

Influence of Edge and Topography on Canopy and Sub-canopy Structure of an Atlantic Forest Fragment in Igarassu, Pernambuco State, Brazil

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ABSTRACT

Edge effects are important factors mediating changes in plant community structure in fragmented forests, along with local variations in environmental factors. The present work aimed at evaluating vegetation structure between edge and three interior sites and assessing to what extent interior sites differ influenced by a topographic gradient. Seven 10 × 25 m plots were set up in each habitat for sampling canopy (DBH ≥ 5 cm), within which fourteen 5 × 5 m sub-plots were set up for sampling sub-canopy (diameter at ground level ≥ 1 cm and < 5 cm). We recorded 1471.43 ind. ha⁻¹, and 113 species in the canopy. Between habitats, the interior terrace was distinguished by its lower density, and there was a significant difference between the edge and interior habitats on height and diameter distributions, edge sites having proportionally more plants at shorter heights. Species richness and diversity did not show differences related to edge influence, and among species recorded, only 13 were found in all habitats. An estimated 8178.57 ind. ha⁻¹ and 115 species were found in the sub-canopy. Edge and mid slopes had lower densities, and were both also distinct from all interior habitats, considering distribution per height and diameter classes. Among habitats, diversity varied from 2.915 nats ind.⁻¹ at the edge to 3.462 nats. ind.⁻¹ at lower slopes. The results presented here indicate that edge influence on the plant community was stronger than the topographical gradient. However, some differences between interior habitats were also found and suggest that variations in humidity and light regimes, whether edge- or topography-induced, influence the physiognomy and structure and composition of canopy and sub-canopy assemblages.

Keywords: edge effect, ombrophilous forest, phytosociology, tree community, understory

INTRODUCTION

The loss of global biodiversity is strongly related to the process of destruction and fragmentation of tropical forests that creates a mosaic of conserved forest areas, secondary forest areas, and managed landscapes (Benitez-Malvido and Martinez-Ramos 2003). It is known that plant and animal populations are reduced in fragmented landscapes, patterns of dispersal and migration are modified, and ecosystem fluxes are altered (Lovejoy *et al.* 1984). Furthermore, area and edge effects have been indicated as important factors in mediating the changes that occur in these communities (Nascimento and Laurance 2006).

Zuidema *et al.* (1996) observed that area and edge effects operate in parallel as the small fragment size results in a larger edge to area ratio, making smaller fragments more subject to edge effects. Changes in abiotic factors, in the composition and abundance of species, as well as alterations in numerous ecological processes are known to occur in response to edge effects (Murcia 1995). There are many reports in the literature indicating that forest edges have larger numbers of thin trees (Williams-Linera 1990) with smaller average heights (Didham and Lawton 1999), and Benitez-Malvido (1998) reported larger sapling density values in the forest interior.

It is worth noting that fragment area and edge effects are not the only factors that can influence species richness in forest communities. Hadley (1994) stated that studies of the richness and density of arboreal populations in fragmented areas should also take into account local variations in topography and soil type, factors that can also greatly influ-

ence community structure and composition. As such, the fact that altitude can integrate diverse environmental variables has stimulated a number of authors to test the relationship between topography and certain parameters of plant communities – especially in terms of alterations of the arboreal component (Espírito-Santo *et al.* 2002; Nunes *et al.* 2003; Pereira *et al.* 2007), which is the habit most studied in tropical forests (Mani and Parthazarathy 2006).

The last few decades, however, have seen an increasing interest in the other plant habits in tropical forests (Gerwing *et al.* 2006) – especially in the understory, which is formed by seedlings, herbs and adult ciophytes (those plants that complete their life-cycles in the forest interior), as well as shrubs and young individuals of arboreal species of the forest canopy (see Gomes *et al.* 2008, for a review of this subject).

Of all the Brazilian forests, the Atlantic forest to the north of the São Francisco River is the most threatened by habitat destruction and fragmentation (Coimbra-Filho and Câmara 1996). In spite of the fact that practically the entire Brazilian coast was occupied in about the same epoch, the historic processes of natural resource exploitation had much more serious consequences for forest conservation in northeastern Brazil. The state of Pernambuco, for example, retains only 4.6% of its original Atlantic forest cover (Lima 1998). Case studies in both the southern (Ranta *et al.* 1998) and northern (Trindade *et al.*, this volume, pp 5-13) portions of the state have shown that a majority of the remaining fragments are smaller than 30 ha.

In general, studies of the Atlantic forest have provided little information about the understory (Salis *et al.* 1996;

Tabarelli and Mantovani 1997, 1999; Oliveira *et al.* 2001), while there have been numerous studies demonstrating the influence of topography on the better-known arboreal strata, especially in seasonal forests (see Rodrigues *et al.* 1989; Moreno and Schiavinni 2001; Cardoso and Schiavani 2002; Nunes *et al.* 2003).

The present work evaluated the edge influence on the vegetation of a fragment of Atlantic forest, through the survey and comparison of canopy and understory structure between edge and interior sites. Our objectives were: 1) to analyze differences in terms of physiognomic parameters, 2) to compare species richness and diversity between sites, and 3) to assess to what extent differences between interior sites could be accounted for by a topographic gradient.

MATERIALS AND METHODS

Study area

The "Mata dos Macacos" - Macacos Forest - covers 356.9 hectares ($7^{\circ} 46' 2,89''$ to $7^{\circ} 47' 40,82''$ S; $35^{\circ} 1' 6,31''$ to $34^{\circ} 59' 42,95''$ W), and is located within the site of the Usina São José sugar mill, in Igarassu, Pernambuco State, Brazil (Fig. 1). The local geology is dominated by the Barreiras Group (Jacomine *et al.* 1973), and altitudes at the study site vary from 50 m above sea level (a.s.l.) in lower areas to 130-145 m on the hilltops. This landscape structure is typical of other forest fragments found in the region, as these wooded remnant areas are located on the slopes and narrow valleys of a hilly landscape otherwise totally occupied by sugarcane fields (Trindade *et al.* this volume).

