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Microclimate of Atlantic Forest Fragments: Regional and Local Scale Heterogeneity

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ABSTRACT

The aim of this work was to investigate whether (i) the organisms within different fragments, on regional scale (separated by up to 100 km), could be submitted to similar climatic conditions (rainfall and temperature), and whether (ii) the edge formation in forest fragments could stimulate microclimatic changes (canopy cover, air temperature and soil humidity), on local scale. The organisms within different fragments, on regional scale, were submitted to different climatic conditions, and the edge formation in the forest fragment stimulated microclimatic changes, on local scale, although in a heterogenic way. Not just the distance from the edge influenced the microclimatic differences. Probably, the edge age, location, the matrix structure, as well as, gap proximity could change the microclimatic even within edges.

Key words: Atlantic forest, canopy openness, edges, fragmentation, soil moisture, temperature

INTRODUCTION

The forest fragmentation could affect the remnants organisms isolating their population and changes the microclimate they were submitted, on regional and local scale. On regional scale, climate may influence many aspects of the biology of tropical organisms, including plant growth and reproduction (Corlett and LaFrankie Jr., 1998). Spatial and long-term climatic and/or microclimatic variability among areas, such as in rainfall and temperature, could alter the reproductive events of plant and animal populations (van Schaik et al., 1993), including pollinator abundance (Augspurger, 1980) and plant phenology (Smith-Ramirez and Armesto, 1994).

Animal or plant populations of the same species in distant areas may show different reproductive patterns depending on the climatic conditions. The periodicity of plant growth and reproduction has a profound impact on most of the animal species that depend on periodically available plant resources: young leaves, pollen, nectar, fruits and seeds (Corlett and LaFrankie Jr., 1998). Thus, temporal variation in flowering season can influence the seed-set success if pollinator activity varies with the flowering of individual species (Kudo et al., 2004).

On a local scale, large variation in understorey micro-environmental factors including light availability (Nicotra et al.; 1999, Bianchini et al., 2001), temperature (Young and Mitchell, 1994) and moisture (Camargo and Kapos, 1995) may be related to gaps and to the structural complexity

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and/or deciduousness of the canopy. The frequency of natural disturbance events in a forest varies among localities and variations in forest microclimate distribution within and among stands profoundly influences overall understorey light availability and its spatial distribution (Nicotra et al., 1999).

The formation of edges, between forested and deforested areas (matrix) by forest fragmentation changes the abiotic conditions and could affect the remnant organisms (Bierregaard Jr. et al.; 1992, Metzger, 1999; Poulin et al., 1999; Debinski and Holt, 2000). The microclimatic changes at the edges of fragments could stimulate biotic modifications, such as alterations in the forest structure of the edge, because the growth, mortality, and distribution of the plants in this new environment may be directly affected by the physical conditions, and by the density and activity of some animal species (Murcia, 1995). Consequently, changes in many aspects of the life histories of plants and animals at the edges may cause alterations in species interactions, including herbivory, seed predation, pollination and seed dispersion (Saunders et al., 1991, Aizen and Feinsinger, 1994). Natural edges (limits between forests and rivers, streams, lakes or natural fields) may also show abiotic and biotic differences in relation to the forest interior (Corbet, 1990; Matlack, 1994; Casenave et al., 1998; Meleason and Quinn, 2004).

The aim of this work was to investigate whether (i) the organisms within different fragments, on regional scale (separated by up to 100 km), could be submitted to similar climatic conditions (rainfall and temperature), and whether (ii) the edge formation in forest fragments could stimulated microclimatic changes (canopy cover, air temperature and soil humidity), on local scale.

MATERIAL AND METHODS

Study sites

Regional scale

Five forest fragments, classified as evergreen forests or ombrophilous dense forest (Radambrasil, 1983) were selected in State of Rio de Janeiro, southeastern Brazil. Four of the fragments were located in conservation units: Parque Estadual do Mendanha (ME), Parque Estadual da Pedra Branca (PB), Parque Nacional da Floresta da Tijuca (FT), Parque Estadual da Serra da Tiririca (ST), and one was a private area: Hotel Fazenda Serra da Castelaña (SC) (Table 1). Fragments along the main highways in the south and southwest of the State were selected in order to facilitate access to them. The distances among fragments ranged from about 16 to 110 km (Table 2).

