



Revista Árvore

ISSN: 0100-6762

r.arvore@ufv.br

Universidade Federal de Viçosa
Brasil

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Revista Árvore, vol. 33, núm. 6, noviembre-diciembre, 2009, pp. 1123-1132

Universidade Federal de Viçosa
Viçosa, Brasil

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TREE STRUCTURE AND RICHNESS IN AN ATLANTIC FOREST FRAGMENT: DISTANCE FROM ANTHROPOGENIC AND NATURAL EDGES¹

Maíra Taquiguthi Ribeiro², Flavio Nunes Ramos³ e Flavio Antonio Maës Dos Santos²

ABSTRACT – Approximately 7.2% of the Atlantic rainforest remains in Brazil, with only 16% of this forest remaining in the State of Rio de Janeiro, all of it distributed in fragments. This forest fragmentation can produce biotic and abiotic differences between edges and the fragment interior. In this study, we compared the structure and richness of tree communities in three habitats - an anthropogenic edge (AE), a natural edge (NE) and the fragment interior (FI) - of a fragment of Atlantic forest in the State of Rio de Janeiro, Brazil (22°50'S and 42°28'W). One thousand and seventy-six trees with a diameter at breast height ≥ 4.8 cm, belonging to 132 morphospecies and 39 families, were sampled in a total study area of 0.75 ha. NE had the greatest basal area and the trees in this habitat had the greatest diameter:height allometric coefficient, whereas AE had a lower richness and greater variation in the height of the first tree branch. Tree density, diameter, height and the proportion of standing dead trees did not differ among the habitats. There was marked heterogeneity among replicates within each habitat. These results indicate that the forest interior and the fragment edges (natural or anthropogenic) do not differ markedly considering the studied parameters. Other factors, such as the age from the edge, type of matrix and proximity of gaps, may play a more important role in plant community structure than the proximity from edges.

Keywords: Forest fragmentation. Natural edge. Vegetation structure.

ESTRUTURA ARBÓREA E DIVERSIDADE EM UM FRAGMENTO DE MATA ATLÂNTICA: DISTÂNCIA DE BORDAS ANTRÓPICAS E NATURAIS

RESUMO – Restam aproximadamente 7,2% da Mata Atlântica no Brasil distribuída em fragmentos, com apenas 16% dela no Estado do Rio de Janeiro. Essa fragmentação florestal pode produzir diferenças bióticas e abióticas entre bordas e interior de fragmentos. Neste estudo, compararam-se a estrutura e riqueza das comunidades arbóreas de três ambientes – bordas antrópica (BA), bordas naturais (BN) e interior (IF) – de um fragmento de Mata Atlântica no Estado do Rio de Janeiro, Brasil (22°50'S e 42°28'O). Mil e setenta e seis árvores com diâmetro à altura do peito $\geq 4,8$ cm, pertencentes a 132 morfoespécies e 39 famílias, foram amostradas em uma área estudada total de 0,75 ha. BN apresentou a maior área basal, e as árvores nesse hábitat tiveram coeficiente alométrico maior, enquanto BA apresentou menor riqueza e maior variação da altura do fuste em relação à altura total. Densidade de árvores, diâmetro, altura e proporção de árvores mortas em pé não diferiram entre ambientes. Foi observada alta heterogeneidade entre repetições de um mesmo tipo de hábitat. Outros fatores, como a idade da borda, o tipo de matriz e a proximidade de clareiras, podem desempenhar papel mais importante na estrutura da comunidade de plantas do que a proximidade das bordas.

Palavras-chave: Borda natural. Estrutura da vegetação. Fragmentação florestal.

¹ Recebido em 11.05.2008 e aceito para publicação em 23.06.2009.

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1. INTRODUCTION

The Atlantic forest is the natural biome of almost the entire eastern region of Brazil and covers close to 1,300,000 km² in sixteen Brazilian states (MORELLATO and HADDAD, 2000). It is characterized by high levels of biodiversity and endemism, as well as intense human activity, and contains the largest urban centers of Brazil (MORELLATO and HADDAD 2000). The devastation and fragmentation of this native vegetation is a consequence of unplanned land occupation and exploitation of natural resources since colonial times. Currently, only 7.2% of the Brazilian Atlantic forest remains, all of which is distributed in fragments and, in the State of Rio de Janeiro, where this vegetation once covered almost the entire territory, barely 16% remains (MORELLATO and HADDAD, 2000).