The local climate is of the As' type according to the Köppen classification system (FIDEM 1993). Meteorological data collected from 1998 to 2006 at the meteorological station of Usina São José indicated an average annual precipitation of 1687 mm, with monthly rainfall rates above 100 mm from January to August, and mean temperature of 24.9°C.

Analysis of a time series of aerial photographs taken in various periods from 1969 to 1989, and high-resolution satellite images from 2005, as well as field investigations, allowed us to certify that the shape and area of the Macacos Forest fragment has remained constant for almost 40 years.

Considering the environmental heterogeneity typical of tropical forests, it was possible to identify four major environmental conditions, one under edge influence (within 50 m from forest boundary according to Silva *et al.* this volume; and Gomes *et al.* 2008) and three types of forest interior following a topographic gradient: 1) Edge - areas on highest slopes (145 m a.s.l.) closer to the forest boundary with the sugar-cane matrix; 2a) Interior mid-slopes - representing the largest proportion of the fragment area, with inclination generally greater than 30°; 2b) Interior lower slopes - the lower third of the slopes; and 2c) Interior lower terraces - adjacent to the lower slopes and at the lowest altitudes (50 m a.s.l.).

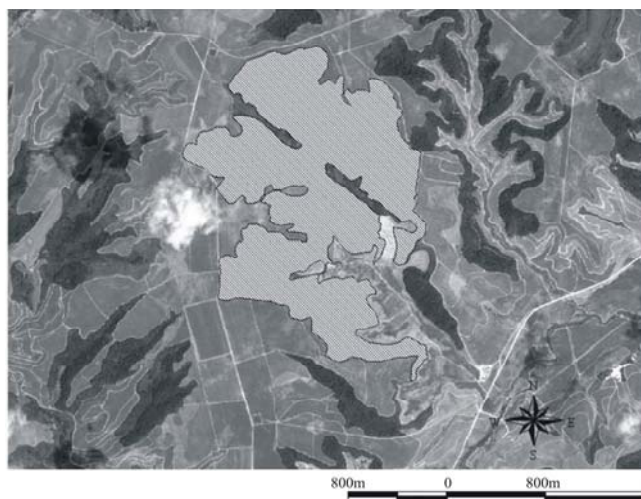


Fig. 1 General view of the Macacos Forest, municipality of Igarassu, Pernambuco State, Brazil.

Data collection and processing

Seven 10×25 m plots (10 m distant from each other) were established in each of the four habitats, to sample canopy plants, in this paper designated those with trunk diameters ≥ 5 cm at standard breast height, being 1.3 m above soil level (DBH ≥ 5 cm). In each of these plots, two 5×5 m sub-plots were nested to sample understory plants, that is, those with stem diameters at soil level ≥ 1 cm and < 5 cm (DSL ≥ 1 cm and < 5 cm).

Sampled plants were measured (diameter and height) and collected for identification. Samples were identified according to the classification system of Cronquist (1981), except for the Fabaceae, which followed APG II (2003). All vouchers were subsequently deposited in the Professor Vasconcelos-Sobrinho herbarium (PEUFR) at the Universidade Federal Rural de Pernambuco, Brazil.

The physiognomy and structure of the canopy and understory were characterized in terms of species richness, Shannon Diversity Index H' (Magurran 2003) per plot and per condition and Importance Value (IV) for species (Brower and Zar 1984), which were calculated using the FITOPAC 1 software package (Shepherd 1995). Additionally, histograms of height and diameter classes were prepared, with intervals of 1 m and 1 cm respectively for the understory, and 3 m and 5 cm for the canopy. The mean densities, heights, and diameters were compared among the four habitats. The normality of the data was tested using the Kolmogorov-Smirnov test. When variables followed a normal distribution, a one-way ANOVA was used; for variables with non-normal distribution, Friedman's non-parametric test was applied. Additionally, comparisons were carried out for species richness and diversity, between the four conditions, seven repetitions in each, using one-way ANOVA, and for frequency distributions per classes of heights and diameters, using a Chi-square test (Zar 1996). All analyzes were run using the Bioestat 2.0 statistical software package (Ayres *et al.* 2000).

