Acta Botanica Brasilica 29(2): 190-197. 2015.
doi: 10.1590/0102-33062014abb3732

The role of temporal scale in linear edge effects on a submontane Atlantic forest arboreal community

Ana Paula Lima do Couto-Santos[1*], Abel Augusto Conceição[2] and Ligia Silveira Funch[2]

Received: August 31, 2014 Accepted: November 25, 2014

ABSTRACT

This study aims to detect the composition, abundance patterns, and successional stage distributions exhibited by arboreal species inside and at the linear edge of a submontane seasonal forest in the Chapada Diamantina (12°28'31'S, 41°23'14'W), Bahia, Brazil. The individual plants with breast height diameters ≥5 cm were sampled in 30 quadrats (10 m × 10 m), 15 in the forest edge and 15 inside the forest. Species were classified according to successional category. Phytosociological and diversity indices were calculated. Shannon indices were compared using Hutcheson's *t*-test, and the remaining parameters were analyzed by ANOVA. Linear edges exerted a high impact on the floristic composition, diversity, and abundance of species, though little interference was observed in the structure of the community, since phytosociological parameters and the proportions of successional categories did not differ between the edge and inner forest fragment. The impact of linear infrastructure was similar to that of other border types. Additionally, even though the distance between forest fragments was very short, an edge effect was observed, which underlines the importance of linear forest edges to biodiversity conservation.

Keywords: Chapada Diamantina, diversity, forest fragmentation, successional categories, vegetation structure

Introduction

Brazil ranks among the countries with the highest plant species richness in the world, and enjoys considerable diversity of forest ecosystems due to its wide variation in climatic conditions and soils (Gentry 1982; Leitão-Filho 1987). In northeastern Brazil, forests occur from the transition zone of the semiarid nucleus in which the *caatinga* vegetation prevails, to the more humid areas at the borders of the region. However, forests are also observed in semiarid areas of greater altitude, on crystalline basement rocks, or even on sedimentary soils (Couto *et al.* 2011). The forests within the transition zone of the semiarid nucleus include the seasonal forests on the east side of Chapada Diamantina National Park, which are considered part of the Atlantic Forest (*sensulato*; Oliveira-Filho & Fontes 2000) and cover the largest forested section of the Chapada Diamantina. These forests are the most degraded in the region, particularly due to timber extraction and agricultural and cattle farming activities (Funch *et al.* 2005). These anthropogenic factors have led to the destruction and loss of biodiversity of such vegetation, even though the natural richness of these regions has not been properly investigated (Funch *et al.* 2008; Ribeiro-Filho *et al.* 2009; Couto *et al.* 2011).

Linear infrastructure work, such as the construction of roads and power lines, alter natural landscapes, and often require the deforestation of corridors inside forests, which can create linear borders (Murcia 1995). These corridors magnify edge effects because their perimeter is twice as long as that of edges that delimit a conventional forest fragment, increasing the impact caused by the degraded area in the surroundings and intensifying the microclimate changes near edges (Goosem 1997; Pohlman *et al.* 2007). Such changes affect the structure of fragments (Ribeiro *et al.* 2009), depending on how much time has passed since the creation of such edges. For instance, a recently opened linear edge may be structurally homogeneous, or quite similar to the inner fragment. However, with time, other changes may occurin association with edge effects and facilitate the emergence of more heterogeneous communities (Rodrigues & Nascimento 2006; Holanda *et al.* 2010).

Edge effects play a key role in understanding the ways landscape structures influence habitat quality (Zanuto *et al.* 2007). Accordingly, these effects have been a consistent research topic for decades (Pohlman *et al.* 2007; Prieto *et al.* 2014). Studies have documented matching patterns of biodiversity deterioration in fragmented environments. These patterns are characterized by the elimination of

---

[1] Departamento de Ciências Exatas e Naturais, Universidade Estadual do Sudoeste da Bahia, BR 415, Km 3, 45700-000, Itapetinga, BA, Brazil
[2] Departamento de Ciências Biológicas, Universidade Estadual de Feira de Santana, BR 116, Km 3, 44036-900, Feira de Santana, BA, Brazil
* Corresponding author: aplcouto@yahoo.com.br

arboreal species of specific functional groups and the impoverishment of tropical forests (Tabarelli *et al.* 2004; Lopes *et al.* 2009). These factors point to the urgent need for more studies on restoration and conservation efforts.

Several studies have investigated the influence of edge effects in neotropical forests (Burkey 1993; Laurance *et al.* 1998; Olander *et al.* 1998; Mesquita *et al.* 1999; Paciencia & Prado 2005; Laurance *et al.* 2009; Ribeiro *et al.* 2009; Reznik *et al.* 2012) and reported changes in composition, diversity, and dynamics of species. Nevertheless, other research suggests that edge effects may actually not have serious negative outcomes, exerting positive influences on some variables, or even no influence at all (Oliveira *et al.* 2013).

The present study evaluates the impact of a linear edge on the heterogeneity of the arbustive-arboreal community in a patch of submontane seasonal forest in Chapada Diamantina, Bahia, Brazil. The aim was to detect composition, abundance patterns, and successional distribution stages inside and at the edge of the forest. Since the linear vegetation suppression by periodic pruning results in two adjacent edges, we expected neutral effects or increases in the richness and heterogeneity at these two adjacent linear edges, in contrast with the expectation for a simple edge of a larger fragment (Paciencia & Prado 2005; Ribeiro *et al.* 2009; Reznik*et al.* 2012).

