundance of *H. dulcis* individuals from all the size classes evaluated (class I, II and III), partially refuting the first hypothesis of the study. However, a greater proportion of individuals occurs at the fragment's edges, regardless of class, size or shape, partially corroborating the first hypothesis of this study. Fragmentation interference (size and shape of forest fragments) drives the edge effect, resulting in a reduction of the forest through a vulnerability of richness and abundance of adult species and seedlings (Tabanez and Viana 2000; Portela and Santos 2007; Ribeiro et al. 2009).

It is important to note that the shape with value 1 is considered a standard shape and equivalent to a square. Therefore, more irregular forest fragments are more susceptible to show a greater edge effect, especially those with small size due to greater interaction with the surroundings (Saunders et al. 1991; Forman 1997; Nascimento et al 2006; Malinowski et al. 2008; Cemin et al. 2009). The shape criterion of the forest fragments herein is not associated with invasion and abundance of *H. dulcis*.

But we emphasize that the invasion pattern was observed in the inner-edge direction when the size classes of the *H. dulcis* individuals were analyzed separately. Furthermore, a greater proportion of adults (81.6%), young (90.4%) and seedlings (83%) was observed at the edges of the forest fragments, suggesting the invasiveness dynamics of this species from the edges. Trees with smaller diameters are generally found in edge areas (Malchow et al. 2006; Oliveira et al. 2008; Silva et al. 2015; Alves et al. 2018), and it is difficult to find large trees (Laurance et al. 2000; Paula et al. 2011). It is also observed that there is high regeneration on the edge, as well as high mortality (Laurance et al. 1998; Harper et al. 2005). Thus, in many cases, the forest is leading to initial succession stages due to these differentiated dynamics in the edge areas (Tabarelli et al. 2008).

It is also noteworthy that the high proportion of individuals from young classes and seedlings may suggest success in recruiting *H. dulcis* on the edges, meaning that the species is finding favorable environmental conditions for its establishment and development in these environments. Young *H. dulcis* individuals and seedlings (Classes II and III) still do not form fruit and have not reached the canopy, at which time they will obtain sufficient light for flower and fruit formation, representing an increase in the species' invasiveness in the forest fragment (Gerber 2018).

Regardless size and shape, the presence of *H. dulcis* is also observed inside the forest fragments. These results highlight that *H. dulcis* individuals (mainly adults) are also established in environmental conditions such as the interior forest fragments (more closed canopy). Large and regular forest fragments may be less susceptible to the edge effect and, consequently to biological invasion. In this study, the fragments with shape < 2 can be considered the areas with integral ecological characteristics and priority for biodiversity conservation (Ribeiro et al. 2009). The results observed in this study showed a lower number of *H. dulcis* individuals in this fragment category.

Some studies have shown evidence that non-native species are not dependent on disturbance and are not restricted to early successional stages (Webb 2000; Martin et al. 2009) or edge areas, showing tolerance to both shade and the ability to invade closed canopy forests (Gilbert and Lechowicz 2005; Martin and

Marks 2006; Major et al. 2013). The success in the establishment and development of the study species seems to be associated with its ecological characteristics, such as: its dispersion form, which increases the distance in which the propagules can reach; food source for the fauna increasing the seed dispersion (Padilha et al. 2015); shade and sun tolerance developing well in open areas and with high light incidence (Carvalho 1994; Lorenzi et al. 2003; Dechoum et al. 2015; Gerber 2018). However, the canopy opening was not related to the *H. dulcis* abundance. The southern region of Brazil has Semi-deciduous Forests, that show 50% leaves drop during May and September months (Klein 1972; IBGE 2012; Vibrans et al. 2012a).

However, this characteristic can be increased due to the high *H. dulcis* abundance, a species with deciduous phenology (Schmidt et al. 2019). Thus, a more open canopy occurs in these months (autumn). These environmental conditions may enable an increase in the establishment and development rate of non-native species, mainly *H. dulcis* inside forest fragments. The absence of a relationship between canopy opening and the abundance of *H. dulcis* may be associated with the species' plasticity in adapting to different physiological characteristics and the light entry into forest fragments in different seasons (Schmidt et al. 2019).

The landscape elements (canopy opening and slope) were not associated with the abundance of *H. dulcis*, refuting the second hypothesis. The forests fragments in the study region are concentrated in areas that have a higher slope and are therefore unsuitable for large scale agricultural production. The Federal Forest Code (2012) can be associated as one of the factors responsible for the considerable increase in small fragments, mainly observed in sloping areas, dispersed in an agricultural matrix. These conditions could facilitate the establishment of *H. dulcis*, mainly due the increased edge effect.