RESULTS AND DISCUSSION

Canopy

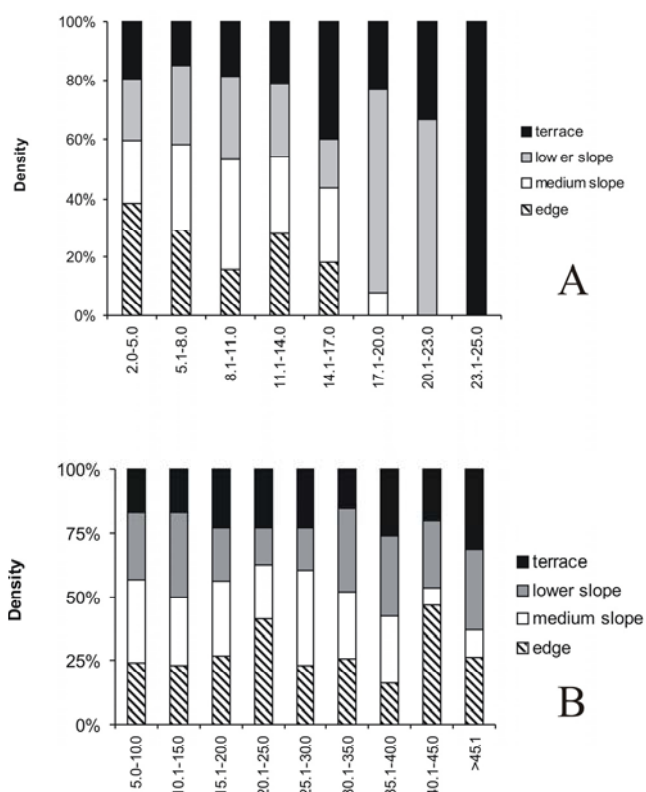
A total of 1030 individuals with 18.78 m^2 were encountered in the 0.7 ha surveyed, which is equivalent to $1471.43 \text{ ind. ha}^{-1}$, $26.83 \text{ m}^2 \text{ ha}^{-1}$, a mean plant height of 8.83 ± 0.59 and a mean diameter of $13.31 \pm 10.60 \text{ cm}$ (Table 1). The total tree density of the fragment was similar to values reported in surveys from other lowland ombrophilous forests in the region (Siqueira *et al.* 2001; Oliveira *et al.* 2004), which varied from 1202 to 1657 ind. ha^{-1} ; likewise, the total basal areas in lowland ombrophilous forests (Siqueira *et al.* 2001; Alves-Júnior *et al.* 2006) varied from 27.17 to $30.1 \text{ m}^2 \text{ ha}^{-1}$.

No significant differences in height, diameter or basal area were noted among habitats, with only the interior terrace area being distinguished by its lower plant density (Friedman's = 13.8; $df=3$; the level of significance in all instances is $p < 0.05$). It is possible that the lack of marked differences between edge and interior sites is due to three facts: firstly, mature sampled trees already existed prior to fragmentation; secondly, there is a natural variation on the arboreal physiognomy related to topography (Nascimento and Laurance 2006); and third, as the fragment was isolated at least 40 years ago, edge may have reached secondary development stages, when the magnitude of edge effects are expected to decrease and tree recruitment increases (*sensu* Harper *et al.* 2005), possibly influencing the density of trees with DBH > 5 cm. According to Lawes *et al.* (2005), stable environmental conditions at older edges in fragmented forests cause similar regeneration conditions and seedling species composition between edge and interior.

When the distributions of individuals per height and diameter classes were analyzed (Fig. 2), there was a significant difference between the edge and interior habitats on height distributions and diameter distributions (edge vs. mid slope; edge vs. low slope). Edge sites had proportionally more plants at shorter heights, confirming the existence of reduced heights near the forest edge and also agreeing with

Table 1 Values of stem density, basal area, diameter, and height of canopy plants (DBH ≥ 5 cm); and of understory plants with DSL ≥ 1 cm and < 5 cm in four habitats in the Macacos forest fragment in Igarassu, Pernambuco State, Brazil. The values for heights and DBH/DSL are means \pm standard deviation.

Habitat parameters	Edge		Interior		Total
	Upper slope	Mid slope	Lower slope	Interior terrace	
Canopy					
Density (ind.ha ⁻¹)	1491	1777	1565	1085	1471.43
Density (ind/ 0.175 ha)	260	307	274	189	1030
Basal area (m ² ha ⁻¹)	35.89	29.66	13.66	28.11	26.83
Basal area (m ² / 0.175 ha)	6.28	15.19	2.39	4.92	18.78
Mean height \pm sd (m)	8.14 \pm 2.85	8.92 \pm 2.65	8.94 \pm 3.4	9.63 \pm 3.7	8.83 \pm 0.59
Mean DBH \pm sd (cm)	13.9 \pm 10.66	11.98 \pm 8.48	12.72 \pm 10.18	14.63 \pm 10.84	13.31 \pm 10.60
Species number	52	61	63	50	113
Diversity H'(nats ind. ⁻¹)	3.247	3.178	3.562	3.448	3.857
Understory					
Density (ind.ha ⁻¹)	4371.43	4971.43	14057.14	9314.29	8178.57
Density (ind/ 0.035ha)	153	174	492	326	1145
Basal area I (m ² ha ⁻¹)	2.48	2.05	4.27	3.23	3.00
Basal area (m ² / 0.035 ha)	0,09	0,07	0.15	0.11	0.42
Mean height \pm sd (m)	2.48 \pm 1.12	2.51 \pm 1.59	1.93 \pm 1.15	2.33 \pm 1.31	2.21 \pm 1.29
Mean DSL \pm sd (cm)	2.52 \pm 0.99	2.14 \pm 0.80	1.82 \pm 0.84	1.92 \pm 0.68	2,01 \pm 0.89
Species number	35	43	79	55	115
Diversity H'(nats ind. ⁻¹)	2.915	3.080	3.462	3.289	3.682

**Fig. 2** Distribution of the relative density of individuals of canopy plants with DBH ≥ 5 cm (A) by height class (m) and (B) by diameter class (cm) in 0.7 ha in four habitats in the Mata dos Macacos, Igarassu, Pernambuco State, Brazil.

other studies which have shown that not only density varies under edge influence, but differences also occur in plant height and diameter (Williams-Linera 1990; Young and Mitchel 1994; Didham and Lawton 1999; Carvalho *et al.* 2007).

This distinction between edge and interior sites was reported by Souza *et al.* (2003), who found a positive and significant correlation of forest structure with altitude and edge influence, stronger than correlations with soil fertility and soil water availability. These two edaphic variables are resultant – and reflects – edge and altitudinal conditions: on higher altitudes, stronger soil drainage will occur; under stronger edge effects, drier soils will occur, an effect also

reported by Murcia (1995).