Material and methods

Study area

The forest fragment studied is located at 12°28'31'S, 41°23'14'W in the Chapada Diamantina National Park, Bahia, Brazil. The topography of the region is slightly wavy, with altitudes varying between 400 m and 600 m. Its soil comprised yellowish-red latosols of a clayish consistency that are poor in organic matter (Couto *et al.* 2011). Due to the altitudinal conditions, the climate in the region is classified as mesothermal type Cwb. The rainy season occurs in summer (December–April), peak rainfall is recorded in March–April, and the dry season occurs in winter. Rainfall varies between 35 mm (July and August) and184 mm (December). Mean monthly temperatures oscillate around 18°C in winter (April–September) and exceed 22°C in hotter months (October–February; Funch *et al.* 2002). These conditions have led to the classification of the vegetation in the area as seasonal submontane forest (IBGE 2012).

A major highway bisects the region, and two perpendicular corridors that measure approximately 10 m in width were deforested to allow the passage of high-voltage electric power lines. Both the road and power lines were constructed in the 60's. The vegetation is characterized by emergent trees up to 26 m in height, including the species *Protium heptaphyllum* (Aubl.) Marchand, *Maprounea guianensis* Aubl., *Hirtella glandulosa* Spreng., and *Aspidosperma discolor* A. DC. Stratification is difficult to detect, but the understory is well lit and formed mainly by young individuals of species that are established in the higher strata and species of the families Rubiaceae, Melastomataceae, and Poaceae. Abundant climbing species are also seen, and epiphytic and hemiparasitic species are rare (Couto *et al.* 2011).

Phytosociological survey

The fieldwork was conducted between May 2006 and August 2007. Given that edge effects may stretch for approximately 100 m (Laurance *et al.* 1998), 30 quadrats measuring 10 m × 10 m (0.3 ha) were established in a forest fragment measuring 6.5 ha using an *Etrex Summit* GPS receiver for randomization of the quadrats location in a forest, compass, and measuring tape. Fifteen quadrats were defined along the forest edge (within the 0–100 m range), and the other quadrats were established in the inner fragment (more than 150 m away from the power lines). Moreover, care was taken to establish quadrats 150 m away from the highway, so as to cover the edge effect of the area deforested for the power lines alone.

In each quadrat, circumferences (C) of shrub and arboreal individuals were measured using a measuring tape. Only individuals with C at breast height (diameter at 1.3 m from ground level) equal to or larger than 15.7 cm [Diameter at breast height (DBH) = 5.0 cm] were sampled. DBH was calculated using the formula $D = C.\pi^{-1}$.Height was estimated visually, using a 2m long stick. All living individuals sampled were tagged to facilitate periodic monitoring.

Samples of botanical material were collected and identified using the collections stored in the Herbarium HUEFS and by consulting specialists and the literature; taxonomic classification was based on the APG III (2009) system. Arboreal species were classified according to successional category as pioneers (P), early secondary (Es), late secondary (Ls), and not defined (nd; Gandolfi *et al.* 1995). This classification was carried out using information about the biology of the species reported in the literature (Gandolfi *et al.* 1995; Nunes 2003; Mariano Neto 2004), supplemented with the authors'knowledge of the subject.

The structure of the forest was described according to the following phytosociological parameters: relative density (RD), relative frequency (RF), and relative dominance (RDo) as well as importance value (IV) and cover value (CV; Mueller-Dombois & Ellenberg 1974), calculated using the software FITOPAC 1.6 (Shepherd 2006). The Shannon–Wienerdiversity index (*H*'; $\log_n$ base) and Pielou's evenness index (*J*') were calculated for edge and inner fragments (Brower & Zar 1998; Nunes *et al.* 2003). Values of *H*' were compared using Hutcheson's *t*-test (Diversity *t*-test) calculated with the software PAST (Hammer *et al.* 2001).

Normality of data was evaluated using the Shapiro–Wilk test ($p > 0.05$). The variables height, diameter, area at ground level, density, floristic composition, and successional categories (in proportion of species and individuals) were compared using a one-way ANOVA. Structural variables were expressed as box plots using the software BioEstat 5.3 (Ayres *et al*. 2007). Height and DBH were analyzed based on the distribution of categories in each quadrat.

Results

In total, 456 arboreal individuals were sampled (1520 individuals.ha^{-1}), belonging to 33 families, 47 genera, and 68 species (four of which were not identified; Tab.1). The inner fragment and edge differed in their most abundant species as well as highest IV and CV (Tab.1). The species with the highest IV at the edge were *Tapirira guianensis, Micropholis gardneriana, Hirtella glandulosa, Maprounea guianensis*, and *Himatanthus bracteatus*. These formed the largest and most common populations in edges, together with *Protium heptaphyllum* and *Pogonophora schomburgkiana*. Such a pattern was also evident in the sum of the density these species (43.6%). Inside the forest, *Eschweilera tetrapetala*, *Copaifera langsdorffii*, *Tapirira guianensis*, *Ocotea nitida*, and *Pouteria*

Table 1. Families and shrub/arboreal species and respective phytosociological parameters and successional stages of individuals sampled in a linear edge and inside a forest fragment of a submontane seasonal forest, Chapada Diamantina National Park, Bahia, Brazil. Data are presented in alphabetical order by family. P = pioneer, Es = early secondary, Ls = late secondary, und = undetermined, N = number of individuals, IV = importance value, CV = cover value, RD = relative density, RDo = Relative dominance, RF = Relative frequency, − = absence of species.

