Analyzing the edge effects in a Brazilian seasonally dry tropical forest

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Abstract

Due to the deciduous nature of dry forests (widely known as seasonally dry tropical forests) they are subject to microclimatic conditions not experienced in other forest formations. Close examinations of the theory of edge effects in dry forests are still rare and a number of questions arise in terms of this topic. In light of this situation we examined a fragment of the dry forest to respond to the following questions: (I) Are there differences in canopy cover along the edge-interior gradient during the dry season? (II) How does the microclimate (air temperature, soil temperature, and relative humidity) vary along that gradient? (III) How does the microclimate influence tree species richness, evenness and abundance along that gradient? (IV) Are certain tree species more dominant closer to the forest edges? Regressions were performed to address these questions. Their coefficients did not significantly vary from zero. Apparently, the uniform openness of the forest canopy caused a homogeneous internal microclimate, without significant differentiation in habitats that would allow modifications in biotic variables tested. We conclude that the processes of edge effect commonly seen in humid forests, not was shared with the dry forest assessed.

Keywords: boundary effects, canopy cover, deciduous forest, edge influence, microclimatic influences.

Analisando o efeito de borda em uma floresta estacional decidual brasileira

Resumo

Devido à natural caducifolia das florestas estacionais deciduais, estas são sujeitas a condições microclimáticas que não são experimentadas por outras formações florestais. Estudos específicos sobre efeito de borda nessas florestas são raros e algumas questões persistem sobre esse tópico. Diante disso, avaliamos um fragmento de floresta decidual para responder as seguintes questões: (I) Existe diferença na cobertura da copa ao longo do gradiente borda-interior durante a estação seca? (II) Como as variáveis microclimáticas (temperatura do ar, temperatura do solo e umidade relativa do ar) variam ao longo deste gradiente durante a estação seca? (III) Como as variáveis microclimáticas influenciam a riqueza, equabilidade e abundância de árvores ao longo do gradiente? (IV) Existem espécies dominantes próximo à borda da floresta? Regressões foram feitas para responder essas questões, no entanto, o coeficiente de angulação da reta não variou significativamente de zero. Aparentemente, a abertura uniforme do dossel da floresta causa uma homogeneidade microclimática no fragmento, sem diferenciação significativa de habitats que permite modificação nas variáveis bióticas testadas. Nós concluímos que os processos de efeito de borda comumente observados em florestas úmidas não são compartilhados com a floresta seca avaliada.

Palavras-chave: efeito de borda, cobertura da copa, mata seca, influência de borda, influência microclimática.

1. Introduction

Although studies focusing on the consequences of forest fragmentation have multiplied in recent decades most of them have been directed towards humid forests (Sánchez-Azofeifa et al., 2005). Limited information is available about the consequences of fragmentation and the mechanisms of ecological responses of dry forests (widely known as seasonally dry tropical forests) which impairs efforts for its conservation.

Interactions between forest fragments and neighboring deforested areas can result in what are known as edge effects (Murcia, 1995), which initiate rapid processes and responses along the fragment edge (Harper et al., 2005). These edges are subject to three effects: abiotic effects (changes in microclimatic conditions), direct biotic effects (changes in the abundance and distribution of species resulting from changes abiotic), and indirect biotic effects (changes in species interactions) (Murcia, 1995). These effects have been observed in diverse forest formations, from tropical humid forest to boreal deciduous (Harper et al., 2005), but in seasonally dry formations the information are incipient.

So far, few studies on the subject were developed in seasonal formations. Noteworthy are Oliveira-Filho et al. (1997, 2007) in semideciduous forest, Lima-Ribeiro (2008) and Dodonov et al. (2013) in differents physiognomy of cerrado (tropical savanna), which found some effect, and Santos and Santos (2008) (in caatinga – tropical shrubland), Sampaio and Scariot (2011) and Oliveira et al. (2013) in dry forest, who did not find.

