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Edge Effects on the Vegetation Structure in a Fragment of Semi-Deciduous Forest, Northeastern Brazil

Efeitos de borda sobre a estrutura da vegetação em um fragmento de Floresta Estacional Semidecidual, Nordeste do Brasil

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Abstract

Most remaining forests today are small, highly disturbed, isolated, and poorly protected patches of vegetation. Studies on forest fragments increase as an answer to the need of investigating the biodiversity in these areas, providing the basis for future conservation and management proposals. Small forests are considered to be more exposed to edge effects, due to their ratio border-interior. The present study was conducted in a 4-hectare forest remnant located in a sub-humid climate area in Northeastern Brazil. Along the margin, six points were marked, apart from one another by 15 meters. From these points, perpendicular to the edge, 100-meter transects were drawn, in which 7 meters plots of 1 squared meter each were marked every 5 meters. The variables temperature and humidity, number of seedlings and herbaceous plants, herbivory, diameter and number of trees, canopy cover, and litter thickness were measured along the border. The abiotic variables and sum of seedlings and trees, herbivory, and canopy cover were positively correlated with the distance from the edge, whereas DBH, herbaceous sum, and litter thickness showed a negative correlation. The variables revealed an average correlation of approximately 0,70 with the distance measured from edge, some of which seem to be affected by human interference. Since the effect was observed in all abiotic and biotic variables analyzed in the entire edge-interior gradient, this semi-deciduous forest fragment behaves as an edge in its entirety.

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Introduction

Habitat fragmentation is a result of the subdivision of a region by natural disturbances, climate, and mainly by human activities, creating an increase of the ratio edge-area (DALE; PEARSON, 1997). Studies of the effects of forest fragmentation on conservation have become more common in recent years (BACLE; JUMP, 2011; EWERS et al., 2011; LOVEJOY et al., 1986; PRYKE; SAMWAYS, 2012), reflecting the fact that today a high percentage of the remaining biodiversity is located in small forest fragments.

Forest fragmentation exposes organisms to edge effects, which might be represented by changes in richness and abundance of species in the marginal part of a forest fragment (FORMAN; GORDON, 1986), or by a variety of influences that the external environment has on the forest area in its marginal part (TABANEZ et al., 1997). These effects often give rise to a distinct community of those species that are closer to the edge - some increase, while others decrease in abundance (YAHNE, 1988) - and also have important implications for attempts to preserve ecosystems found on one side of border.

Generally, edge effects can be perceived in three levels: physical structure of vegetation, floristic composition, and population dynamics (ZAÚ, 1998). In community forestry, woody and herbaceous plants are altered in quality and quantity, depending on the type and appearance of the border (MARCHAND; HOULE, 2005). Concerning abiotic factors, the formation of edges between forested and deforested areas might cause changes in abiotic conditions that significantly affect populations. Microclimatic changes might stimulate biotic modifications, such as in forest structure, once growth, mortality, and distribution of plants in this new environment can be directly affected by the physical conditions and the density and activity of some animal species (MURCIA, 1995). Consequently, changes in many aspects of life history of plants and animals on the edges can cause changes in species interactions, including herbivory, seed predation, pollination, and seed dispersal (AIZEN; FEINSINGER, 1994).

The creation of forest edges results in an increase in mortality rates and consequent damage to trees, shrubs, and herbs (FERREIRA; LAURANCE, 1997, LAURANCE et al., 1998). Thus, changes in relative abundance and species composition of plants may occur, largely due to an increase in recruitment and density of pioneer tree species (SIZER et al., 2000), increase in the density of vine species adapted to degraded sites (LAURANCE et al., 2001), and a reduction in the density of seedlings of late succession species (BENITEZ-MALVIDO, 1998). Roads and invasive species can further deteriorate the habitat along the edge, allowing generalists species to enter the edge zone and disrupt natural systems (IVANOV; KEIPER, 2010; PINHEIRO et al., 2010)

Nevertheless, most studies related to vegetation edges focused on the effects on communities of angiosperm trees and shrubs (D'ANGELO et al., 2004; GALE, 2000; NASCIMENTO; LAURANCE, 2006). Studies on herbaceous species or other life--forms and abiotic functions are still necessary to assess the response of a greater number of front groups to edge effects, especially in tropical forests, since a large current problem of these ecosystems is extensive depletion and reduction of their original areas (TURNER, 1996).

Edge effects strongly increase the pre-existing heterogeneity linked to variations in the mosaic of successional forests, which underlines the importance of the size of forest fragments for the conservation of samples of communities (OLIVEIRA-FILHO et al., 2007). The study of fragmented environments, although essential for management and conservation, might be considered limited in the literature, especially for Northeastern Brazil. In order to contribute to this research area and provide specific scientific knowledge for management and conservation, this work aims at analyzing edge effects of a forest patch, correlating biotic and abiotic variables along the gradient edge-interior to distance from the border.