Forest fragmentation, resulting from the reduction and isolation of native forests, produces an increased region of forest edge (MURCIA, 1995; HARPER et al., 2005). The forest edge is the area exposed to the anthropogenic landscape (matrix) formed after fragmentation (METZGER, 1999). Consequently, compared to the interior of the forest fragment, a forest edge can experience changes in microclimatic conditions such as increase in temperature, light exposure and wind intensity, and decrease in air and soil moisture (MURCIA, 1995; TABARELLI et al., 1999; NELSON and HALPERN, 2005). These microclimatic changes may cause differences in the tree density and structure of these forest remnants (METZGER et al., 1997; OLIVEIRA-FILHO et al., 1997). For example, since the incidence of light is elevated at the forest edges, the number of plants can increase, but with a lower basal area. Furthermore, microclimatic modifications can produce biotic differences in plant composition and diversity because of tree mortality and recruitment (LAURENCE et al., 1998; OLIVEIRA et al., 2004).

Tree structure can also be affected by the availability of light and space, which determine plant forms (HOLBROOK and PUTZ, 1989; KOHYAMA and HOTTA, 1990; MOURELLE et al., 2001). Plant form is the result of a tradeoff between the vertical growth to reach better light and spatial conditions and the horizontal growth required to support the plant's own weight and allow efficient energy assimilation (KING,

1990; HENRY and AAERSSSEN, 1999). Hence, plant allometry is related to the immediate environmental conditions. Natural edges, such as forest borders with rivers and lakes, can exhibit similar abiotic and biotic modifications to those seen at anthropogenic edges of forest fragments (CORBET, 1990; MATTLACK, 1994). However, there is little information regarding these variations.

The aim of this study was to compare the structure of the tree communities, as well as its richness, among anthropogenic edges, natural edges and forest interior of a fragment of Atlantic forest in southeastern Brazil. The expectation of this study is that the tree community structure from both anthropogenic and natural edges will be similar among them, because of the probable akin abiotic conditions, and their structure will be very different from fragment interior.

2. MATERIALS AND METHODS

2.1 Study area

The study area was located in the coastal mountain range of the Serra do Palmital, Saquarema, in the State of Rio de Janeiro, Brazil. This Atlantic forest fragment of approximately 1,200 ha is located mostly on private properties. This study was done in 180 ha of the fragment (22°50'S and 42°28'W), at altitudes ranging from 30 m to 600 m. The forest bordered pastures and cropland of private properties, producing anthropogenic edges. Within the study area, a stream 2-5 m wide and 900 m long creates a natural edge with the forest.

The regional climate is classified as Cwa according to the Köppen system (VIANELLO and ALVEZ, 1991), and is characterized by warm, wet summers and dry winters. The annual rainfall for 2003 was 1,210 mm, with the greatest precipitation occurring between November and April (RAMOS and SANTOS, 2005). The vegetation is classified as evergreen forest or Tropical Moist Forest ("Floresta Ombrófila Densa") (RADAMBRASIL, 1983).

2.2 Methods

Three habitats of the forest fragment were studied: (1) forest at 50 m from the stream (NE = natural edge), (2) forest at 50 m from areas modified by human action (AE = anthropogenic edge) and (3) forest 200 m or more from any edge (FI = forest interior). Five areas were randomly chosen within each habitat. Five sample

plots of 10 m x 10 m were sampled per area (0.05 ha/area), resulting in a sampling area of 0.25 ha per habitat and a total area of 0.75 ha.

All trees with a diameter at breast height (DBH, at 1.3 m) ≥ 4.8 cm in each plot were tagged, their height and perimeter were measured, and voucher specimens were collected for identification. The diameter (D) was obtained from the perimeter (P) as $D = P \cdot \pi^{-1}$. The tree diameter (D) and height (H) were used to estimate the basal area (Ba) as $Ba = \pi(0.5 \cdot D)^2$ and the cylindrical volume (V) as $V = Ba \cdot H$. However, when a tree had more than one trunk at breast height, the diameter was obtained from the sum of the basal areas (Ba, in cm^2) of each trunk, using the formulas $Ba = P^2 \cdot (4\pi)^{-1}$ and $D = 2(\Sigma Ba \cdot \pi)^{0.5}$.