A total of 113 species was recorded in the fragment, a value similar to those reported by Siqueira *et al.* (2001) and Alves-Júnior (2006) for lowland forests near the Atlantic coast. Species richness and diversity in the forest interior habitats were not significantly different from values found at the forest edge (Table 1). In fact, the greatest richness and diversity (63 species, 3,562 nats. ind.⁻¹ at lower slopes) and the lowest (50 species at interior terrace, and 3,178 nats. ind.⁻¹ at mid slopes) were found in forest interior (Table 1). The absence of significant differences in species richness and diversity is contrary to that reported by Oliveira *et al.* (2004) and Santos *et al.* (2008) for the Atlantic forest. In those studies, the authors found twice the number of species in the interior than in edge habitats. However, this pattern was reported for trees with DBH ≥ 10 cm, whereas in our study the sample DBH criterion was ≥ 5 cm.

Among species recorded, only 13, less than 10% of the total, were found in all habitats. Some had high structural importance (IV) in all habitats, notably: *Eschweilera ovata* (Lecythidaceae), *Pogonophora schomburgkiana* (Euphorbiaceae), *Tapirira guianensis*, and *Thyrsodium spruceanum* (Anacardiaceae), although their IVs tended to diminish towards the more interior habitats (see Fig. 3). *Bowdichia virgilioides* had greatest IV at lower slope, *Inga thibaudiana* (Fabaceae) in the interior terrace and *Schefflera morototoni* showed high IV in the edge. All species listed are secondary species (Lins-e-Silva and Rodal 2008). This indicates that differences in the distribution of species between different successional guilds may not occur as much as found by Oliveira *et al.* (2004) and Nascimento and Laurance (2006).

Other species with a number of individuals greater than five showed a preferential distribution in relation to different environmental conditions, which is the case for *Inga thibaudiana* DC. (Fabaceae), with greatest IV in the terrace, followed by *Simarouba amara* Aublet. (Simaroubaceae) and *Jacaratia dodecaphylla* Hassl. (Caricaceae), making this environment the most distinct in the forest interior.

Understory

A total of 1145 individuals (in 0.14 ha.) were sampled in the four habitats, which is equivalent to an estimated 8178.57 ind. ha⁻¹, with a basal area of 3 m² ha⁻¹. The mean understory plant height was 2.21 \pm 1.29 m and the mean diameter 2.01 \pm 0.89 cm (Table 1). Overall, understory density in this fragment was less to values reported (using the same criterion) carried out by Gomes *et al.* (2008) at smaller fragments in the Usina São José (27 ha, 15360 ind. ha⁻¹; 99 ha, 18733 ind. ha⁻¹).