			Edge						Inner fragment					
Species	Family	Successional stage	N	IV(%)	CV(%)	RD	RDo	RF	N	IV(%)	CV(%)	RD	RDo	RF
*Tapiriraguianensis*Aubl.	Anacardiaceae	P	15	25.05	19.53	6.22	13.31	5.52	15	21.09	15.16	6.91	8.25	5.93
Guatteria oligocarpa Mart.	Annonaceae	Ls	7	9.06	5.99	2.9	3.09	3.07	1	1.43	0.58	0.46	0.12	0.85
Xylopia sp.	Annonaceae	Es	2	1.66	1.01	0.83	0.18	0.61	-	-	-	-	-	-
*Aspidosperma discolor*A. DC.	Apocynaceae	Ls	3	9.69	7.85	1.24	6.61	1.84	5	7.19	4.64	2.3	2.34	2.54
Himatanthus bracteatus (A.DC.) Woodson	Apocynaceae	Es	15	14.55	10.25	6.22	4.03	4.29	5	7.06	2.82	2.3	0.52	4.24
Schefflera sp.	Araliaceae	P	-	-	-	-	-	-	1	1.37	0.52	0.46	0.06	0.85
Cordia bicolor A. DC.	Boraginaceae	Es	-	-	-	-	-	-	3	3.35	1.65	1.38	0.27	1.69
Protium heptaphyllum (Aubl.) Marchand	Burseraceae	Es	14	13.09	8.18	5.81	2.37	4.91	3	4.74	2.20	1.38	0.81	2.54
Maytenus robusta Reissek	Celastraceae	Es	5	5.18	2.73	2.07	0.65	2.45	3	11.26	8.72	1.38	7.34	2.54
Couepia impressa Prance	Chrysobalanaceae	Ls	1	1.66	1.04	0.41	0.63	0.61	-	-	-	-	-	-
Couepia sp.	Chrysobalanaceae	Ls	-	-	-	-	-	-	5	9.24	5.00	2.3	2.69	4.24
Hirtella glandulosa Spreng.	Chrysobalanaceae	Ls	11	19.58	14.67	4.56	10.11	4.91	8	13.14	8.06	3.69	4.37	5.08
Hirtella gracilipes (Hook. f.) Prance	Chrysobalanaceae	Es	2	2.32	1.09	0.83	0.26	1.23	-	-	-	-	-	-
Clusia nemorosa G. Mey	Clusiaceae	Es	2	2.27	1.04	0.83	0.21	1.23	-	-	-	-	-	-
Diospyros sericea A.DC.	Ebenaceae	Es	2	2.21	0.98	0.83	0.15	1.23	-	-	-	-	-	-
Chaetocarpus echinocarpus (Baill.) Ducke	Euphorbiaceae	Ls	7	6.65	3.58	2.9	0.68	3.07	1	1.40	0.55	0.46	0.09	0.85
Maprounea guianensis Aubl.	Euphorbiaceae	Ls	8	14.95	11.27	3.32	7.95	3.68	1	1.55	0.71	0.46	0.25	0.85
Pogonophora schomburgkiana Miers ex Benth.	Euphorbiaceae	Ls	15	12.74	8.45	6.22	2.22	4.29	8	9.80	5.57	3.69	1.88	4.24
Andira fraxinifolia Benth.	Fabaceae	Es	1	1.38	0.77	0.41	0.35	0.61	-	-	-	-	-	-
Copaifera langsdorffii Desf.	Fabaceae	Ls	4	5.52	4.29	1.66	2.63	1.23	13	34.68	29.59	5.99	23.6	5.08
Hymenolobium janeirense var. *stipulatum* (N. Mattos) Lima	Fabaceae	Ls	2	13.59	12.37	0.83	11.54	1.23	1	1.37	0.52	0.46	0.06	0.85
Inga sp.1	Fabaceae	Es	-	-	-	-	-	-	1	6.60	5.76	0.46	5.3	0.85
Inga sp.2	Fabaceae	Es	1	1.09	0.48	0.41	0.06	0.61	-	-	-	-	-	-
Inga thibaudiana D.C	Fabaceae	Es	1	1.09	0.48	0.41	0.06	0.61	-	-	-	-	-	-
Swartizia apetala Raddi	Fabaceae	Es	1	1.12	0.50	0.41	0.09	0.61	-	-	-	-	-	-
Vismia guianensis (Aubl) Choi	Hypericaceae	P	-	-	-	-	-	-	1	1.40	0.55	0.46	0.09	0.85
Lacistema robustum Schinizl.	Lacistemataceae	P	1	1.09	0.48	0.41	0.06	0.61	-	-	-	-	-	-
Cinnamomum sp.	Lauraceae	Ls	-	-	-	-	-	-	1	1.40	0.55	0.46	0.09	0.85

Continues.

Table 1. Continuation.