2.3 Statistical analysis

The basal area, diameters, tree heights, and tree density were analyzed by a two-level nested ANOVA, after testing for normality and homoscedasticity (ZAR 1996). The factors tested were the habitat (fixed factor) and its five replicates (nested within habitats). The proportion of standing dead trees with a DBH ≥ 4.8 cm relative to the total of sampled trees was compared among and within habitats using a chi-square (χ^2) test (ZAR, 1996).

To assess the variation in tree forms among habitats, we did a morphometric analysis based on the ratio of tree height to tree diameter, and on the ratio of total height to the height at first branching). The diameter (D) and height (H) were related by the expression $H = a \cdot D^b$. The r^2 and the allometric coefficient (b) of the regression equations were compared among habitats. The allometric coefficients were compared by ANCOVA followed by the Scheffé test ($p = 0.05$) (ZAR, 1996).

The trees were divided into three classes based on the ratio of the first branching height to total tree height: Class I – plants with a first branch at $\leq 1/3$ of the total height, Class II – plants with a first branch between $>1/3$ and $\leq 2/3$ of the total height, and Class III – plants with a first branch at $>2/3$ of the total height. The proportion of plants in each class relative to the total number of sampled plants in each habitat was compared by a chi-square (χ^2) test (ZAR, 1996). The species richness was estimated using rarefaction curves based on species, with the Rarefact module from the Krebs program (KREBS, 1989).

3. RESULTS

3.1 Tree structure

3.1.1. Among habitats

In the total area (0.75 ha), 1,168 trees were recorded; 1,076 of them were living plants ($1,434.7 \pm 80.8$ trees. ha^{-1}), and 92 (7.9%) were standing dead trees (122.7 ± 62.3 trees. ha^{-1}). The natural edge (NE) had 347 living trees (32.2%; $1,388.0 \pm 177.5$ trees. ha^{-1}), whereas the forest interior (FI) had 382 (35.5%; $1,528.0 \pm 510.0$ trees. ha^{-1}) and the anthropogenic edge (AE) had 347 (32.2%; $1,388.0 \pm 223.0$ trees. ha^{-1}). The total basal area was 30.9 ± 8.1 $\text{m}^2 \text{ha}^{-1}$ and the total cylindrical volume was 433.2 ± 168.3 $\text{m}^3 \text{ha}^{-1}$.

The density of living trees ($F_{2,12} = 0.280$, $p = 0.760$), the DBH ($F_{2,12} = 2.750$, $p = 0.100$), the total tree height ($F_{2,12} = 1.300$, $p = 0.300$) and the proportion of standing dead trees ($\chi^2_2 = 0.556$, $p = 0.757$) did not vary significantly among habitats. However, there was a significantly greater basal area in the NE ($F_{2,12} = 5.200$, $p = 0.023$), while the FI and AE did not differ significantly among each other (Figure 1).

3.1.2 Within habitats

Within each habitat, tree height ($F_{12,1061} = 2.500$; $p = 0.002$) and density ($F_{12,60} = 3.500$; $p = 0.001$) differed significantly, with the greatest internal variation in density occurring in the FI (coefficient of variation: AE = 16.1%, FI = 33.4%, NE = 12.8%). This variation occurred principally because one of the FI replicates was established in a gap environment and had an elevated number of thin trees. However, the DBH ($F_{12,1061} = 1.100$; $p = 0.330$), basal area ($F_{12,60} = 0.600$, $p = 0.840$), and the proportion of standing dead trees (AE $\chi^2_{2,4} = 3.006$; $p = 0.557$, FI $\chi^2_4 = 8.356$; $p = 0.079$, NE $\chi^2_4 = 3.389$; $p = 0.495$) did not differ significantly within habitats.

3.2. Allometry

The relationship between tree height and diameter was significant in the three habitats (Figure 2, AE $r^2_{345} = 0.545$; FI $r^2_{380} = 0.586$; NE $r^2_{345} = 0.705$; $p < 0.001$ for each), and the allometric coefficients were low for the three habitats. Nevertheless, the trees in the NE showed less variation around the regression line and a greater allometric coefficient ($b = 0.54$) than trees in the AE and FI ($b = 0.46$ for both, $F_{2,1070} = 6.21$, $p = 0.003$).