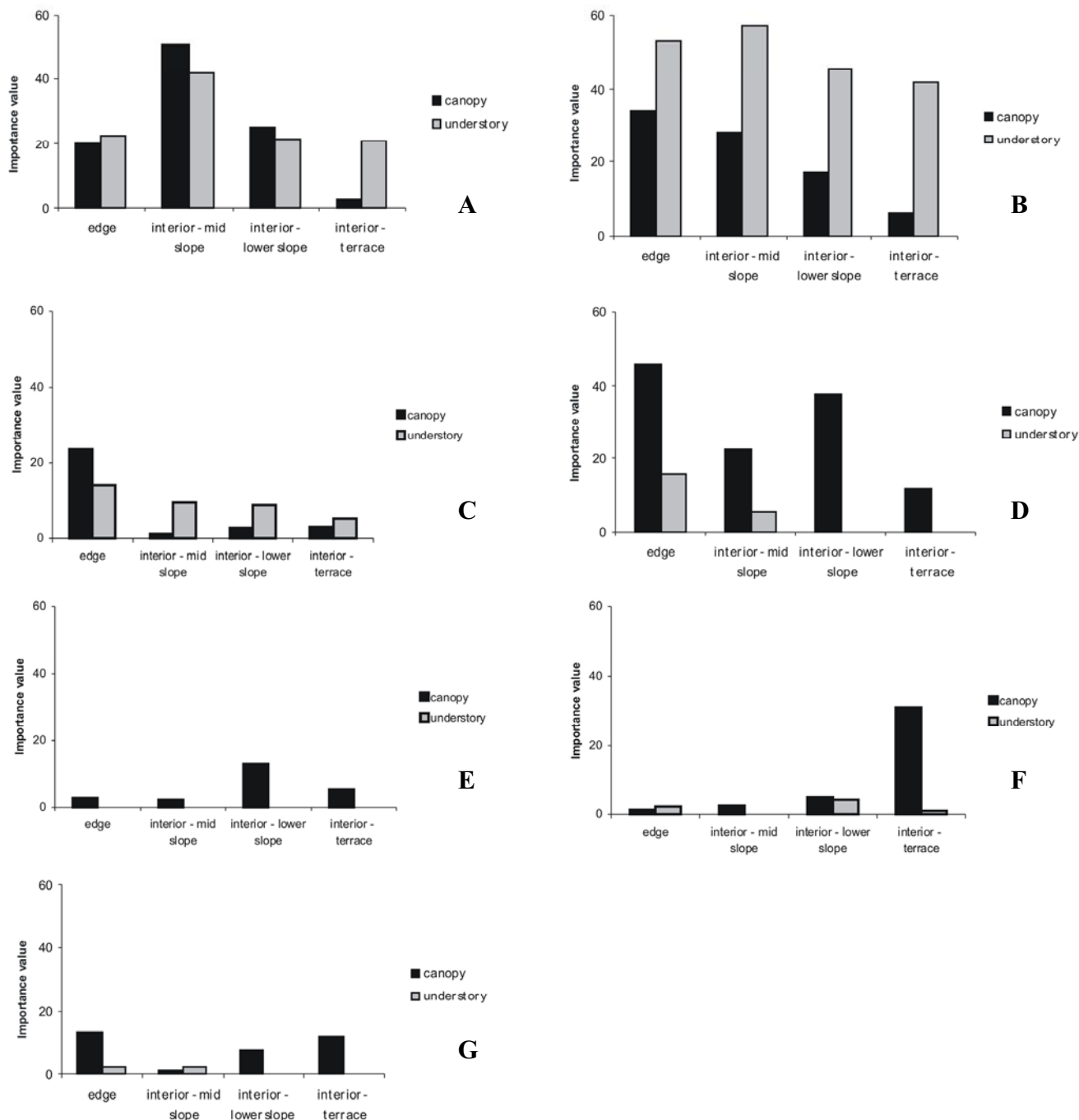


Fig. 3 Importance value of species in the canopy plants with DBH ≥ 5 cm and understory plants with DSL ≥ 1 cm and < 5 cm in four habitats in the Mata dos Macacos, Igarassu, Pernambuco State, Brazil. (A) *Pogonophora schomburgkiana* Miers ex Benth. (Euphorbiaceae). (B) *Eschweilera ovata* Mart. ex Miers (Lecythidaceae). (C) *Thyrsodium schomburgkianum* Benth. (Anacardiaceae). (D) *Tapirira guianensis* Aubl. (Anacardiaceae). (E) *Bowdichia virgilioides* Humb. Bonpl. & Kunth (Fabaceae). (F) *Inga thibaudiana* DC. (Fabaceae). (G) *Schefflera morototoni* (Aubl.) Maguire, Steyer. & Frodin (Araliaceae).

Analyses indicated that the edge and mid slopes had similar densities, which are lower than the densities found at the two other habitats ($p < 0.05$). In fact, differences in understory density are expected to occur between edge and interior habitats, as reported by Tabanez *et al.* (1997) and Delamónica *et al.* (2001). However, these differences do not follow the same pattern. For example, Gomes *et al.* (2008) found greater densities at interior habitats in a 99 ha fragment and a reversed pattern in a 27 ha fragment. Therefore, densities may decrease (Benitez-Malvido 1998), such as happened in the present study, or increase (Oosterhorn and Kappelle 2000). Studies focusing on understory dynamics could possibly explain the reasons for different patterns found, which can be related to canopy openness, edge age or management of adjacent fields.

Analysis of plant distribution per height classes (Fig. 4A) and diameter classes (Fig. 4B) revealed that the edge is

distinct from all interior habitats (for heights and diameters). Moreover, differences were also detected between forest interior habitats, the mid slope condition being distinct from other interior habitats.

A total of 115 species was recorded in the understory (Table 1). Understory species richness in this fragment was much higher than values found for smaller fragments in the Usina São José (65 and 67 species) by Gomes *et al.* (2008). These differences can be related to area effect or to a stronger edge influence in smaller fragments. Macacos Forest is three and ten times bigger than the other two remnants and may contain a greater diversity of available habitats. According to Nascimento and Laurance (2006), edge effect and area effect are rarely discriminated in studies of fragmented forests. In terms of species richness, the edge was also distinct, with a lower number of sampled species, whereas the other three environments were more homoge-

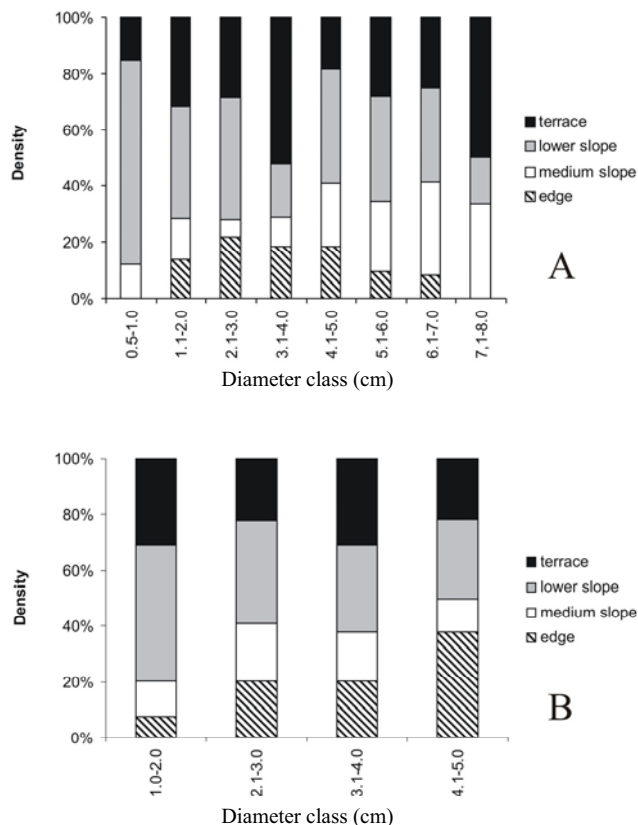


Fig. 4 Distribution of the relative density of individuals of understory plants with $DSL \geq 1$ cm and < 5 cm (A) by height class (m) and (B) by diameter class (cm) in 0.14 ha in four habitats in the Mata dos Macacos, Igarassu, Pernambuco State, Brazil.

neous.