The results of this study indicated that the landscape elements were not associated with the pattern of occurrence of *H. dulcis*. However, the observed results highlight that the greater *H. dulcis* abundance occurs mainly at the edge of forest fragments, regardless of the individuals' size. This pattern of occurrence can be used as an aid in environmental decisions and highlight the potential of *H. dulcis* for establishing and growth, regardless of the size and shape of the subtropical forest fragments.

Declarations

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Authors’ contribution:

The authors Marciana Brandalise, Silvia Vendruscolo Miseli, Tanise Luísa Sausen and Vanderlei Secretti Decian declare to be responsible for producing the manuscript entitled “Do landscape elements interfere in *Hovenia dulcis* Thunb. invasions in subtropical forest fragments?”, all of whom participated in producing the article.

- Marciana Brandalise: Data collection, data analysis, statistical analysis, mapping, writing and review of the article.

- Silvia Vendruscolo Milesi: Statistical analysis, writing and review of the article.

- Tanise Luísa Sausen: Guided all stages and participated in data analysis, writing and review of the article.

- Vanderlei Secretti Decian: Guided all stages and participated in the preparation of maps, data analysis, writing and review of the article.

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Figures

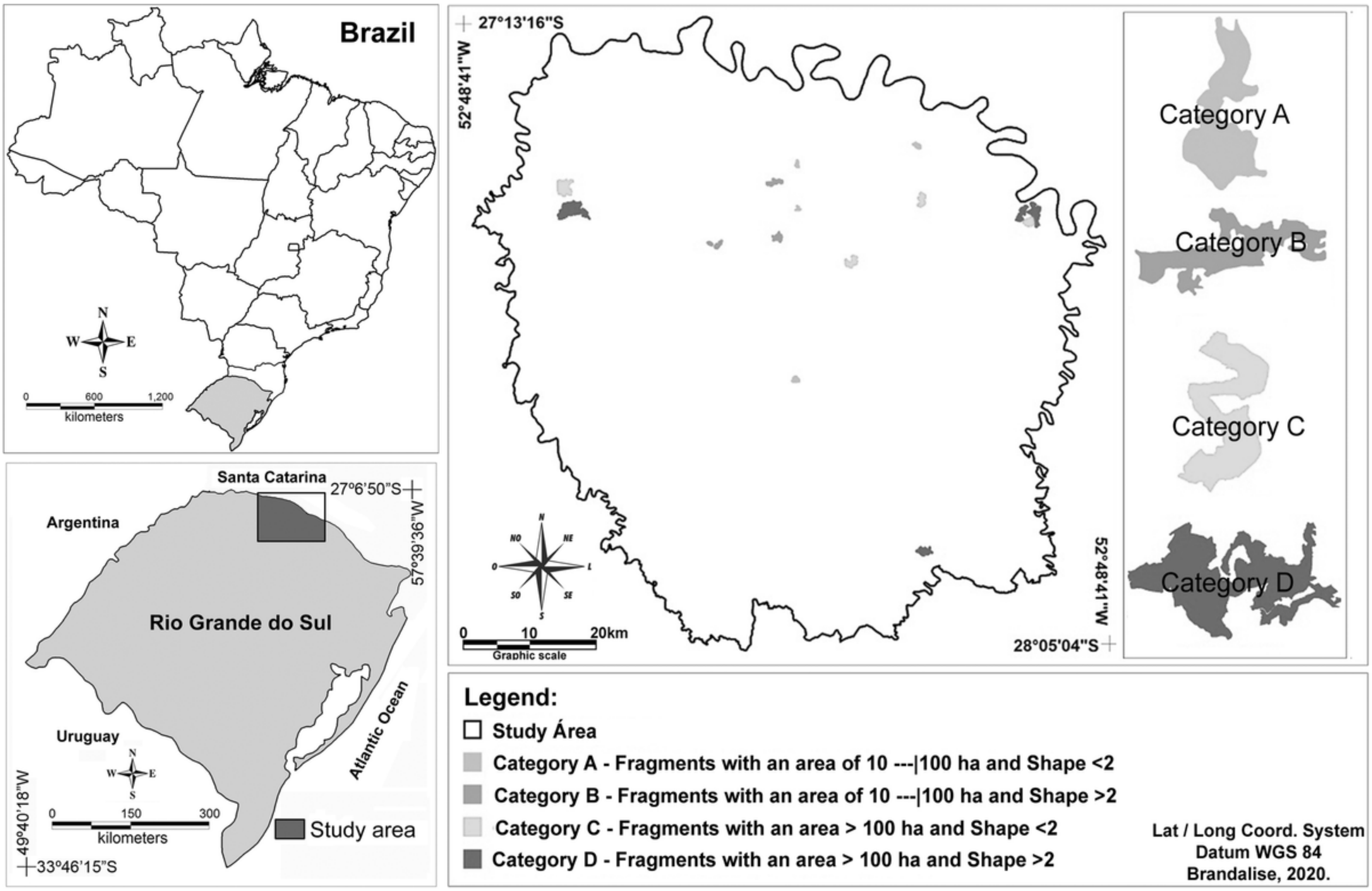

Figure 1

Location of the study area and forest fragments sampling sites (n = 16). Sampling sites are located in Atlantic Forest with Araucarias and Seasonal Semi-deciduous Forest of the South Brazil. The forest fragments were selected in the categories (A, B, C and D) according the shape (≤ 2 and> 2) and sizes (10 — 100 ha and > 100 ha) for data collection. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

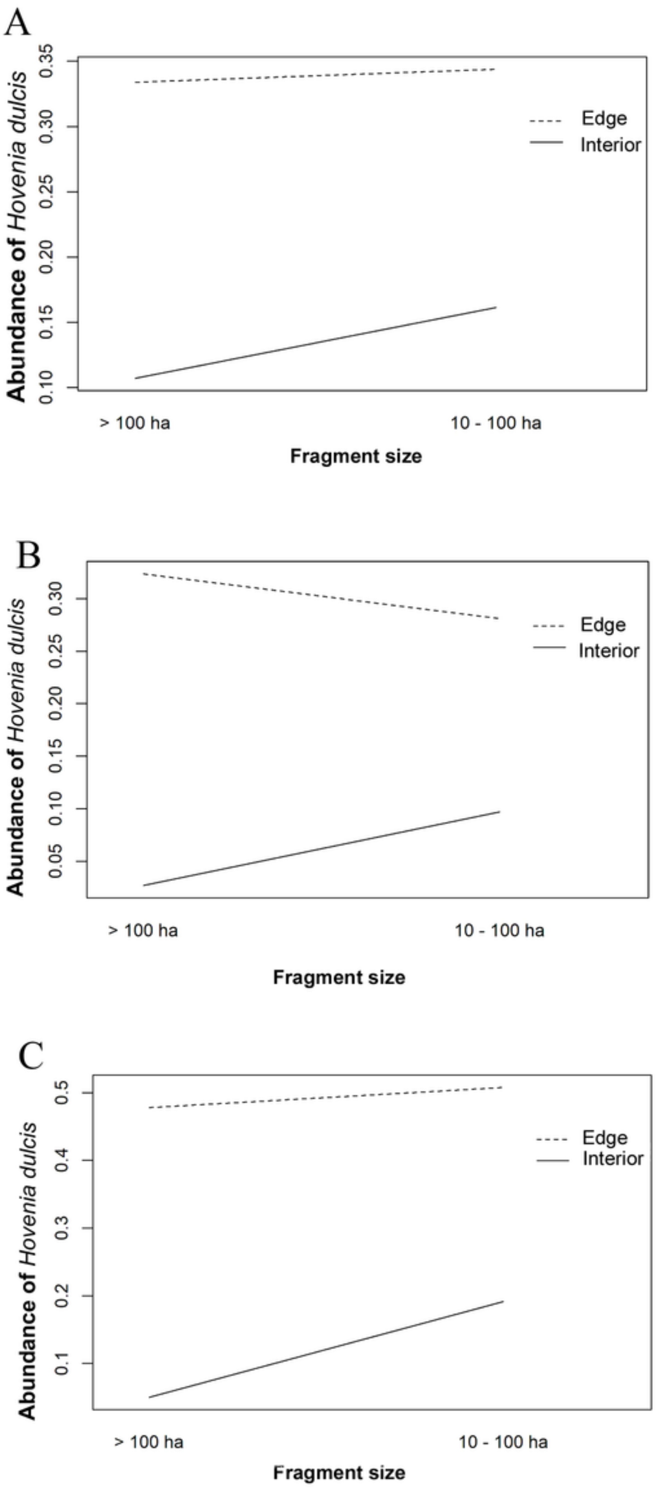

Figure 2

Relative abundance of adult (A), young (B) and seedlings (C) Hovenia dulcis individuals in the interior and edge of the forest fragments.

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