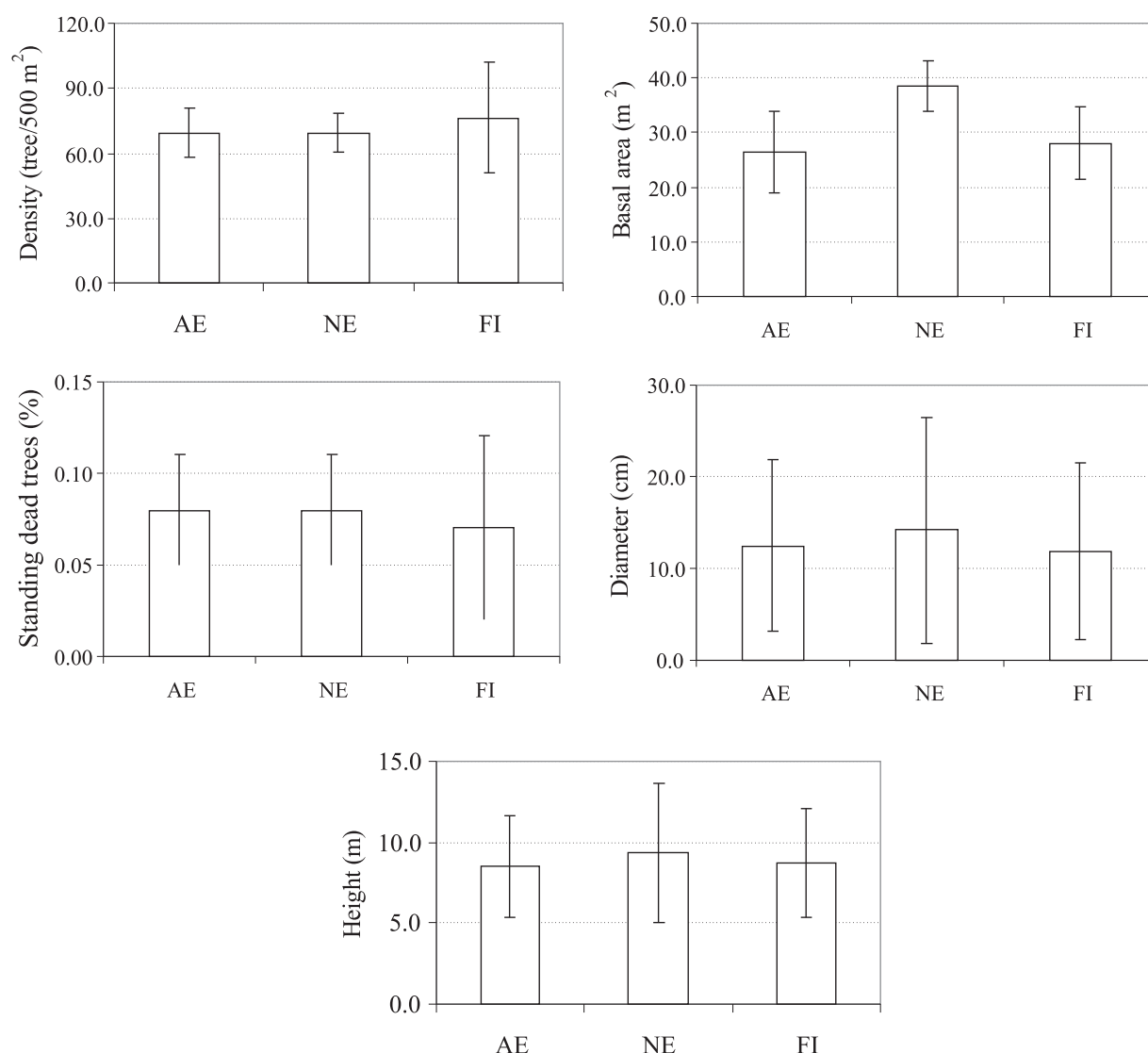


Figure 1 – Comparative data for tree density, basal area, standing dead trees, tree diameter and height among the three habitats. The columns are the mean \pm standard deviation of the five areas per habitat. AE = anthropogenic edge, FI = forest interior, NE = natural edge.

Figura 1 – Dados comparativos da densidade de árvores, área basal, árvores mortas em pé, diâmetro e altura das árvores entre os três ambientes. As colunas são as médias \pm desvio-padrão das cinco repetições por ambiente. AE = borda antrópica, FI = interior da floresta e NE = borda natural.