Overall diversity, considering all sample plots, was 3.682 nats ind.⁻¹, varying from 2.915 nats ind.⁻¹ at the edge (153 ind., 35 species) to 3.462 nats ind.⁻¹ (492 ind., 79 species) at lower slopes (Table 1), with significant differences in richness and diversity between edge-mid slopes and the other habitats. Hence, the edge was the least diverse environment, followed by mid slope. As was observed by Gomes *et al.* (2008), the estimated species diversity of a site is greater when its habitats are systematically sampled. In the study area, understory species richness and diversity have a tendency to increase towards forest interior. Possibly, these variations are related to species dynamics and habitat preference in different ecological groups (Schorn and Galvão 2006) influenced principally by edge effect and secondly by a topographic gradient. Richness and diversity are also related to canopy openness (Oliveira and Felfili 2005; Salles and Schiavini 2007).

Among species with the greatest structural importance values (IV), *Eschweilera ovata* and *Pogonophora schomburgkiana*, two arboreal species, were observed to occur in the understory in all habitats. *E. ovata* had high IV in all sites, and occurred in all diameter classes, except in the largest diameter class of the understory on the mid slope (Fig. 5A). *P. schomburgkiana*, which had approximately half of the IV as *E. ovata*, was absent in the smallest diameter class of the edge (Fig. 5B). Note that in the interior terrace and the lower slope, these two species tended to show larger numbers of individuals in the smaller diameter classes, which suggests a greater recruitment in these habitats. However, only future studies that can follow the dynamics of these forest populations will make it possible to confirm this observation.

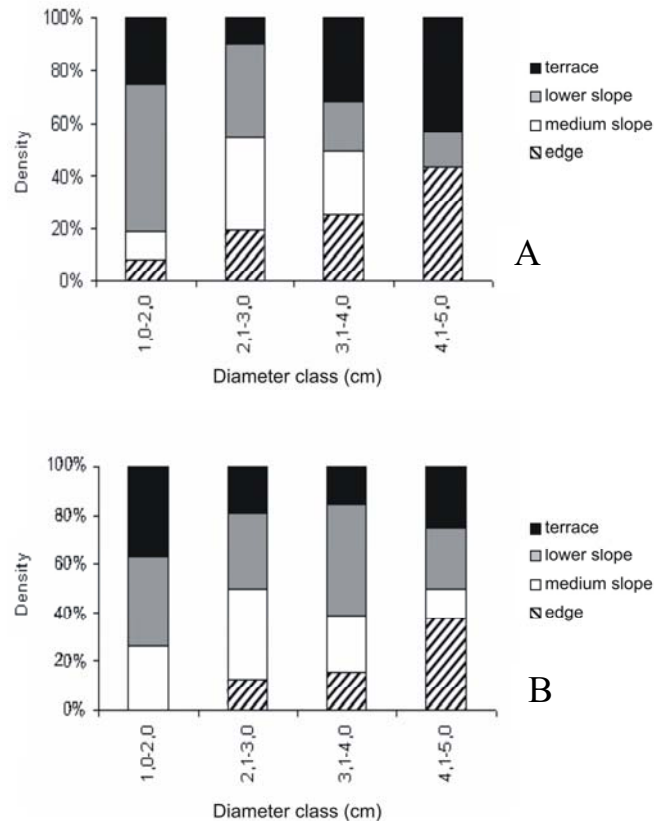


Fig. 5 Distribution of number of individuals of the understory plants with $DSL \geq 1$ cm and < 5 cm of (A) *Eschweilera ovata* (Cambess.) Meirs (Lecythydaceae), and (B) *Pogonophora schomburgkiana* Meirs ex Benth. (Euphorbiaceae) by diameter class in four habitats in the Mata dos Macacos, Igarassu, Pernambuco State, Brazil.

FINAL CONSIDERATIONS

The results presented here indicate that edge influence on the plant community of Macacos forest was stronger than the topographical gradient, based on the physiognomy and structure of canopy and sub-canopy individuals. However, some differences between interior habitats were also found and suggest that, in addition to edge effects, variations in topography can result in variations in the physiognomy and structure of interior habitats, as was also reported by Carvalho *et al.* (2007). In addition they found that humidity and soil fertility were also factors to take into consideration.

Overall, results found for the understory reinforce the distinctiveness of edge environments. Also, understory on mid slope was distinct from other habitats, in a way different from that observed for trees. This result is probably related to canopy openness at mid slopes, which influences light and moist conditions (Svenning *et al.* 2004). Indeed, Enoki and Abe (2004) found site preferences of species following a gradient from concave slopes with little canopy openness to convex slopes with greater canopy openness. Therefore, variances in environmental conditions, such as moist and light regimes, whether edge- or topography-induced, seem to be crucial factors for the distribution of canopy and understory assemblages in the studied fragment.

ACKNOWLEDGEMENTS

The authors would like to thank the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and the Bundesministerium für Bildung und Forschung (BMBF) for financially supporting the project "Sustainability of remnants of the Atlantic rainforest in Pernambuco and its implications for conservation and local development" (process n° 590039/2006-7) and BMBF (01 LB 0203 A1), the owners of the Usina São José/ Group Cavalcanti Petribú for their cooperation; and the student assistants from the

Phytosociology and Plant Ecology laboratories at UFRPE for their invaluable help with the field work.