Climate was compared for the five fragments by constructing climatic diagrams using long-term rainfall and temperature data (more than 30 years). The precipitation data were obtained from Serla (Secretaria Estadual de Rios e Lagoas) and the temperature data were obtained from InMet (Instituto Nacional de Meteorologia) (PB: 22º55’ S, 43º25’ W; ME : 22º51’ S, 43º32’ W; ST: 22º52’ S, 43º14’ W; FT: 22º57’ S, 43º16’; SC: 22°51’S, 42°33’ W).

Local scale

The study was carried out in the forest fragment of the Hotel Fazenda Serra da Castelaña (SC), city of Saquarema, RJ, including 1200 ha of Atlantic forest with a hilly topography, with altitudes varying from 30 to 400 m. The fragment was probably not deforested because its topography was not appropriate for cropland and cattle pasture.

Table 1 - Characteristics of the five Atlantic forest fragments in Rio de Janeiro: their sizes (ha), elevations (m) and coordinates S (C.S) and W (C.W). Parque Estadual do Mendanha (ME), Parque Estadual da Pedra Branca (PB), Hotel Fazenda Serra da Castelhaña (SC), Parque Estadual da Serra da Tiririca (ST), Parque Nacional da Floresta da Tijuca (FT).

	SIZE	ELEV	C. S	C. W
ME	7700	23	22°49’	43°33’
PB	12500	202	22°55’	43°26’
FT	3200	13	22°58’	43°13’
ST	2400	215	22°56’	43°00’
SC	1200	160	22°50’	42°28’

Table 2 - Distances (km) among the studied Atlantic forest fragments in Rio de Janeiro. Parque Estadual do Mendanha (ME), Parque Estadual da Pedra Branca (PB), Hotel Fazenda Serra da Castelhaña (SC), Parque Estadual da Serra da Tiririca (ST), Parque Nacional da Floresta da Tijuca (FT).

	PB	**SC**	**ST**	**FT**
ME	15.8	109.9	57.6	36.7
PB	-	99.1	44.9	22.4
SC	-	-	54.9	77.8
ST	-	-	-	23.0

The study was done in a 180-ha sector (22° 50' S e 42° 28' W) of this area in order to facilitate access to the habitats. The forest studied was surrounded by pasture and cropland, thus creating anthropogenic edges. Within the forest, there was a stream 2-5 m wide and 700 m long that created a natural edge with the forest. Three habitats were investigated at the study site: (1) the edge of the forest with pasture and cropland (AE = anthropogenic edges ~50 m from the pasture), (2) the edge of the forest with the stream (NE = natural edges ~50 m from the stream), and (3) the forest interior (FI = 200 m or more from any edge). Five sample plots of 10 x 50 m in each habitat were non-systematically located, and the distances among sample plots ranged from 150 to 883 m (Fig. 1). The climate was classified as Cwa based on the Köppen system (Veanello and Alvez, 1991).

Microclimatic differences

a) *Temperature measurements*

The maximum and minimum air temperatures were recorded once a month from March 2003 to February 2004, using maximum and minimum thermometers placed 1.2 m above the ground in each of the 15 sample plots.

b) Soil moisture measurements

At monthly intervals from March 2003 to February 2004, three 40 g samples of the 0-20 cm soil layer (excluding litter) were taken from each sample plots in each habitat. The samples were double wrapped in plastic bags and weighed fresh in the lab (digital balance), them dried in a oven at *ca.* 65°C for 48 h and weighed again when dry. The percent water content was calculated as: 100 times (fresh weight – dry weight) / fresh weight.

c) Canopy openness

Five canopy openness measurements were taken in each sample plot in each habitat twice in 2003, in the summer (wet season) and winter (dry season) (January and September, respectively). To measurements it was used hemispherical photographs taken with a Nikon Coolpix 950 with fish-eye lens autofocus Nikon 8mm (180º), placed 60 cm above the ground. The hemispherical photographs were analyzed for canopy openness (percentage of the hemispherical image not covered by vegetation) using the software Gap Light Analyzer 2.0 (GLA) (Frazer et al., 1999). This program transforms the colors from the photos to black and white in order to quantify the pixels before calculation of canopy openness. To minimize subjectivity, three different persons transformed independently the colored images to black and white, and the mean among these was used for the calculation of canopy openness

Statistical analysis

The differences in canopy openness, temperature (minimal, maximal and amplitude) and soil moisture among the three habitats (AE, NE and FI) within the fragment were tested by two-way nested ANOVA (Zar, 1996). Time was the second factor tested: seasons (canopy openness) and months (temperature and soil moisture).