In all habitats, most of trees first branched between 1/3 and 2/3 of the total height (Figure 3), although in the NE ($\chi^2_2 = 11.096$; $p = 0.004$) and FI ($\chi^2_2 = 19.959$; $p < 0.001$) there was less tree branching at $\leq 1/3$ of the total tree height than if there was even distribution among classes. There was greater variation in the ratio of the first branching height to the total height

in the AE since there were no differences in the proportion of trees in each class (Figure 3; $\chi^2_2 = 4.329$; $p = 0.115$).

3.3. Diversity

Of the 1,076 trees sampled, 1,068 were identified in 132 morphospecies belonging to 39 families; eight

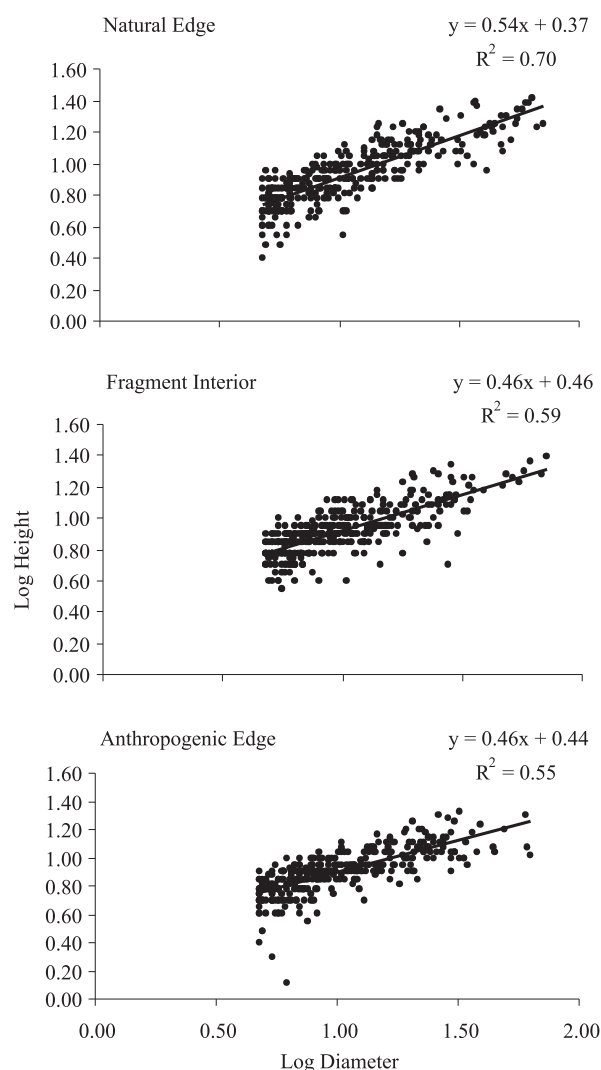


Figure 2 – Relationship between the logarithm for the height and diameter of trees sampled in the three habitats, showing the tendency lines, regression coefficients and equations ($y = bx + a$), where y = height, x = diameter and b = allometric coefficient.

Figura 2 – Relação entre o logaritmo da altura e o diâmetro das árvores amostradas nos três habitats, apresentando as linhas de tendência, coeficientes de regressão e equações ($y = bx + a$), em que y = altura, x = diâmetro e b = coeficiente alométrico.

individuals were not determined. The AE had fewer morphospecies (56) compared with the other habitats, whereas the greatest number of families (31) occurred in the FI. The estimated species richness based on

the rarefaction curves was lower for the AE than for the other habitats starting at 150 individuals (Figure 4a). The species richness for the NE and FI diverged starting at 300 individuals. The rarefaction curve for the total sample estimated a greater number of species for the same number of trees sampled than for each habitat separately (Figure 4b). The NE and the total sample had similar curves, with all of the NE deviations overlapping the deviations of the sum of all habitats.

4. DISCUSSION

Our results indicated that the forest interior and fragment edges (natural or anthropogenic) were not structurally different habitats since they did not show significant structural variation among themselves. The main differences were that the NE had a greater basal area and greater allometric coefficient for the ratio between diameter and height when compared to the other habitats, and the AE had a lower species richness and greater variation in the height of the first tree branch than the other two habitats.

During this study, there were no significant differences in the minimum temperature, soil moisture or canopy openness among the three habitats, mainly because of the great variation in these parameters within each habitat (RAMOS and SANTOS, 2006). However, the AE showed the greatest average maximum temperature and amplitude, while the NE had the lowest values (RAMOS and SANTOS, 2006). The different microclimatic conditions at the AE were apparently not sufficient to cause structural differences when compared to the other two habitats.