			Edge						Inner fragment					
Species	Family	Successional stage	N	IV(%)	CV(%)	RD	RDo	RF	N	IV(%)	CV(%)	RD	RDo	RF
Nectrandra membranaceae Griseb.	Lauraceae	Ls	3	3.64	2.41	1.24	1.16	1.23	3	4.09	2.40	1.38	1.02	1.69
Ocotea corymbosa (Meisn.) Mez.	Lauraceae	Es	2	3.56	2.33	0.83	1.5	1.23	1	1.55	0.71	0.46	0.25	0.85
Ocotea dyospirifolia (Meisn.) Mez.	Lauraceae	Es	1	2.11	1.50	0.41	1.08	0.61	-	-	-	-	-	-
Ocotea glomerata (Ness.) Mez.	Lauraceae	Es	4	4.83	2.38	1.66	0.72	2.45	10	8.39	5.85	4.61	1.24	2.54
Ocotea nítida (Meisn.) Rohwer	Lauraceae	Ls	5	4.99	2.53	2.07	0.46	2.45	12	18.27	12.34	5.53	6.81	5.93
Ocotea sp.1	Lauraceae	Es	1	1.15	0.54	0.41	0.12	0.61	-	-	-	-	-	-
Ocotea sp.2	Lauraceae	Es	1	1.09	0.48	0.41	0.06	0.61	2	3.07	1.38	0.92	0.46	1.69
Eschweilera tetrapetala Mori	Lecythidaceae	Ls	6	6.53	4.07	2.49	1.58	2.45	49	42.31	32.99	22.58	10.4	9.32
Byrsonima crassifolia (L.) Kun	Malpighiaceae	Ls	-	-	-	-	-	-	1	1.66	0.82	0.46	0.35	0.85
Byrsonima sericea DC.	Malpighiaceae	Es	3	4.24	2.4	1.24	1.16	1.84	1	1.55	0.71	0.46	0.25	0.85
Byrsonima sp.	Malpighiaceae	Es	3	4.24	2.4	1.24	1.16	1.84	-	-	-	-	-	-
Eriotheca gracilipes (K. Schum.) A. Robyns	Malvaceae	Es	1	1.15	0.54	0.41	0.12	0.61	-	-	-	-	-	-
Miconia holosericea (L.) DC.	Melastomataceae	P	8	8.02	4.34	3.32	1.02	3.68	-	-	-	-	-	-
Miconia rimalis Naudin.	Melastomataceae	P	8	7.13	4.07	3.32	0.75	3.07	-	-	-	-	-	-
Calyptranthes lucida DC.	Myrtaceae	Es	3	3.30	1.46	1.24	0.21	1.84	-	-	-	-	-	-
Egenia laxa DC.	Myrtaceae	Es	1	1.12	0.50	0.41	0.09	0.61	-	-	-	-	-	-
Eugenia sp.	Myrtaceae	Es	3	2.04	1.43	1.24	0.18	0.61	-	-	-	-	-	-
Myrcia detergens Miq.	Myrtaceae	Es	9	8.54	4.86	3.73	1.12	3.68	5	5.27	7.73	2.3	0.43	2.54
Myrcia fallax (Rich.) DC.	Myrtaceae	Es	2	2.30	1.08	0.83	0.25	1.23	-	-	-	-	-	-
Myrcia obovata (Berg) Niedenzu	Myrtaceae	Es	1	1.09	0.48	0.41	0.06	0.61	2	2.86	1.17	0.92	0.25	1.69
Myrciaria dubia (H.B.K.) McVa	Myrtaceae	Es	-	-	-	-	-	-	1	1.4	0.55	0.46	0.09	0.85
Psidium brawniannum DC.	Myrtaceae	Es	-	-	-	-	-	-	5	6.36	2.97	2.3	0.67	3.39
Heisteria perianthomiga (Vell.) Sleumer	Olacaceae	Es	1	1.12	0.50	0.41	0.09	0.61	-	-	-	-	-	-
Schoepfia obliquifolia Turcz.	Olacaceae	Es	1	1.09	0.48	0.41	0.06	0.61	2	2.31	1.46	0.92	0.54	0.85
Euplassa sp.	Proteaceae	Es	1	1.09	0.48	0.41	0.06	0.61	-	-	-	-	-	-
Hortia arborea Engl.	Rutaceae	P	-	-	-	-	-	-	1	2.39	1.55	0.46	1.09	0.85
Casearia arborea (Rich.) Urb.	Salicaceae	Es	2	2.18	0.95	0.83	0.15	1.23	8	6.8	4.26	3.69	0.57	2.54
*Casearia commersoniana*Cambess.	Salicaceae	Ls	3	3.35	1.51	1.24	0.27	1.84	-	-	-	-	-	-
Cupania oblongifolia Mart.	Sapindaceae	Es	2	2.21	0.98	0.83	0.15	1.23	1	1.37	0.52	0.46	0.06	0.85
Micropholis gardneriana (DC.) Pierre	Sapotaceae	Es	27	22.48	15.73	11.2	4.53	6.75	14	13.8	9.56	6.45	3.11	4.24
Pouteria ramiflora (DC.) Pierre	Sapotaceae	Ls	9	13.45	9.77	3.73	6.04	3.68	12	15.45	9.52	5.53	3.99	5.93
Pouteria torta (DC.) Pierre	Sapotaceae	Ls	6	10.91	9.69	2.49	7.2	1.23	3	4.33	1.79	1.38	0.41	2.54
Simarouba amara Aubl.	Simaroubaceae	P	-	-	-	-	-	-	1	1.67	0.82	0.46	0.36	0.85
Siparuna guianensis Aubl.	Simaroubaceae	Ls	3	3.61	1.77	1.24	0.52	1.84	2	2.05	0.82	0.92	0.28	0.85
Simplocos nitens (Pohl.) Benth.	Simplocaceae	Ls	2	2.23	1.01	0.83	0.18	1.23	-	-	-	-	-	-
Qualea sp.	Vochysiaceae	Es	1	1.4	0.78	0.41	0.37	0.61	-	-	-	-	-	-
Undetermined 1	und 1	Sc	1	2.56	1.95	0.41	1.53	0.61	-	-	-	-	-	-
Undetermined 2	und 2	Ls	-	-	-	-	-	-	1	2.87	2.02	0.46	1.56	0.85
Undetermined 3	und 3	Ls	-	-	-	-	-	-	3	9.38	7.69	1.38	6.31	1.69
Undetermined 4	und 4	Sc	-	-	-	-	-	-	1	2.73	1.88	0.46	1.42	0.85

ramiflora predominated, which, except for *T. guianensis*, are late successional species. *Eschweilera tetrapetala* was prominent not only inside the forest, but also in the whole environment studied, with 326.7 individuals.ha^{-1} presenting IV higher than 40%.