When compared to humid forests, dry forests can be seen to demonstrate a number of strong contrasts including different structural and functional patterns (Murphy and Lugo, 1986) and different dispersal and species abundance patterns (Hubbell, 1979). Hubbell (1979) highlights theories that were well-adjusted in humid forests (such as the theories put forward by Janzen-Connell), but have not been validated for dry forests.

Dry forests occur in tropical regions demonstrating extreme seasonality of rainfall patterns, with dry seasons lasting from four to seven months (Janzen, 1988) when more than half of the plants lose their leaves (IBGE, 2012). This seasonality regulates the growth and reproduction of the species living there (Murphy and Lugo, 1986). Additionally, solar radiation easily reaches to the forest floor during the dry season, reducing soil humidity and delaying the decomposition of organic matter (Janzen, 1988). Due to their high fertility soils and their occurrence associated with mesic climate, the dry forests are being replaced by agropastoral systems since the colonial period.

Microclimatic variations are very important to forest structure and composition, and plants usually grow more densely at forest edges – creating a buffer zone that can minimize the impacts of abiotic effects originating in the deforested matrix (Williams-Linera, 1990; Gascon et al., 2000). The predominance of deciduous species in dry forests, however, probably creates different environmental conditions and the adaptation of different survival strategies. As such, the present work examined the abiotic and biotic alterations along an edge-interior gradient in a dry forest in southeastern Brazil in order to respond to the following questions: (I) Are there differences in canopy cover along the edge-interior gradient during the dry season? (II) How do air temperatures, soil temperatures and the relative humidity vary along this gradient during the dry season? (III) How does the microclimate influence tree species richness, evenness and abundance along that gradient? (IV) Are certain species more dominant closer to the forest edges? The findings are contrasted with different vegetation types.

2. Material and Methods

2.1. Study area

The study was conducted in a private reserve located in the city of Montes Claros in Minas Gerais State, Brazil (600 m a.s.l.; 16°34'S and 43°46'W). The reserve is a dry forest fragment (Deciduous Seasonal Forest *sensu* IBGE, 2012) with 6 to 8 m in height covering 91 ha and the forest edge examined here is surrounded by pastures but protected by a fence. The regional climate is tropical savannah with dry winters (type Aw, according to Köppen's classification system) with six consecutive months with less than 60 mm of rainfall (Antunes, 1994). The temperature and mean annual rainfall is 22.4 °C and 1,082 mm, respectively (INMET, 2011).

2.2. Data sampling

Four 90 m transects spaced 30 m from each other were established at least 300 m from the lateral borders at the southern edge of the forest fragment. Each transect was composed of seven 5×20 m plots with their long axes being aligned perpendicular to the transect gradient being investigated. These plots were set up at 0 m, 10 m, 25 m, 40 m, 55 m, 70 m and 85 m from the forest edge (Figure 1).

In order to quantify canopy cover, hemispheric photographs were taken in the center of each sample plot. The images were processed using Gap Light Analyzer software (Frazer et al., 1999).

Microclimatic data were recorded at the peak of the dry season (corresponding to the month of September). The air temperature was measured 30 cm above ground level, soil temperatures 2 cm below the leaf litter layer, and the relative humidity of the air 130 cm above ground level. Microclimatic data were recorded in the centers of all of the plots during three measurement cycles in which one transect per day was randomly accompanied - totaling 12 monitoring days at the end of the three cycles. The variables were always measured at midday (12h00 mim).

The biotic variables were obtained by measuring all of the woody plants in the plots that had stem circumferences ≥ 15 cm at 130 cm above ground level. The plants were identified and the samples collected were deposited in the herbarium VIC at the Departamento de Biologia Vegetal of the Universidade Federal de Viçosa.