Forest communities commonly have allometric coefficients of ~ 0.67 (MCMAHON, 1973). In contrast, the allometric coefficients for the three habitats in this study were low (close to 0.50). These values were similar to those of the constant stress model ($H \propto D^{0.5}$, SPOSITO and SANTOS, 2001) in which trees have a proportionally greater diameter than expected based on their height. This is unexpected for trees in forests, and may indicate that the trees in the three habitats suffer some type of mechanical pressure.

The presence of neighbors increases the height:diameter ratio because of the influence on the availability of space and light (HENRY and AARSEN, 1999). However, our results for tree density and those of RAMOS and SANTOS (2006) for canopy openness

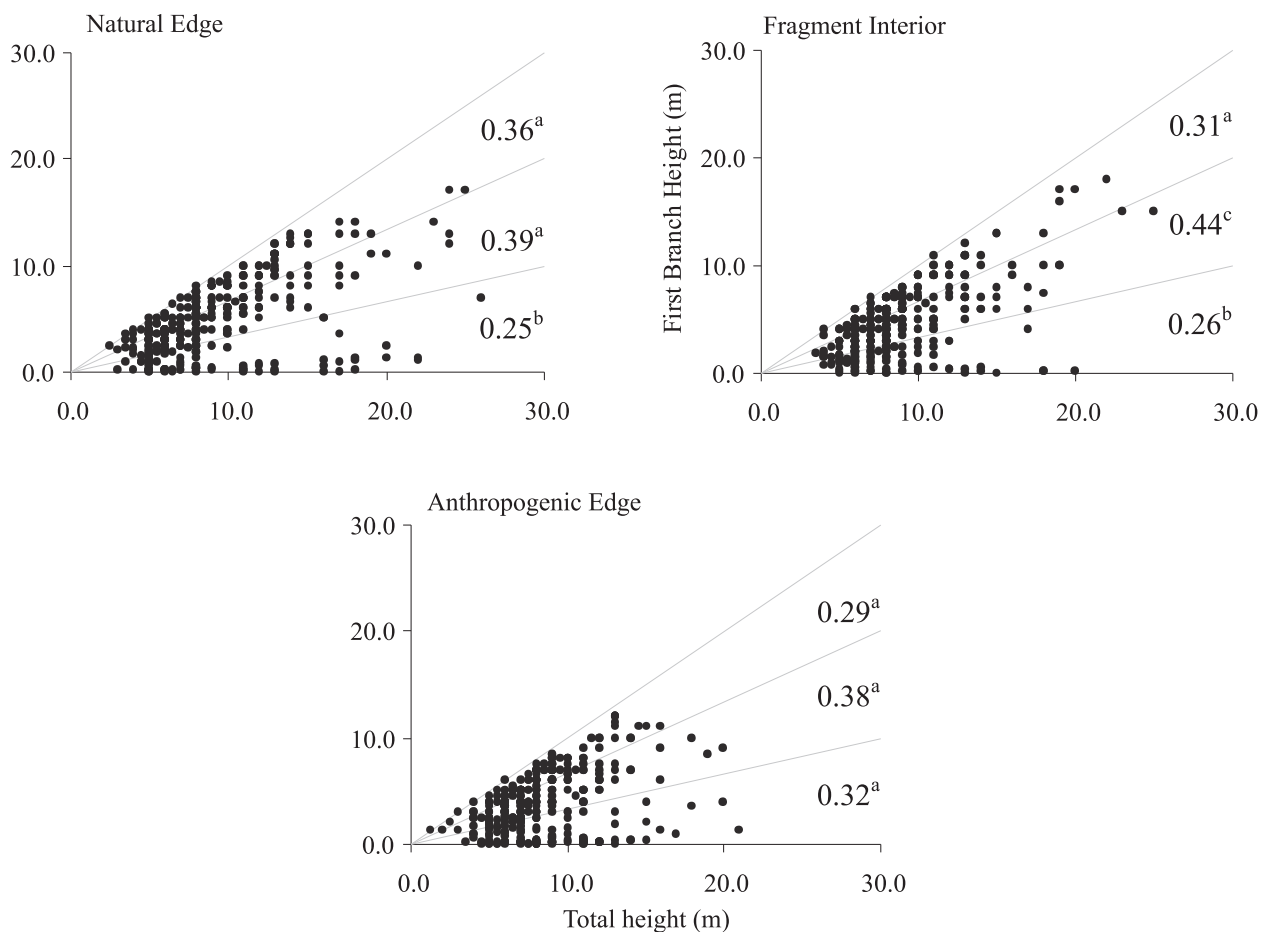


Figure 3 – Relationship between total height and first branching height of trees sampled in the three habitats. The lines delimit the three proportion classes (1/3, 2/3 and 3/3) and the numbers at the right indicate the proportion of trees in each class. Different letters next to these numbers indicate significantly different values.