To improve the homoscedasticity and normality of the distributions, the data for canopy openness measurements and soil moisture were arcsine transformed before analysis (Zar, 1996). Means were back-transformed for use in the figures.

In the nested analyses of variance, the tested factor was the habitat. The five sample plots (nested within each habitat) were randomly sampled and were considered as random effects.

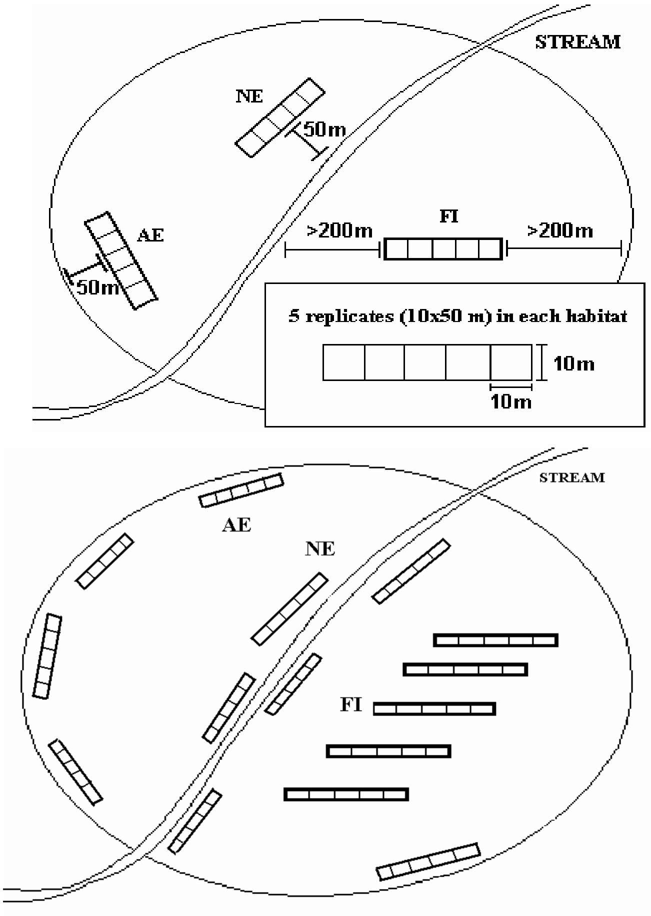

Figure 1 - Schematic design of plot distribution in each habitat. A = Detail of the sample plots in each habitat and the distance from edges. B = General distribution of the five replicates of sample plots within each habitat. AE = anthropogenic edge; NE = natural edge; FI = fragment interior.

Habitat, sample plots and canopy openness, and temperature and soil moisture were tested against the corresponding next lower hierarchical level (Sokal and Rohlf, 1995).

RESULTS

Regional scale

None of the five fragments showed dry months, i.e. the temperature and rainfall lines did not overlap each other. However, all areas except FT had 1-3 months of low rainfall. FT had an annual rainfall almost twice as high as the other four areas (1200 mm). Also, FT had the lowest minimum and maximum temperatures while ME had the highest values (Fig. 2).

Local scale

a) Temperature

The minimum and maximum temperatures during the year (2003) ranged from 12.6-19.0 °C and 23.8-34.2°C, respectively, and the temperature amplitude was 10.6-17.6°C, regardless of the habitats (Fig. 3). There were no significant differences in the minimum temperature ($F_{2,12}$ = 1.8; p = 0.20) among the habitats, probably because of the great variation among the sample plots within habitats ($F_{12,132}$ = 5.2; p = 0.0001). However, AE showed the greatest average maximum temperature ($F_{2,12}$ = 12.3; p = 0.0001) and amplitude ($F_{2,12}$ = 5.3; p = 0.02), while NE had the lowest values. There were differences in the minimum temperature among the months, independently of the habitats ($F_{11,132}$ = 35.8; p = 0.0001). However, the interaction between months and habitat was significant, both for the maximum temperatures ($F_{22,132}$ = 1.9; p = 0.02) and amplitude ($F_{22,132}$ = 1.8; p = 0.03).

b) Soil moisture

The soil moisture of all habitats during 2003 ranged from 7.2% to 19.9% (Fig. 4). There were no differences in soil moisture ($F_{2,12}$ = 1.6; p = 0.25) among the habitats, probably because of the great variation among the sample plots within habitats ($F_{12,132}$ = 14.3; p = 0.0001). However there was a significant interaction between months and habitat ($F_{22,132}$ = 3.0; p = 0.0001).