2.3. Data analysis

In order to respond to question I (about differences in canopy cover along of the gradient), the generalized linear models (GLM) were adjusted with binomial errors, with the percentage canopy covers as response variables and the distances from the edge as explanatory variables

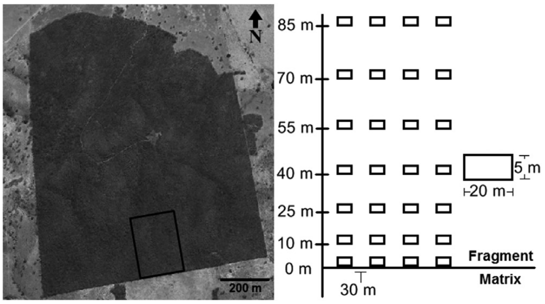

Figure 1. Image of the sampled fragment and schematic drawing of the experimental design.

(n = 28). To respond to question II (microclimate variability along of the gradient), the GLMs were adjusted with Gaussian errors, with the averages of the microclimatic data per plot as response variables and distances from the edge as explanatory variables. To respond to question III (microclimate influence in tree species richness, evenness and abundance along of the gradient), the GLMs were adjusted with Poisson errors, with species richness and abundance as response variables (and Binomial errors for evenness as response variables) and averages of the microclimatic data and the distances from the edges were used as explanatory variables. Chi-square (χ^2) tests for Poisson and Gaussian distributions were used and the F test when over- or under-dispersion was corrected (Crawley, 2007). A stepwise backward model simplification was used to evaluate the significance of these explanatory variables, using the P value to exclude the least significant variables. Adjusted models were subjected to residual analyses to evaluate the adequacy of the model (Crawley, 2007). To respond to question IV (about tree species dominance close to the edge), a species abundance data matrix was submitted to Indicator Species Analysis (Dufrêne and Legendre, 1997), which is based on relative frequency of occurrence in the distance groups. All analyses were performed using R (R Core Team, 2011).

3. Results

A total of 510 individuals were sampled, belonging to 54 tree species, distributed in 24 botanical families. The list of the species found in different distance from the edge is presented in Table 1. The mean canopy cover was 36.9%

Table 1. Species list sampled in different distances from the edge of a seasonally dry tropical forest fragment in the city of Montes Claros in Minas Gerais State, Brazil.

Species	Families	0 m	10 m	25 m	40 m	55 m	70 m	85 m
Acacia polyphylla DC.	Fabaceae		X	X	X	X		
Acacia sp.	Fabaceae					X	X	
Acacia sp.2	Fabaceae						X	
Anadenanthera colubrina (Vell.) Brenan	Fabaceae		X			X		X
Aralia excelsa (Griseb.) J.Wen	Araliaceae				X			
Aspidosperma pyrifolium Mart.	Apocynaceae		X	X	X	X		X
Aspidosperma subincanum Mart. ex A.DC.	Apocynaceae	X	X	X	X	X	X	X
Astronium fraxinifolium Schott ex Spreng.	Anacardiaceae	X	X	X	X	X	X	X
Bauhinia cheilantha (Bong.) Steud.	Fabaceae		X	X	X	X	X	X
Bauhinia rufa (Bong.) Steud.	Fabaceae		X	X		X	X	
Callisthene fasciculata (Spreng.) Mart.	Vochysiaceae	X		X			X	X
Callisthene major Mart.	Vochysiaceae	X	X					X
Campomanesia guazumifolia (Cambess.) O.Berg	Myrtaceae	X				X	X	
Casearia rupestris Eichler	Salicaceae	X	X	X	X	X	X	X
Celtis brasiliensis (Gardner) Planch.	Cannabaceae	X	X	X				
Chomelia sericea Müll.Arg.	Rubiaceae						X	
Cordia trichotoma (Vell.) Arrab. ex Steud.	Boraginaceae						X	
Dalbergia brasiliensis Vogel	Fabaceae			X	X	X	X	
Dalbergia cearensis Ducke	Fabaceae						X	
Dilodendron bipinnatum Radlk.	Sapindaceae	X	X	X	X	X	X	X
Erythroxylacea sp.	Erythroxylacea	X						
Eugenia ligustrina (Sw.) Willd.	Myrtaceae				X			
Eugenia sonderiana O.Berg	Myrtaceae						X	
Guazuma ulmifolia Lam.	Malvaceae	X	X	X	X	X	X	X
Jacaranda brasiliana (Lam.) Pers.	Bignoniaceae	X						
Luehea candicans Mart. and Zucc.	Malvaceae	X	X					
Machaerium floridum (Mart. ex Benth.) Ducke	Fabaceae							X
Machaerium scleroxylon Tul.	Fabaceae	X			X	X		X
Machaerium villosum Vogel	Fabaceae					X	X	X
Machaonia brasiliensis (Hoffmanss. ex Humb.) Cham. and Schltdl.	Rubiaceae			X				
Maclura tinctoria (L.) Steud.	Moraceae				X			
Magonia pubescens A.St.-Hil.	Sapindaceae	X					X	X
Myracrodruon urundeuva Allemão	Anacardiaceae	X	X	X	X	X	X	X