Figura 3 – Relação entre altura total e altura do fuste das árvores amostradas nos três ambientes. As linhas delimitam as três classes de proporção (1/3, 2/3 e 3/3), e os números à direita indicam a proporção de árvores em cada classe. Diferentes letras próximas a esses números apontam valores significativamente diferentes.

do not support this argument as an explanation of why the NE had the greatest ratio. Nevertheless, the greater allometric coefficient and basal area in the NE may indicate that this habitat places a greater restriction on plant establishment. This restriction may be more related to soil declivity in the valley than to an influence of the stream, particularly since there is no periodical flooding or microclimatic variation that could influence the NE vegetation, as found in other studies with riparian forests (METZGER et al., 1997).

There was marked variation in the first branching height of AE plants. Branching architecture is affected by climatic conditions and consequently determines the competitive advantage of plants in aspects such as light capture, mechanical support and wind resistance (FARNSWORTH and NIKLAS, 1995). Anthropogenic edges are expected to have greater contact with human activities such as logging and hunting, which may cause stump sprouting or stem breakage and thereby influence the shape of the trees in this habitat. Moreover, variations

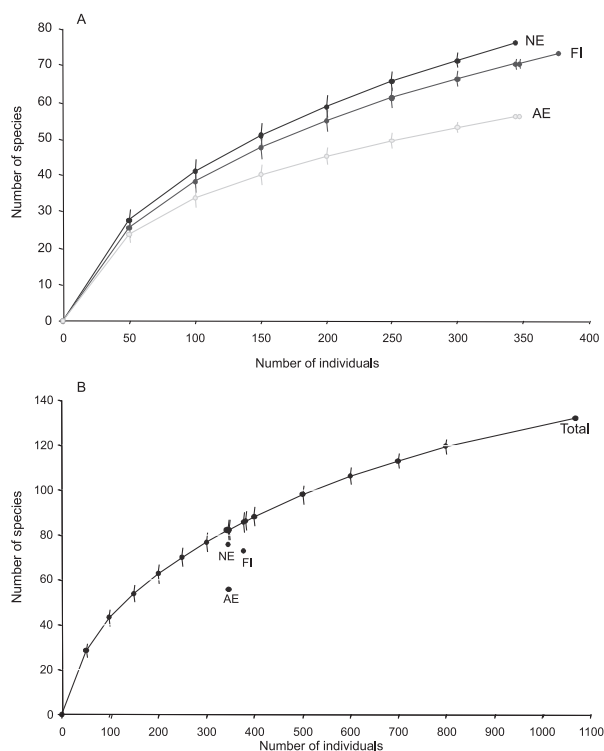


Figure 4—Rarefaction curves for the mean of randomly selected species for different numbers of trees in the three habitats (a) and for the total sample (b). The standard deviation is shown for each point. The maximum value for each curve is equal to the total number of trees identified (1,068) and therefore there is no deviation. AE = anthropogenic edge (347), FI = fragment interior (377), NE = natural edge (344 identified trees).

Figura 4—Curva de rarefação da média das espécies selecionadas aleatoriamente para diferentes números de árvores nos três ambientes (a) e para a amostra total (b). O desvio-padrão de cada ponto é apresentado. O valor máximo de cada curva é igual ao número total de árvores identificadas (1,068) e, portanto, não há desvio. AE = borda antrópica (347), FI = interior da floresta (377) e NE = borda natural (344 indivíduos identificados).

in the first branch height may be related to differences in the histories of the plants in this habitat, with some plants branching before the present environmental conditions and other plants branching after fragmentation.