When the edge and inner fragment were compared (Tab.2), even though 26 species were shared by these two environments, the floristic composition varied significantly (F = 5.221; p = 0.0239), as did diversity (Hutcheson's t = 2.40; p = 0.018). However, no variation was observed in proportions of successional categories ($F_{species}$ = 0.152; p = 0.7135 and $F_{individuals}$ = 0.039; p = 0.8501). A significant difference was observed between the edge and inner fragment in height but only in the class of trees between 10 m and 15 m in height (F = 6.703; p = 0.0158). However, these environments did not differ in DBH (F = 0.17; p = 0.69), D (F = 1.137; p = 0.296), and area at ground level (F = 1.45; p = 0.242), in spite of the presence of outliers (Fig. 1). In the two environments, the DBH distribution curve (Fig. 2) indicates that a higher number of individuals lie in the classes denoting larger diameters. Extreme diameter values were recorded in the edge for *Hymenolobium janeirense var. stipulatum* (63.4 cm), *Aspidosperma discolor* (48.4 cm), and *Pouteria ramiflora* (38.2 cm) and in the inner fragment for *Copaifera langsdorffii* (63.4 cm), *Maytenus robusta* (54.1 cm), and undetermined individual 3 (47.8 cm), which are the outliers shown in the box plot (Fig. 1). Most arboreal individuals did not exceed 10 m in height (Fig. 3). Extreme values were recorded for *Hymenolobium janeirense var. stipulatum* (26 m) and *Hirtella glandulosa* (25 m) in the edge and *Copaifera langsdorffii* (22 m) and *Maprounea guianensis* (20 m) in the inner fragment.

Discussion

The present study showed the greatest impact of linear edge on floristic composition, diversity, and abundance of species, whereas little interference was observed in the structure of the tree community. Phytosociological parameters and proportions of successional categories did not vary between the edge and the inner fragment, showing that the structure of the arboreal community in these environments is not consistently affected. Heterogeneity was also observed based on the number of pioneer and early secondary species at the edge and late secondary species inside the forest. In spite of the floristic peculiarities, the edge and inner fragment were similar in the families presenting the highest species richness, such as Lauraceae, Myrtaceae, Fabaceae, Sapotaceae, and Euphorbiaceae, which are important groups in the Brazilian as well as global flora (Gentry 1998; Oliveira Filho *et al.* 2004; Saravanan *et al.* 2013).

Higher heterogeneity in edges (*H'*) has also been reported for other linear edges (Olander *et al.*1998; Laurance *et al.* 2002; Prieto *et al.* 2014) as well as for other kinds of edges (Nunes *et al.* 2003). Disturbances and edge effects may strongly influence species diversity. Often, higher diversity in edge areas is explained by the presence of typical inner fragment species as well as plant species with different light demands (Nunes *et al.* 2003; Tabarelli *et al.* 2012; Arroyo-Rodríguez *et al.* 2013).

The *H'* value observed in the edge is in agreement with previous results reported for the Chapada Diamantina region, which vary between 3.4 and 3.6 nats/individual (Stradmann 2000; Souza 2007; Ribeiro-Filho *et al.* 2009), and forests in northeastern and southeastern Brazil, which

Table 2. Comparison of linear edge and inner fragment of a submontane seasonal forest, Chapada Diamantina National Park, Bahia, Brazil. LAU = Lauraceae, MYRT = Myrtaceae, FAB = Fabaceae, CHRY = Chrysobalanaceae, SAP = Sapotaceae, EUPH = Euphorbiaceae.

	Edge		Inner fragment	
Number of individuals	241		217	
Number of species	54		42	
Density (individuals.ha^{-1})	1607		1447	
Richest families (%)	LAU (13.21); MYRT. FAB (11.32); CHRY. SAP. EUPH (5.66)		LAU (14.29); MYRT (9.52); FAB. SAP. EUPH (7.14)	
Richest genera (number of species)	*Ocotea* (6); *Myrcia* (3)		*Ocotea* (4)	
Shannon index (nats.$individual^{-1}$)	3.51		3.08	
Evenness (J)	0.88		0.82	
Successional stage (%)	Richness	Abundance	Richness	Abundance
Pioneer	7.4	13.1	9.5	8.3
Early secondary	57.4	47.1	38.1	30.1
Late secondary	33.3	39.3	50.0	61.3
Not defined	1.9	0.4	2.4	0.5

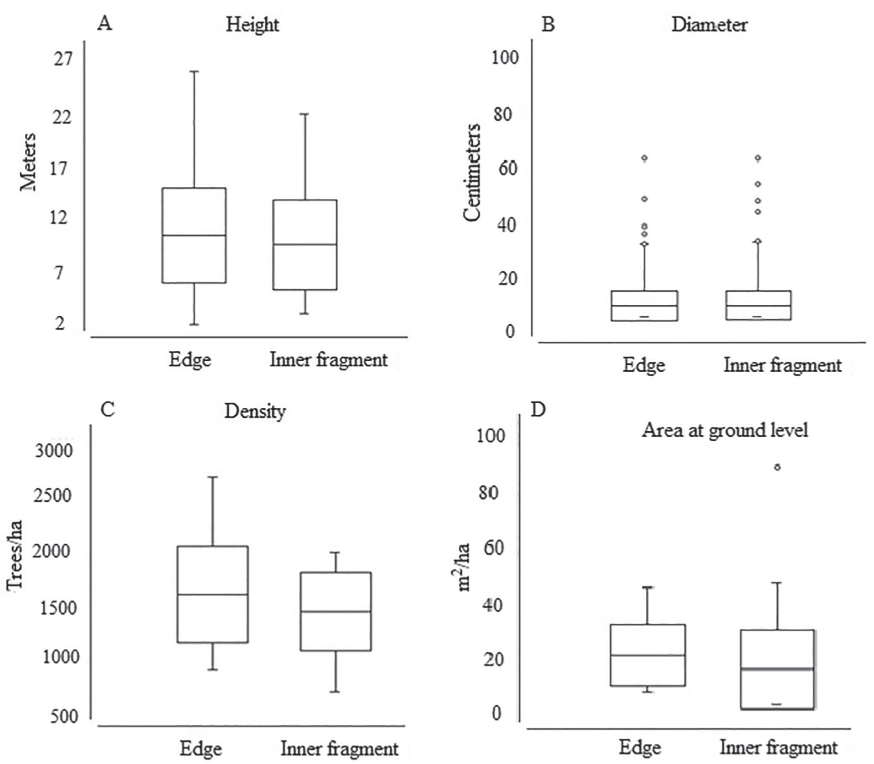

Figure 1. Box plot comparing height (A), diameter (B), density (C),and area at ground level (D) of trees in a linear edge and inside a forest fragment of a submontane seasonal forest in Chapada Diamantina National Park, Bahia, Brazil. Horizontal lines represent the arithmetic means (middle line) ± standard deviation (upper and lower lines); outer horizontal lines represent the minimum and maximum values; o = outliers; ha = hectares; m = meters.