Table 1. Continued...

Species	Families	0 m	10 m	25 m	40 m	55 m	70 m	85 m
Myrcia tomentosa (Aubl.) DC.	Myrtaceae					X		
Myrtaceae sp.1	Myrtaceae					X		
Myrtaceae sp.2	Myrtaceae	X						
Pisonia tomentosa Casar.	Nyctaginaceae					X		
Platymiscium blanchetii Benth.	Fabaceae	X	X	X	X	X	X	
Platymiscium floribundum Vogel	Fabaceae				X			
Platypodium elegans Vogel	Fabaceae				X		X	
Poecilanthe falcata (Vell.) Heringer	Fabaceae						X	X
Pouteria gardneriana (A.DC.) Radlk.	Sapotaceae			X				
Pseudobombax tomentosum (Mart. and Zucc.) A.Robyns	Malvaceae						X	X
Rhamnidium elaeocarpum Reissek	Rhamnaceae			X				
Rubiaceae sp.	Rubiaceae				X			
Schinopsis brasiliensis Engl.	Anacardiaceae	X	X	X	X	X	X	X
Schinus molle L.	Anacardiaceae	X		X				
Schoepfia brasiliensis A.DC.	Olacaceae							X
Sebastiania brasiliensis Spreng.	Euphorbiaceae	X			X		X	
Tabebuia impetiginosa (Mart. ex DC.) Standl.	Bignoniaceae		X					X
Terminalia argentea (Cambess.) Mart.	Combretaceae	X	X				X	X
Terminalia glabrescens Mart.	Combretaceae	X	X	X			X	
Triplaris gardneriana Weddell	Polygonaceae				X			
Vernonanthura divaricata (Spreng.) H.Rob.	Asteraceae						X	

Table 2. Mean and standard deviation of variables obtained along the edge-interior gradient in a dry forest.

Dist.	Canopy	Air Temp.	Soil Temp.	Air Hum.	S	Abun.
Pasture*	0	39.26 ± 1.83	49.13 ± 1.69	24.25 ± 2.6	0	0
0	41.2 ± 7.15	37.56 ± 2.04	34.36 ± 3.91	23.42 ± 2.38	9 ± 1.41	23.25 ± 4.79
10	38.5 ± 3.26	37.41 ± 1.72	33.62 ± 3.17	23.42 ± 2.47	8 ± 0	22 ± 7.26
25	38.57 ± 7.82	38.74 ± 0.87	36.41 ± 3.78	23.92 ± 1.4	8 ± 0.82	15.75 ± 5.44
40	34.39 ± 8.12	37.87 ± 1.03	35.83 ± 6.19	24.08 ± 1.85	7 ± 3.16	16.25 ± 4.65
55	32.36 ± 3.25	39.22 ± 1.29	35.09 ± 3.09	23.75 ± 2.15	5.75 ± 3.3	14.5 ± 7.68
70	38.52 ± 9.76	38.42 ± 0.98	33.49 ± 1	24.5 ± 2.53	9.25 ± 1.26	18.5 ± 3.42
85	34.68 ± 7.08	38.04 ± 1.4	38.12 ± 3.54	25.33 ± 1.78	8.5 ± 1.29	17.25 ± 4.03

Distance (m), canopy cover (%), air temperature (°C), soil temperature (°C), humidity of air (%), richness – S – and abundance.
*The values obtained in the pasture were just for characterization, therefore, were not used in analysis.