REFERENCES

- Alves-Júnior FT, Brandão CFLS, Rocha KD, Silva JT, Marangon LC, Ferreira RLC (2007) Estrutura diamétrica e hipsométrica do componente arbóreo de um fragmento de Mata Atlântica, Recife-PE. *Cerne* **13**, 83-95
- APG II (2003) An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG II. *Botanical Journal of the Linnean Society* **141**, 399-436
- Ayres M, Ayres Júnior AM, Ayres DL, Santos AS (2000) *Bioestat 2.0: aplicações nas áreas das ciências biológicas e médicas*. Sociedade Civil Mamirauá, Brasília
- Benítez-Malvido J (1998) Impact of forest fragmentation on seedling abundance in a tropical rain forest. *Conservation Biology* **12**, 380-389
- Benítez-Malvido J, Martínez-Ramos M (2003) Impact of forest fragmentation on understory plant species richness in Amazonia. *Conservation Biology* **17**, 389-400
- Brower JE, Zar JH (1984) *Field and Laboratory Methods for General Ecology*, W.C. Brown Publishers, Duxbury, 161 pp
- Cardoso E, Schiavini I (2002) Relação entre distribuição de espécies arbóreas e topografia em um gradiente florestal na Estação Ecológica do Panga (Uberlândia, MG). *Revista Brasileira de Botânica* **25**, 277-289
- Carvalho WAC, Oliveira-Filho AT, Fontes MAL, Curi N (2007) Variação espacial da estrutura da comunidade arbórea de um fragmento de floresta semidecídua em Piedade do Rio Grande, MG, Brasil. *Revista Brasileira de Botânica* **30**, 315-335
- Coimbra-Filho AF, Câmara IG (1996) *Os Limites Originários do Bioma Mata Atlântica na Região Nordeste do Brasil*, FBCN, Rio de Janeiro, 86 pp
- Cronquist A (1981) *An Integrated System of Classification of Flowering Plants*, Columbia University Press, New York, 1262 pp
- Delamônica P, Laurance WF, Laurance SG (2001) A fragmentação da paisagem. In: Oliveira AA, Daly DC (Eds) *As Florestas do Rio Negro*, UNIP, São Paulo, pp 283-302
- Didham RK, Lawton JH (1999) Edge structure determines the magnitude of changes in microclimate and vegetation structure in tropical forest fragments. *Biotropica* **31**, 17-30
- Enoki T, Abe A (2004) Saplings distribution in relation to topography and canopy openness in an evergreen broad-leaved forest. *Plant Ecology* **173**, 283-291
- Espírito-Santo FDB, Oliveira-Filho AT, Machado ELM, Souza JS, Fontes MAL, Marques JGGSM (2002) Variáveis ambientais e a distribuição de espécies arbóreas em um remanescente de Floresta Estacional Semidecídua Montana no Campus da Universidade Federal de Lavras, MG. *Acta Botanica Brasilica* **16**, 331-356
- FIDEM (Fundação de Desenvolvimento da Região Metropolitana do Recife) (1993) *Monitoramento das Reservas Ecológicas da Região Metropolitana do Recife*, FIDEM, Recife, 55 pp
- Gerwing JJ, Schnitzer SA, Burnham RJ, Bongers F, Chave J, Dewalt SJ, Ewango CEN, Foster R, Kenfack D, Martínez-Ramos M, Parren M, Parthasarathy N, Perez-Salicipú DR, Putz FE, Thomas DW (2006) A standard protocol for liana censuses. *Biotropica* **38**, 256-261
- Gomes JS, Lins e Silva ACB, Rodal MJN, Silva HCH (2008) Estrutura do sub-bosque lenhoso em ambientes de borda e interior de dois fragmentos de Floresta Atlântica em Igarassu, Pernambuco. *Rodriguésia* in press
- Hadley KS (1994) The role of disturbance, topography, and forest structure in the development of a montane forest landscape. *Bulletin of the Torrey Botanical Club* **121**, 47-61
- Harper KA, Macdonald E, Burton PJ, Chen J, Brosowski KD, Saunders SC, Euskirchen ES, Roberts D, Jaithe MS, Essen P (2005) Edge influence on forest structure and composition in fragmented landscapes. *Conservation Biology* **19**, 768-782
- Jacome PT, Cavalcanti AC, Burgos N, Pessoa SCPE, Silveira CO (1973) *Levantamento exploratório-reconhecimento de solos do estado de Pernambuco* (Vol 1), SUDENE/Divisão de Pesquisa Pedológica, Recife (Boletim Técnico 26, Pedologia 14), 359 pp
- Lawes MJ, Lamb BCC, Boudreau S (2005) Area- but no edge-effect on woody seedling abundance and species richness in old Afromontane forest fragments. *Journal of Vegetation Science* **16**, 363-372
- Lima MLFC (1998) *A Reserva da Biosfera da Mata Atlântica em Pernambuco - Situação Atual, Ações e Perspectivas*, Conselho Nacional da reserva da biosfera da Mata Atlântica, São Paulo, 24 pp
- Lins-e-Silva ACB, Rodal MJN (2008) Tree community structure in an urban Atlantic forest Remnant in Pernambuco, Brazil. *Memoirs of the New York Botanical Garden* **100**, 511-533
- Lovejoy TE, Rankin JM, Bierregaard RO Jr., Brown K Jr., Emmons LH, van der Vort, ME (1984) Ecosystem decay of Amazon forest remnants. In: Nitecki MH (Ed) *Extinctions*, University of Chicago Press, Chicago, pp 295-325
- Magurran AE (2003) *Measuring Biological Diversity*, Blackwell, Cornwall, 256 pp
- Mani S, Parthasarathy N (2006) Tree diversity and stand structure in inland and coastal tropical dry evergreen forests of peninsular India. *Current Science* **90**, 1-10
- Moreno MIC, Schiavini I (2001) Relação entre vegetação e solo em um gradiente florestal na Estação Ecológica do Panga, Uberlândia (MG). *Revista Brasileira de Botânica* **24**, 537-544