Material and Methods

The study was conducted in May 2008, in a fragment of semi-deciduous forest in the city of Fortaleza, Ceará, Northeastern Brazil, between the geographical coordinates of 3º 34 '16.79" and 3º 34' 43.49" South , 38° 34' 03.81" and 38º 34' 42.71" West. The site occupies an area of approximately 4 ha, and the characteristic climate is sub-humid.

This patch was chosen for its position and easy access by the urban population, being inside the biggest University of the city. Moreover, it is one of the few remnants of semi-deciduous seasonal forest in the city, which reinforces the importance of its characterization regarding environmental pressures caused by human activities.

Seven parcels of 1 m x 1 m (1 m²) were selected in each of the six 100-meter replicates along an edge-interior gradient, totaling 42 plots. A distance of 15 m between the replicas of transects and 5 m between parcels was established. The first portion of each transect was set along the edge of the fragment and the direction of the lines was pointed towards the interior of the fragment.

Temperature and humidity were measured using a thermo-hygrometer. The biotic measures were: number of seedlings, number of herbaceous plants, number and diameter at breast height (DBH) of trees, herbivory, thickness of litter, and canopy cover. Seedlings and herbaceous plants were counted by the method of direct observation. DBH number of trees and herbivory rate were measured in all trees found within a 3-meter radius from the center of each plot. Thickness of litter and canopy cover were observed at 1 m from the center of each plot towards both right and left directions.

To analyze herbivory, the method of visual assessment was used (DIRZO; DOMINGUEZ, 1995), in which the degree of herbivory is classified into five categories according to the percentage of leaf area predated: 0 (0%), 1 (1% to 6%), 2 (6% to 12%), 3 (12% to 25%), 4 (25% to 50%), and 5 (50% to 100%). The estimate was made by random choice of three leaves at different heights in each specimen analyzed. For every point, a herbivory index (HI) was calculated, given by $HI=\Sigma(ni*i)/N$, where ni = number of leaves by category, i = herbivory category (0-6), and N = number of leaves for each point (n=36).

For the analysis of the correlations between the biotic and abiotic components and distance from the edge, the software Statistica version 7.0 was used. Significant correlations were identified with a *p*-value < 0.05.

Results and Discussion

Table 1 shows the positive or negative correlation between the variables and the distance to the edge, including p-value and r². The correlations can be visualized by polynomial trend lines in Figure 1.

Table 1. Relationship between abiotic and biotic variables and its p-value ,r², and correlation with distance to the edge.

Variables	*p*-value	r²	Correlation
Temperature	0.02	0.49	-
Air humidity	<0.01	0.45	-
Trees	0.02	0.94	+
DBH	0.28	0.55	-
Seedlings	0.04	0.72	+
Herbaceous	0.01	0.91	-
Litter thickness	0.04	0.73	-
Canopy cover	0.04	0.91	+
Herbivory	0.02	0.60	+

There was a significant negative correlation for temperature and humidity along the gradient edge--interior (temperature: $r^2 = 0.49$, $p = 0.02$; humidity: $r^2= 0.45$, $p < 0.01$), in agreement with previously documented higher temperature, humidity, and light incidence in areas near the edge (LOVEJOY et al; 1986; MURCIA, 1995).The trend between temperature and distance from the edge is a temperature variation in waves throughout the gradient, which probably occurs due to the presence of vegetation gaps of anthropogenic origin (tracks and deforested patches), revealing that, evenin places farther from the edge, there is an influence of the temperature gradient (MÜLLER; BATAGHIN; SANTOS, 2010;

PRIMACK; RODRIGUES, 2001).

The influence of the edge can be evidenced by an increase in the intensity of sunlight penetration (MURCIA, 1995) and greater intensity of wind (LAURANCE et al., 1998). These changes cause a temperature rise at the site and an increase in evapotranspiration (MATLACK, 1993), leading to the reduction of the relative humidity of soil and air (KAPOS, 1989).

The linear regression for the number of individual trees and the distance from the edge was positive and significant ($r^2 = 0.94$, $p = 0.02$).This finding may be indicative of a strong anthropogenic pressure exerted on the edge of the fragment and the consequent changes in plant structure (MÜLLER; BATAGHIN; SANTOS et al, 2010).Moreover, this correlation may indicate that tree mortality is greater at the edge and that germination, seedling and youth recruitment may also be adversely affected. The proliferation of frequent open areas close to the edges (CAMARGO; KAPOS, 1995) is a result of high rates of mortality and damage trees (FERREIRA; LAURANCE, 1997; LAURANCE et al., 1998).