Figure 2. Canopy cover during the rainy season – January – (a) and canopy cover during the dry season – September – (b) in a seasonally dry tropical forests in southeastern Brazil.

Table 3. Statistical values of the model referring to questions I, II and III.

Questions	Response Variables	Explanatory Variables	F	P
I	Canopy	Distance	1.989	0.17
II	Air Temperature	Distance	1.143	0.295
II	Soil Temperature	Distance	0.989	0.329
II	Air Humidity	Distance	2.347	0.138
III	Richness	Distance: Air Temperature	0.028	0.869
III	Richness	Distance: Soil Temperature	0.535	0.472
III	Richness	Distance: Air Humidity	0.195	0.663
III	Evenness	Distance: Air Temperature	0.165	0.689
III	Evenness	Distance: Soil Temperature	0.004	0.952
III	Evenness	Distance: Air Humidity	0.139	0.713
III	Abundance	Distance: Air Temperature	1.053*	0.305
III	Abundance	Distance: Soil Temperature	0.101	0.808
III	Abundance	Distance: Air Humidity	0.336	0.668

I= Are there differences in canopy cover along the edge-interior gradient during the dry season?; II= How does the microclimate vary along this gradient during the dry season?; III= How does the microclimate influence tree species richness, evenness, and abundance along that gradient? **:** = interactions between explanatory variable. * = $\chi 2$–value. After the simplification of the interaction models, none variable were observed to be significant ($P > 0.05$).

(SD=3.1) (Figure 2). A summary with mean and standard deviation of variables used is presented in Table 2.

In terms of questions I (about differences in canopy cover along of the gradient), II (microclimate variability along of the gradient), and III (microclimate influence in tree species richness, evenness, and abundance along of the gradient), none of the 13 regressions demonstrated inclinations significantly different from zero ($P > 0.05$), indicating that the distance from the edge did not provide effect on the response variables tested, not even with interaction between microclimatic variables (Table 3).

In terms of question IV (about tree species dominance close to the edge), the Indicator Species Analysis did not indicate preferential species in sampling sites according to their positions in relation to the edge (p-values greater than 0.05 for all of the species), suggesting that the species distribution patterns were not influenced by different distances from the forest edge.

4. Discussion

The homogeneity of the microclimatic variables along the edge-interior gradient was observed to be a response to the canopy cover pattern. Canopy openness in dry forests is greater than 54% (Nascimento et al., 2007), with high associated levels of solar radiation that would desiccate the vegetation if not for its xerophytic character.

Kapos (1989) reported observing edge effects in microclimatic parameters up to 40 m from the forest edge but suggested that microclimatic alterations in humid forests could extend 60 m from the edge, depending on canopy height and the degree of seasonal water stress in the region. Additionally, managed edges and high canopy enhances the magnitude of edge effects from the first few meters of distance (Harper et al., 2005). However, is probable that the homogeneity of the microclimatic variables along the 85 m transects from the forest edge in the present study is a reflection of the poorly developed vertical strata of this forest type.