The AE differed from the other habitats in species richness, but not in the general structure of the tree community. Other studies have also reported differences

in the floristic composition and diversity of edges compared to the forest interior (FOX et al., 1997; OOSTERHOORN and KAPALLE, 1999; TABARELLI et al., 1999). Many studies have also shown that edges have higher dynamics (BIERREGARD et al., 1992; CHEN et al., 1992; LAURENCE et al., 1998), which could reduce the number of species tolerant to edge conditions. HARPER et al. (2005) stated that species diversity and composition were a secondary response such that even when different habitats have similar general structures they can differ in these parameters. However, these results should be carefully interpreted, because species richness is different from floristic composition. The number of species could be the same, but the species could be completely different between two any habitats.

Several studies of forest fragmentation indicated that edge habitats and small fragments have a lower average canopy height, greater tree density and a greater proportion of smaller trees than fragment interiors, larger fragments or contiguous forest (METZGER et al., 1997; OLIVEIRA-FILHO et al., 1997; HARPER et al., 2005). However, these results cannot be standardized since edge tree communities in different studies have shown different responses to the variety of studied parameters (CHEN et al., 1992; MURCIA, 1995; RODRIGUES and NASCIMENTO, 2006). Overall, the degree of influence exerted by AE remains controversial since microclimatic and structural variations are generally observed from within a few meters of the border to more than 500 m inside the fragment (MURCIA, 1995; DIDHAM and LAWTON, 1999; GEHLHAUSEN et al., 2000; LAURENCE, 2000).

In contrast, the few studies done on NE have shown that the findings for AE are not necessarily similar applicable to NE (CHEN et al., 1992; RESTREPO et al., 1999; HARPER and MCDONALD, 2001; VREELAND and TIETJE, 2004; ZANNE and CHAPMAN, 2005) since the formation of NE does not occur abruptly nor is induced as is the case for AE (RODRIGUES and NASCIMENTO, 2006). As shown here, the vegetation structure along the stream border in this forest was more similar to the FI than to the AE, although it did have specific characteristics related to the habitat conditions.

The internal heterogeneity in tree structure and microclimatic conditions reported by RAMOS and SANTOS (2006) shows that variations within each habitat

stronger determine the community structure than proximity from the edge. Consequently, the replicates within the three habitats may have different histories. For example, AE replicates were under the influence of different matrices, such as banana plantations or pasture, and differed in their age of formation (personal observation). The importance of other factors on community structure has been frequently mentioned in the literature, with particular emphasis on the age and type of edges, and the perturbation history of the forest (SAUNDERS et al., 1991; MURCIA, 1995; METZGER et al., 1997; DIDHAM and LAWTON, 1999; PINTO et al., 2007, SANTOS et al., 2007). However, few studies on fragmentation have considered the heterogeneity within the same habitat type (CHEN et al., 1992; WILLIAMS-LINERA et al., 1998), which is very important in plant community structure formation (RODRIGUES and NASCIMENTO, 2006). Besides, the size of each sample size could also influence the variation found inside each habitat. Smaller the plot, fewer trees we can measure and consequently, greater is the coefficient of variation.

In conclusion, the results of this study show that there was a marked heterogeneity among the replicates within each habitat, and other factors, such as edge age, matrix type, and the proximity of gaps may be more important than the proximity of AE or NE. Clearly, factors other than edges should be taken into consideration when modeling and evaluating the availability of "edge" and "interior" habitats in fragmented landscapes and designing natural reserves (RESTREPO et al., 1999; HARPER et al., 2005). The consideration of more sample plots along the edges in future studies would help to demonstrate the natural heterogeneity of fragments and would prevent wrong conclusions about the influence of edges on resident or persistent organisms. Finally, we could be very careful and do not denote a fixed distance from edge effects within an forest fragment, because this distance could vary due to some of these characteristics cited above.

5. ACKNOWLEDGMENTS

The authors thank Vanessa Rosseto, Carolina Virillo, Élcio and Antônio for their help with the field work, Roque Cielo Filho, Leonardo Meirelles, M. Edileide Alencar, Jorge Y. Tamashiro, Luis C. Bernacci, Rosely B. Torres, Sigrid L. Jung-Mendaçolli, Washington Marcondes-Ferreira Neto, Ângela B. Martins, Pedro

L. R. de Moraes and Sérgio Romaniuc for helping with the morphospecies identification, and Paul Rogé and Marsha Habib for helping in translating this article into English and Stephen Hyslop for correcting the English. M.T.R. was supported by an undergraduate research scholarship from the Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP, grant #02/01802-9), and F.A.M.S. was supported by a research fellowship from the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq, grant #207132/2004-8).

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