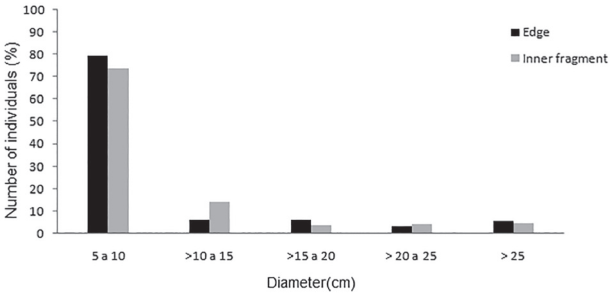

Figure 2. Distribution of the number of individuals according to diameter at breast height (DBH) in a linear edge and inside a forest fragment of a submontane seasonal forest in Chapada Diamantina National Park, Bahia, Brazil.

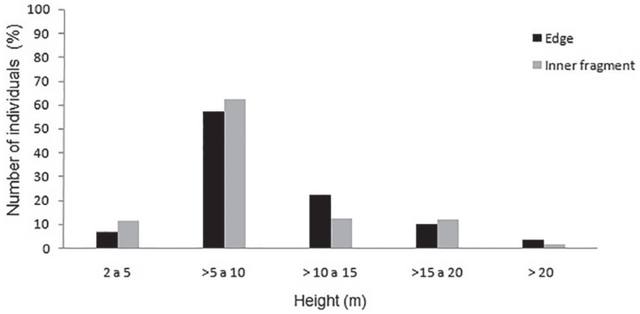

Figure 3. Distribution of the number of individuals according to height in a linear edge and inside a forest fragment of a submontane seasonal forest in Chapada Diamantina National Park, Bahia, Brazil.

range from 3.0 to 4.3 nats/individual (Sambuichi 2002; Mariano Neto 2004; Oliveira Filho *et al.* 2004; Catharino *et al.*2006). Despite the high species diversity, the inner fragment presented *H*' values below those reported for forests in other studies. Here, the most important species in this environment was *Eschweilera tetrapetala* (called *sapucaia*), which is an endemic species in submontane seasonal forests of the region.

The analysis of the successional stages of species showed that the edge had a higher proportion of early secondary species, which are less tolerant to shade. Conversely, the inner fragment had a higher number of late secondary species, which germinate and manage to grow under the low light conditions of the understory and reach maturity in this stratum, at the canopy, or in some cases, become emergent trees (Nunes *et al.* 2003).

According to Chazdon (2012), fragments still undergo several changes, including changes due to edge effects, even 15–50 years after an environmental disturbance, thus, the forest studied is susceptible to edge effects. Furthermore, the linear edge observed in this study is preserved by periodic pruning, which is required for the maintenance of linear infrastructure. These procedures disrupt the regeneration process and sustain the edge effect. Ultimately, shade-tolerant species and those that produce large fruit and seeds may be substituted by shade-intolerant, small-fruited, small-seeded species typical of secondary forests (Laurance *et al.* 2006). Some pioneer species seem to benefit from habitat fragmentation, which have increased in abundance in small fragments (Arroyo-Rodríguez *et al.* 2013) and in edge zones (Oliveira *et al.* 2004), while abundance of the more shade-tolerant, edge-sensitive species has decreased (Chazdon 2012).

This explains the influence of linear edges in plant communities, in light of the evidence that successional processes vary with the degree of fragmentation and with the implementation of man-made edges (Rodrigues & Nascimento 2006). In a study that compared the edges and an inner fragment surrounded by sugarcane plantations in the state of Alagoas, northeastern Brazil, Oliveira *et al.* (2004) observed significant differences in the proportion of species in different successional stages. These authors also reported the prevalence of pioneer species at the edge, while shade-tolerant species predominated within the fragment surveyed. In the present study, the edge presented elevated mean density values and smaller mean DBH compared with the inner fragment, though with no statistically significant differences. These differences point to the existence of a relatively young community at the edge, where a higher density of trees with small DBH is observed. On the other hand, inside the fragment, thicker trees were more common, which suggests a more advanced regeneration stage (Nunes *et al.* 2003).

As a rule, edges exhibit higher density values than preserved inner fragments (Laurance *et al.* 2002). This may result from the growth of individuals (for instance, seedlings or propagules) as well as the establishment of species linked with less advanced successional stages (Rodrigues & Nascimento 2006). Assuming that this is true, edges may increase ground-level area because of greater light incidence (Murcia 1995). Moreover, here we observed that taller emergent trees were more common in the edge, similar to what was reported by Ribeiro *et al.* (2009), in a comparison between an inner fragment environment and natural and anthropogenic borders in an Atlantic Forest fragment in the state of Rio de Janeiro, Brazil.

The higher number of individuals with small DBH, both in the edge and in the inner fragment, and the scarcity of larger DBH trees indicate that the forest physiognomy in the environment studied develops into more advanced successional stages, in light of the great number of young individuals that may succeed over older individuals (Lopes *et al.* 2002). This dynamic promotes this forest's maintenance, indicating that it is undergoing a regeneration phase triggered by previous disturbances.