The microclimates of humid forests demonstrate significant vertical differences, being more stable and amenable in the lower third and governed by swings in conditions above the canopy (Madigosky, 2004). The simpler structures and vertical complexities of dry forests (Murphy and Lugo, 1986) can make their microclimatic conditions more instable and more sensitive to alterations above the upper canopy. Additionally, due to the fact that the edges of these dry forest fragments are frequently managed to maintain grazing areas, have a high matrix harshness, in which the microclimate alteration into the forest interior are even more accentuated than in unmanaged edges (Gascon et al., 2000). This lack of a buffer zone along the managed edges, summed to deciduousness of the forest itself, creates what are essentially “edge conditions” throughout the entire fragment. Additionally, the influence of other effects (principally indirect biotic effects) should not be overlooked.

Changes in the physical environments at forest edges often result in alterations in species distributions (due to their different physiological tolerances) (Murcia, 1995). Many of the environmental alterations are due to changes in light intensity that drive the differentiation of ecological groups (Whitmore, 1975) – resulting in a predominance of pioneers species near the fragment edge (Laurance et al., 2006). However, the absence of preferential species at different distances from the forest edge proved to be a response (or lack of response) to the relative homogeneity microclimatic, as essentially uniform light levels did not favor the formation of microenvironments appropriate for distinct ecological groups. This evidence fits integrally with the main principle of neutral theory (Hubbell, 2001), which the species are equivalent ecologically, but contrary to the principle of stochasticity, since the patterns of distribution and abundance of species was determined cause. Otherwise, forest hosting many pionner species, which are adapted to change microclimatic conditions of the edge, may exhibit lower magnitude or distance of edge effect (Harper et al., 2005). Anyway, it may be more difficult to define ecological groups in dry forests than in humid forests.

Similar pattern seems to occur in deciduous temperate forests. Matlack (1994) found no differences in species richness and composition of edges in temperate forests. According to this author, it is due to the homogeneity of several microclimatic variables measured in fragments in a previous study (Matlack, 1993). Similarly, Morecroft et al. (1998) described a homogeneous microclimatic gradient in a temperate forest during the winter season.

Currently there are few fragments in the present study region favorable for evaluation of edge effect - that meet the assumptions suggested by Murcia (1995) – which resulted in the small sampling of this study. However, a number of other authors have noted the absence of edge effects in tropical dry vegetation formations: Sampaio and Scariot (2011) did not find any differences between the forest edge and interior in relation to the composition and abundance of seedling and adult individuals in a fragment of dry forests subjected to the same type of climate as the present study; Oliveira et al. (2013) did not find difference in tree height, stem diameter, basal area, species richness, abundance and LAI index; and Santos and Santos (2008) did not observe any significant edge and internal differences in a shrub caatinga site. In these cases, the absence of edge effects could be explained by the fact that these vegetations do not have continuous canopies (temporally and spatially, in the case of shrub caatinga) that could protect them from climatic adversities. It is therefore possible that "traditional" edge effects in biotic communities are directly related to the presence of a continuous canopy, and that vegetation forms adapted to seasonal environments are resistant at least in the stratum assessed. Nevertheless, Dodonov et al. (2013) demonstrated difference in microclimatic edge of savanna formations and attributed to wind actions. According to Harper et al. (2005) canopy cover, winds and a host of other variables, in fact determine the magnitude and distance of the edge effect, however, in seasonal environments the most of processes and responses remain unknown.

This study emphasized only the dry season and considered biotic variables (richness, evenness, abundance and indicator tree species of distance) that do not change with other season. However, it is possible that the canopy density in the wet season promotes a microclimate change and therefore alterations in other biotic variables. Additionally, future research involving indirect biotic effects (*sensu* Murcia, 1995) or a series of secondary responses (*sensu* Harper et al., 2005), as changes in the understory, invasion of exotic species or phenological studies may bring other important contributions to the theory when treated in deciduous seasonal environments.

It is important to note that ecological processes commonly seen in humid forest (such as edge effects or the establishment of ecological groups) may not necessarily shared with dry forest (well as other patterns already demonstrated by Hubbell, 1979), since the few studies in this vegetation begin to indicate patterns. Anyway, more studies are needed to better understand the different edge effects in dry forests.

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