- Murcia C (1995) Edge effects in fragmented forest: implications for conservation. *Trends Ecology and Evolution* **10**, 58-62
- Nascimento HEM, Laurance WF (2006) Efeito de área e de borda sobre a estrutura florestal em fragmentos de floresta de terra-firme. *Acta Amazonica* **36**, 183-192
- Nunes YRF, Mendonça AVR, Botzelli 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
- Oliveira ECL, Felfili JM (2005) Estrutura e dinâmica da regeneração natural de uma mata de galeria no Distrito Federal, Brasil. *Acta Botanica Brasilica* **19**, 801-811
- 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 RJ, Mantovani W, Melo MMRF (2001) Estrutura do componente arbustivo-arbóreo da Floresta Atlântica de encosta, Peruíbe, SP. *Acta Botanica Brasilica* **15**, 391-412
- Oosterhorn M, Kappelle M (2000) Vegetation structure and composition along an interior-edge-exterior gradient in a Costa Rican Montane Cloud Forest. *Forest Ecology and Management* **7**, 385-403
- Pereira JAA, Oliveira-Filho AT, Lemos-Filho JP (2007) Environmental heterogeneity and disturbance by humans control much of the tree species diversity of Atlantic montane forest fragments in SE Brazil. *Biodiversity and Conservation* **16**, 1761-1784
- Ranta P, Brom T, Joensuu E, Mikko S (1998) The fragmented Atlantic forest of Brazil: size, shape and distribution of forest fragments. *Biodiversity and Conservation* **7**, 385-403
- Rodrigues RR, Morelato LPC, Joly CA, Leitão-Filho HF (1989) Estudo florístico e fitossociológico em um gradiente altitudinal de mata estacional mesófila semidecidual, na Serra do Japi, Jundiá, SP. *Revista Brasileira de Botânica* **12**, 71-84
- Salis MS, Zickel CS, Tamashiro JY (1996) Fitossociologia do sub-bosque da mata da reserva municipal de Santa Genebra, Campinas (Estado de São Paulo). *Naturalia* **1**, 171-179
- Salles JC, Schiavini I (2007) Estrutura e composição do estrato de regeneração em um fragmento florestal urbano: implicações para a dinâmica e a conservação da comunidade arbórea. *Acta Botanica Brasilica* **21**, 223-233
- Santos BA, Carlos A, Peres CA, Oliveira MA, Grillo A, Alves-Costa CP, Tabarelli M (2008) Drastic erosion in functional attributes of tree assemblages in Atlantic forest fragments of northeastern Brazil. *Biological Conservation* **141**, 249-260
- Schorn LA, Galvão F (2006) Dinâmica da regeneração natural em três estágios sucessionais de uma Floresta Ombrófila Densa em Blumenau, SC. *Floresta* **36**, 59-74
- Shepherd GJ (1995) *FITOPAC I: Manual do Usuário*, Universidade Estadual de Campinas/Departamento de Botânica, Campinas, 94 pp
- Silva HCH, Lins-e-Silva ACB, Gomes JS, Rodal MJN (2008) The effect of internal and external edges on vegetation physiognomy and structure in a remnant of Atlantic lowland rainforest in Brazil. In: Rodal MJN, Lins-e-Silva ACB, Gottsberger G (Eds) *The Fragments Project. Bioremediation, Biodiversity and Bioavailability 2 (Special Issue 1)*, 47-55
- Siqueira DR, Rodal MJN, Lins-e-Silva ACB, Melo AL (2001) Physiognomy, structure and floristic in an area of Atlantic Forest in Northeast Brazil. In: Gottsberger G, Liede S (Eds) *Life Forms and Dynamics in Tropical Forest*, J. Cramer, Berlin, pp 11-27
- Souza JS, Espírito-Santo FB, Fonte MAL, Oliveira-Filho AT, Botzelli L (2003) Análise das variações florísticas e estruturais da comunidade arbórea de um fragmento de floresta semidecídua às margens do rio Capivari, Lavras-MG. *Arvore* **27**, 185-206
- Svenning J-C, Kinner DA, Stallard RF, Engelbrecht BMJ, Wright SJ (2004) Ecological determinism in plant community structure across a tropical forest landscape. *Ecology* **85**, 2526-2538
- Tabanez AJ, Viana VM, Dias AS (1997) Consequências da fragmentação e do efeito de borda sobre a estrutura, diversidade e sustentabilidade de um fragmento de floresta de planalto de Piracicaba, SP. *Revista Brasileira de Biologia* **57**, 47-60
- Tabarelli M, Mantovani W (1997) Colonização de clareiras naturais na Floresta Atlântica no sudeste do Brasil. *Revista Brasileira de Botânica* **20**, 57-66
- Tabarelli M, Mantovani W (1999) A regeneração de uma floresta tropical montana após corte e queima (São Paulo - Brasil). *Revista Brasileira de Biologia* **59**, 239-251
- Trindade MB, Lins-e-Silva ACB, Silva HP, Figueira SB, Schessl M (2008) Fragmentation of the Atlantic Rainforest in the Northern Coastal Region of Pernambuco, Brazil: Recent changes and implications for conservation. In: Rodal MJN, Lins-e-Silva ACB, Gottsberger G (Eds) *The Fragments Project. Bioremediation, Biodiversity and Bioavailability 2 (Special Issue 1)*, 5-13
- Williams-Linera G (1990) Vegetation structure and environmental conditions of forest edges in Panama. *Journal of Ecology* **78**, 356-373
- Young A, Mitchell N (1994) Microclimate and vegetation edge effects in a fragmented podocarp-broadleaf forest in New Zealand. *Biological Conservation* **67**, 63-72
- Zar JH (1996) *Biostatistical Analysis* (3rd Edn), Prentice Hall, New York, 662 pp
- Zuidema PA, Sayer JA, Dijkman W (1996) Forest fragmentation and biodiversity: the case for intermediate-sized conservation areas. *Environmental Conservation* **23**, 290-297