Thus, the present study shows that linear edge effects have little influence on the structure and successional categories in the forest. However, the linear edge effect increases species richness and heterogeneity (*H*' and abundances) while affecting the maintenance of endemic species, like *E. tetrapetala*, which was recorded only inside the forest fragment. Accordingly, the implementation of linear infrastructures causes similar impacts to those triggered by other types of edge. It should be stressed that, no matter how short the distance between forest fragments, edge effects will indeed occur, which necessitates studies addressing management and recovery from the creation of linear edges.

Acknowledgements

The authors would like to thank the National Research Council (CNPq 480508/2008-09) and the Research Support Foundation of the State of Bahia (FAPESB 5303/2009) for financing this research project, the Brazilian Institute for the Environment and Natural Renewable Resources (IBAMA) for the permission to conduct the research, and the Chapada Diamantina Foundation for accommodations and assistance with the fieldwork. AAC and LSF were supported by grants (PQ2) from CNPq.

References

APG. 2009. The Angiosperm Phylogeny Group. An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG III. Botanical Journal of the Linnean Society 161: 105-121.

Arroyo-Rodríguez V, Rös M, Escobar F, *et al.* 2013. Plant b-diversity in fragmented rain forests: testing floristic homogenization and differentiation hypotheses. Journal of Ecology 101: 1449-1458

Ayres M, Ayres JRM, Ayres DL, Santos AAS. 2007. Bioestat: aplicações estatísticas nas áreas das ciências bio-médicas. Belém, Sociedade Civil Mamirauá.

Brower JE, Zar JH, Carl N. 1998. Field and Laboratory Methods for General Ecology, 4th.edn.Boston, WCB McGraw-Hill.

Burkey TV. 1993. Edge effects in seed and egg predation at two neotropical rainforest sites. Biological Conservation 66: 139-143.

Catharino ELM, Bernacci LC, Franco GADC, Durigan G, Metzger JP. 2006. Aspectos da composição e diversidade do componente arbóreo das florestas da Reserva Florestal do Morro Grande, Cotia, SP. Biota Neotropica 6: 1-28.

Chazdon RL. 2012. Regeneração de florestas tropicais. Boletim do Museu Paraense Emílio Goeldi. Ciências Naturais 7:195-218.

Couto APL, Funch LS, Conceição AA. 2011. Composição florística e fisionomia de floresta estacional semidecídua submontana na Chapada Diamantina, Bahia, Brasil. Rodriguésia 61: 391-405.

Funch LS, Funch RR, Barroso GM. 2002.Phenology of gallery and montane forest in the Chapada Diamantina, Bahia, Brazil.Biotropica 34: 40-50.

Funch LS, Funch RR, Harley R, *et al.* 2005. Florestas estacionais semideciduais. In: Juncá FA, Funch L, Rocha W. (eds.) Biodiversidade e conservação da Chapada Diamantina. Brasilia, Ministério do Meio Ambiente. p. 181-193

Funch LS, Rodal MJN, Funch RR. 2008.Floristic aspects of the forests of the Chapada Diamantina, Bahia, Brazil. In: Thomas W, Briton EG. (eds.) The Atlantic Coastal Forest of Northeastern Brazil. New York, Springer & NYBG Press. p 193-220.

Gandolfi S, Leitão-Filho HF, Bezerra CLF. 1995.Levantamento florístico e caráter sucessional das espécies arbustivo-arbóreas de uma floresta mesófila semidecídua no município de Guarulhos, SP. Revista Brasileira de Biologia 55: 753-767.

Gentry AH. 1982. Patterns of neotropical plant species diversity. Evolution Biological 15:1-84.

Goosem M. 1997. Internal fragmentation: the effects of roads, highways and powerline clearings on movements and mortality of rainforest vertebrates. In: Laurance WF, Bierregaard RO. (eds.) Tropical forest remnants: ecology, management, and conservation of fragmented communities. Chicago, University of Chicago Press. p. 241-255.

Hammer O, Harper DAT, Ryan PD. 2001. PAST: Paleontological Statistics Software Package for Education and Data Analysis. Palaeontologia Electronica 4: 9p. http://palaeo-electronica.org/2001_1/past/issue1_01.htm.

Holanda AC, Feliciano AP, Marangon LC, Santos MS, Melo CLSMS, Pessoa MML. 2010. Estrutura de espécies arbóreas sob efeito de borda em um fragmento de floresta estacional semidecidual em Pernambuco. Revista Árvore 34: 103-114.

IBGE - Instituto Brasileiro de Geografia e Estatística. 2012. Manual Técnico da Vegetação Brasileira. 2nd. edn. Rio de Janeiro, Instituto Brasileiro de Geografia e Estatística.

Laurance WF, Ferreira LV, Merona JMR, Laurance SG. 1998. Rain forest fragmentation and the dynamics of amazonian tree communities. Ecology 79: 2032-2040.

Laurance WF, Goosem M, Laurance SGW. 2009. Impacts of roads and linear clearings on tropical forests. Trends in Ecology and Evolution 24: 659-669.

Laurance WF, Lovejoy TE, Vasconcelos HL, *et al*. 2002. Ecosystem Decay of Amazonian Forest Fragments: a 22-Year Investigation. Conservation Biology 16: 605-618.

Laurance WF, Nascimento HEM, Laurance SG, *et al*. 2006. Rain forest fragmentation and the proliferation of successional trees. Ecology 87: 469-82.

Leitão-Filho HF. 1987.Considerações sobre a florística de florestas tropicais e sub-tropicais do Brasil. Instituto de Pesquisas e Estudos Florestais 35: 41-46.

Lopes AV, Girão LC, Santos BA, Peres CA, Tabarelli M. 2009. Long-term erosion of tree reproductive trait diversity in edge-dominated Atlantic forest fragments. Biological Conservation. doi:10.1016/j.biocon.2009.01.007.