Although the number of trees is greater inside the fragment, the DBH did not show a significant correlation along the gradient ($r^2 = 0.55$, $p = 0.28$), once fewer trees at the edge showed a large DBH. In addition, there is a greater recruitment and growth of young individuals within the fragment and a decrease in the number of medium-sized individuals at the edge of the fragment, causing this constancy (MÜLLER; BATAGHIN; SANTOS, 2010).

This result is in alignment with what occurs with the incidence of seedlings, since the sum of the seedlings was positively correlated with the distance from the edge ($r^2 = 0.72$, $p = 0.04$). This is caused by the removal of trees which follows the opening of trails and glades in the forest interior (AGUILAR; GALLETO, 2004) and facilitates seed germination due to greater exposure to solar radiation.The smaller number of regenerating individuals at the edge is a result of the intense deposition of litter, damaging the development of seedlings (SIZER et al, 2000). Benitez-Malvido (1998) showed that the density of seedlings belonging to late succession species declined in areas near the edges, indicating that the establishment of these species is negatively impacted by the different conditions in border areas.

The number of trees, seedlings, and herbaceous plants demonstrated the expected correlation, because the life history of the forest vegetation is closely related to environmental conditions, i.e. light and water (PACIENCIA; PRADO, 2004). While the edges may constitute fragments of inhospitable environments for some species, given the reduction in area of use and the changes in shape and structural features of the fragment, they should not be regarded necessarily as adverse sites for the establishment and development of forest species. Biological groups do not always respond in the same manner to the edge effects and these, in turn, are not manifested exactly the same way on all edges.

Regarding herbs, their total number was negatively correlated with distance from the edge ($r^2 = 0.91$, $p = 0.01$), which can be noticed by a predominance of herbaceous pioneer species tolerant to the climatic conditions existing on the edge (r-strategists). This group of species has higher rates of growth and development because of the light-rich environments characteristic of the edge.

Edge effects apply differently in terms of type of effect and intensity on the various biological groups or guilds. For example, a large increase in mortality of forest tree species can be observed near the edge (DBH> 20 cm, see LAURANCE, 1991), while there is an increase in the number of the pioneer species (LAURANCE et al., 1998; WILLIAMS-LINERA, 1990).

Consistently with the study conducted by Sizer et al. (2000), the thickness of the litter showed a negative correlation with distance from the edge ($r^2 = 0.73$, $p = 0.04$).This relationship is explained by the increase in the number of pioneer species at the edge habitat, where the combination of rapid plant growth, high leaf turnover rate, and an intense exposure to the wind generates a greater amount of litter (DIDHAM; LAWTON, 1999). The increase in fine litterfall production occurs in smaller scales, possibly because of the fact that microclimatic changes are more intense in areas closer to the edges (CARVALHO; VASCONCELOS, 1999; DIDHAM, 1998; PORTELA; SANTOS, 2007).

Nascimento and Laurance (2006) showed that the turnover of coarse woody and the fraction of biomass that decomposes annually were negatively correlated with distance from the edge, suggesting that in fragmented forests decomposition of woody litter is faster. Therefore, as the biomass stored in long-life trees is being lost over the years, the subsequent decomposition of necromass will be the primary mechanism that results in the increase of carbon emissions and global warming.

A positive correlation was found between distance from the edge and canopy cover (r2 = 0.91, p = 0.05), which is in agreement with the large number of trees within the fragment.However, the scatter plot had a ripple effect, which reflects trails and open clearings in the forest (BATAGHIN; BARROS; PIRES, 2010). The canopy cover is correlated with the number of trees, since a smaller variance in the canopy openness is indicative of a well-developed and more closed forest canopy structure (VIDAL et al., 2007).

Herbivory was positively correlated with the distance from the edge, although not significantly (r^2 = 0.60, p = 0.02).These results oppose those obtained by Barbosa et al. (2005) and Wahungu, Catterall e Olsen (2001), which shows that, in general, herbivores benefit from the creation of edge environments, thanks to favorable microclimatic conditions, more