c) Canopy openness

Canopy openness in the winter was greater than in summer for all habitats, probably because of the deciduousness of many tree species in the dry season (Fig. 5). Canopy openness ranged from 4.0% to 18.9% for all habitats in both seasons. There were no differences in canopy openness among habitats ($F_{2,12}$ = 2.9; p = 0.10), but there was a significant interaction between season and habitat ($F_{2,132}$ = 3.6; p = 0.03). The sample plots within the habitats showed great heterogeneity ($F_{12,132}$ = 15.4; p = 0.0001) in both seasons, although the greatest variations among them were seen in the winter. NE3 showed the lowest medians for canopy openness in the summer (5.7%) and winter (4.6%), whereas the greatest medians were displayed by FI4 in the summer (12.0%), and by AE3 in winter (15.9%) (Fig. 6).

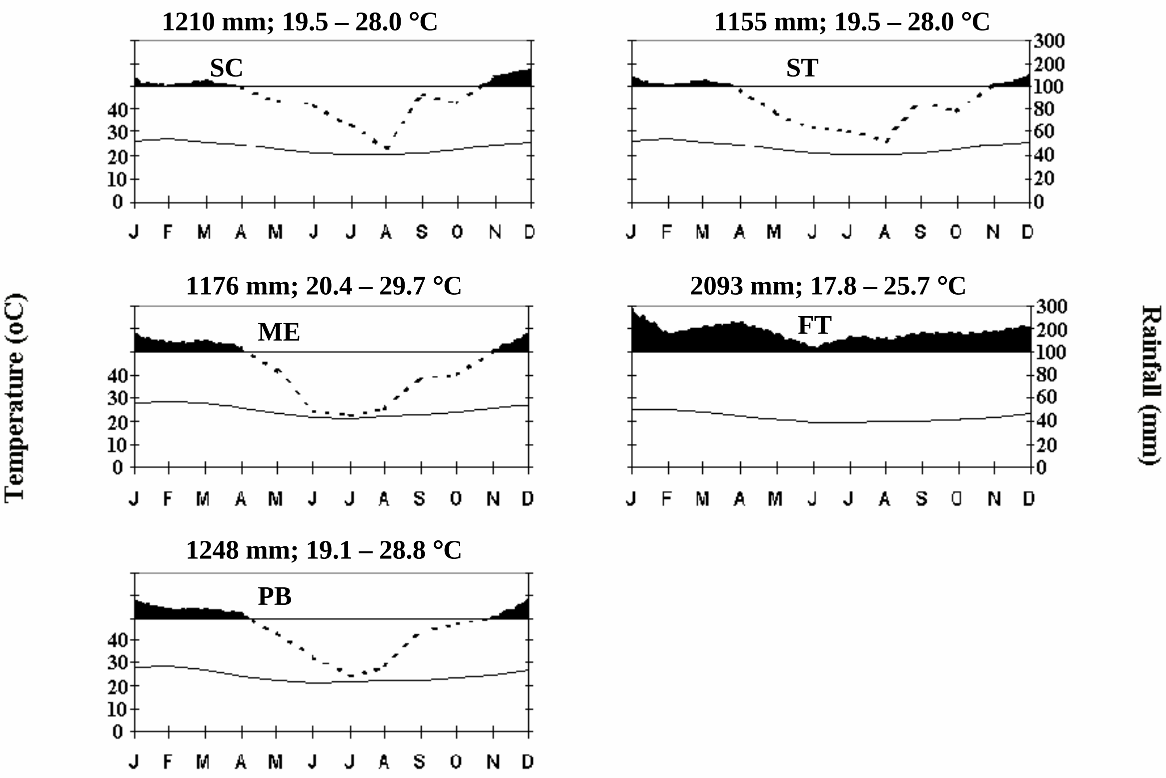

Figure 2 - Climatic diagrams for five forest fragments of Rio de Janeiro Atlantic forest. The annual rainfall and the minimum and maximum mean temperatures are shown at the top of each diagram. Hotel Fazenda Serra da Castelhaña (SC), Parque Estadual da Serra da Tiririca (ST), Parque Estadual do Mendanha (ME), Parque Nacional da Floresta da Tijuca (FT), Parque Estadual da Pedra Branca (PB)