Lopes WP, Silva AF, Souza AL, Neto JAAM. 2002. Estrutura fitossocióloga de um trecho de vegetação arbórea no parque estadual do rio doce - Minas Gerais, Brasil. Acta Botanica Brasilica 16: 443-456.

Mariano Neto E. 2004. Efeitos da fragmentação sobre comunidades arbustivo-arbóreas em Mata Atlântica, Una BA. PhD Thesis, Instituto de Biociências da Universidade de São Paulo, Brazil.

Mesquita RCG, Delamonica P, Laurance WF. 1999. Effect of surrounding vegetation on edge-related tree mortality in Amazonian forest fragments.Biological Conservation 91: 129-134.

Mueller-Dombois D, Ellenberg H. 1974.Aims and methods of vegetation ecology. New York, Wiley.

Murcia C. 1995. Edge effects in fragmented forests: implications for conservation. Trends in Ecology and Evolution 10: 58-62.

Nunes YRF, Mendonça AVR, Botezelli L, Machado ELM, Oliveira-Filho AT. 2003. Variações da fisionomia, diversidade e composição de guildas da comunidade arbórea em um fragmento de Floresta Semidecidual em Lavras, MG. Acta Botanica Brasilica 17: 213-229.

Olander LP, Scatena FN, Silver WL. 1998. Impacts of disturbance initiated by road construction in a subtropical cloud forest in the Luquillo Experimental Forest, Puerto Rico. Forest Ecology and Management 109: 33-49.

Oliveira DG, Prata APN, Souto LS, Ferreira RA. 2013. Does the edge effect influence plant community structure in a tropical dry forest? Revista Árvore 37: 311-320.

Oliveira MA, Grillo AS, Tabarelli M. 2004. Forest edge in the Brazilian Atlantic forest: drastic changes in tree species assemblages. Oryx 38: 389-394.

Oliveira-Filho AT, Carvalho DA, Fontes MAL, Berg E, Curi N, Carvalho WAC. 2004. Variações estruturais do compartimento arbóreo de uma floresta semidecídua alto-montana na chapada das Perdizes, Carrancas, MG. Revista Brasileira de Botânica 27: 291-309.

Oliveira-Filho AT, Fontes MAL. 2000. Patterns of floristic differentiation among Atlantic forests in Southeastern Brazil and the influence of climate. Biotropica 32: 793-810.

Paciência MLB, Prado J. 2005. Effects of forest fragmentation on pteridophyte diversity in a tropical rain forest in Brazil. Plant Ecology 180: 87-104.

Prieto PV, Sansevero JBB, Garbin ML, Braga JMA, Rodrigues PJFP. 2014. Edge effects of linear canopy openings on understorey communities in a lowland Atlantic tropical forest. Applied Vegetation Science 17: 121-128.

Pohlman CL, Turton SM, Goosem M. 2007. Edge effects of linear canopy openings on tropical rain forest understory microclimate. Biotropica 39: 62-71.

Reznik G, Pires JPA, Freitas L. 2012. Efeito de bordas lineares na fenologia de espécies arbóreas zoocóricas em um remanescente de Mata Atlântica. Acta Botanica Brasilica 26: 65-73.

Ribeiro MT, Ramos FN, Santos FAM. 2009. Tree structure and richness in an Atlantic Forest fragment: distance from anthropogenic and natural edges. Revista Árvore 33: 1123-1132.

Ribeiro-Filho AA, Funch LS, Rodal MJN. 2009. Composição florística da Floresta Ciliar do Rio Mandassaia, Parque Nacional da Chapada Diamantina, Bahia, Brasil. Rodriguésia 60: 265-276.

Rodrigues PJFP, Nascimento MT. 2006. Fragmentação florestal: breves considerações teóricas sobre efeitos de borda. Rodriguésia 57: 63-74.

Sambuichi RHR. 2002. Fitossociologia e diversidade de espécies arbóreas em Cabruca, na região sul da Bahia. Acta Botanica Brasilica 16: 89-101.

Saravanan S, Ravichandran K, Balasubramanian A, Paneerselvam K. 2013. Structure and floristic composition of tree diversity in Andaman tropical evergreen forest of middle Andaman, India. Indian Journal of Forestry 36: 167-171.

Shepherd GJ. 2006. FITOPAC 1.6. Campinas, Universidade Estadual de Campinas.

Sousa AEA. 2007. Composição florística e estrutura de uma Mata de Encosta, Serra da Bacia, Parque Nacional da Chapada Diamantina, Palmeiras, Bahia, Brasil. Msc Thesis, Universidade Estadual de Feira de Santana, Brazil.

Stradmann MTS. 2000. Composição florística da mata ciliar da foz do Rio Capivara e análise quantitativo do estrato arbustivo-arbóreo, Rio Ribeirão Parque Nacional a Chapada Diamantina. Msc Thesis, Universidade Federal da Bahia, Brazil.

Tabarelli M, Silva JMC, Gascon C. 2004. Forest fragmentation, synergisms and the impoverishment of neotropical forests. Biodiversity and Conservation 13: 1419-1425.

Tabarelli M, Santos BA, Arroyo-Rodríguez V, Melo FPL. 2012. Secondary forests as biodiversity repositories in human-modified landscapes: insights from the Neotropics. Boletim do Museu Paraense Emílio Goeldi Ciências Naturais 7: 319-328.

Zanuto SL, Szilagyi VJ, Voltolini JC. 2007.Comparação da estrutura da vegetação na borda e no interior de um fragmento de hectares de floresta semidecídua, Campinas, SP, Brasil. In: Anais do VIII Congresso de Ecologia do Brasil. Caxambu, Minas Gerais. p. 1-2.