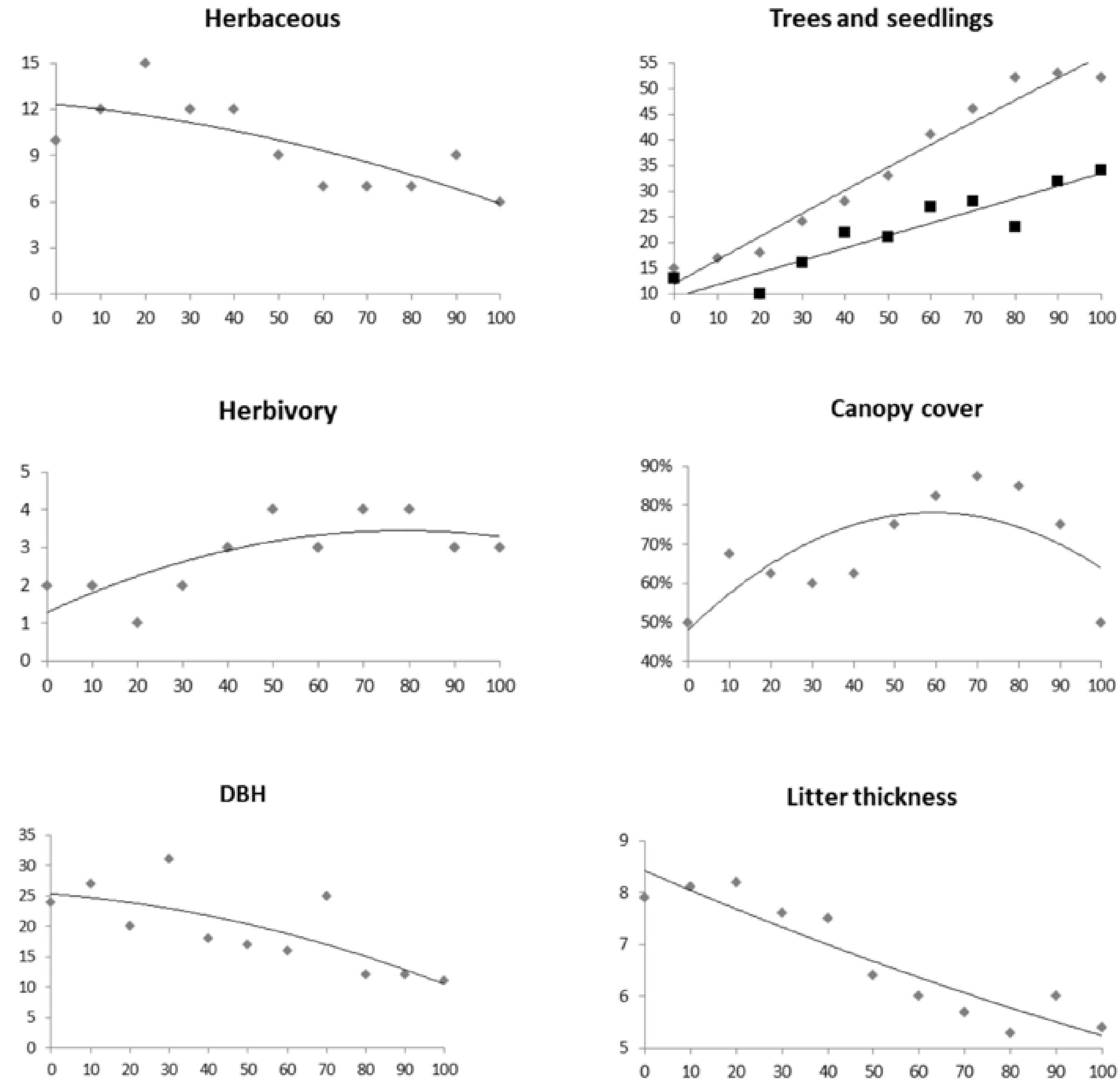

Figure 1: Correlation between number of trees, seedlings, herbaceous, DBH, litter thickness, canopy cover and herbivory with the distance to the edge (0-100m).

resources,and fewer natural enemies. However, Benitez-Malvido (1998) found lower rates of herbivory in forests fragments than in continuous forests.

There is no clear pattern about the extent to which climatic and biotic changes in the edges can be perceived inside the fragments. However, studies with fragments in forest reserves show that the distance of penetration of these changes reaches 40 m from the physical limit between the fragment and the matrix (KAPOS, 1989). Other authors report less intense penetrations effects, such as 15-25 m (WILLIAMS-LIMERA, 1990), 7-12 m (MACDOUGALL; KELLMAN, 1992), and 10-20 m (ESSEEN; RENHORN, 1998). Therefore, the study fragment seems to be over-impacted by the edge or even behave entirely as an edge.

Small forest fragments may become extensive edges and changes can manifest themselves multiplicatively because the microclimate of the forest core is strongly influenced by the distance from the periphery of the fragment (PACIENCIA; PRADO, 2004).

Conclusions

Considering that the interior of a patch is characterized by the complete lack of observed edge effects, the fragment of semi-deciduous forest here analyzed behaves in a whole as an edge, since the effects were observed in all assessed abiotic and biotic variables along the entire border-core gradient. Some of these variables were influenced by human activity, which thus modifies environmental conditions, promoting changes in dynamics, structure, and composition of vegetation.

Edge effects are important factors to help detect the degree of fragmentation of forest remnants and, therefore, research on this subject is necessary to provide insights for management and conservation of patchy landscapes.

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