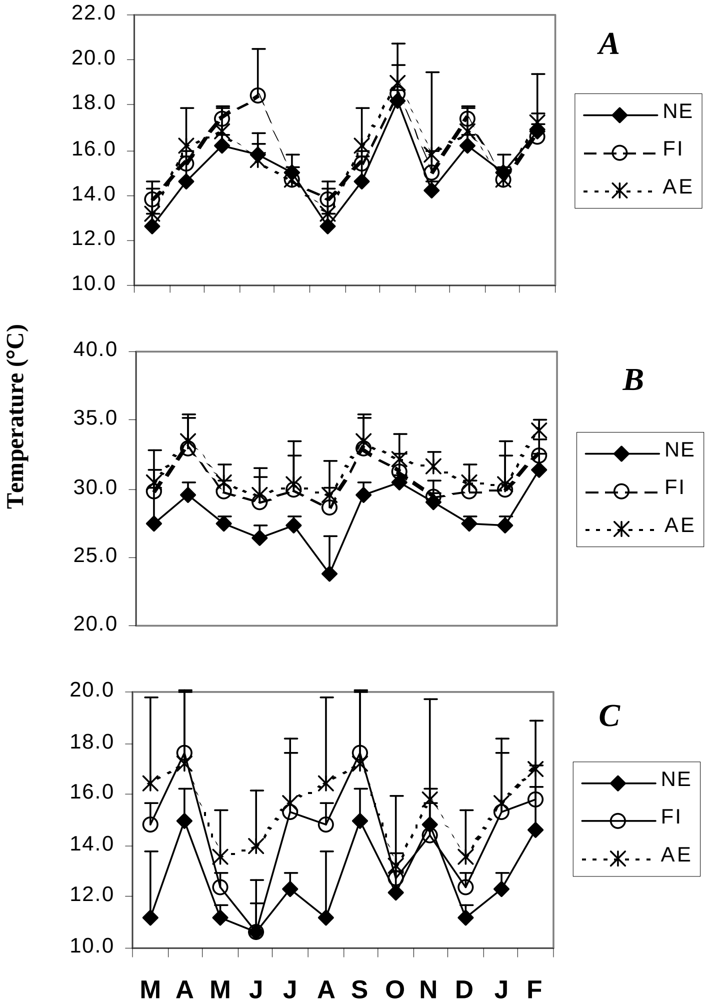

Figure 3 - Mean (and 1 standard deviation) of the minimum (A), maximum (B) and amplitude (C) temperatures for a natural edge (NE), forest interior (FI) and anthropogenic edge (AE) at Hotel Fazenda Serra da Castelhaña (SC) (March 2003 to February 2004).

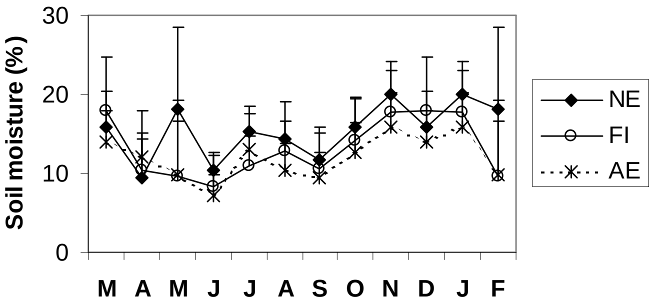

Figure 4 - Mean (and 1 standard deviation) of soil moisture (%) for a natural edge (NE), forest interior (FI) and anthropogenic edge (AE) at Hotel Fazenda Serra da Castelhaña (SC) (March 2003 to February 2004) (back-transformed means and standard deviations).

DISCUSSION

The forest fragments, on a regional scale, were submitted to different climatic conditions. Some fragments showed drier periods in the year, although this did not imply hydric deficit, and others displayed more constant precipitation throughout the year.

It seemed that the climatic patterns were not related to the distances among fragments (Table 2, Fig. 2). Probably, the dissimilarity was related to their different proximity to the sea and their different altitudes. The variations in rainfall and temperature observed, among fragments separated by up to 100 km, could be sufficient to influence some populations of organisms living in these fragments.

For instance, the reproduction among different populations of some plant and animal species were affected by climatic variations (Silvertown and Lovelt-Doust, 1993), and the synchronisation of reproduction among populations was essential for their long-term success, especially in self-incompatible plants, and for the satiation of seed predators (van Schaik et al., 1993).

On a local scale, the microclimatic variables showed spatial and temporal variations in the area studied in agreement with other reports (Murcia, 1995; Didham, 1997; Renhorn et al., 1997; Restrepo and Vargas, 1999; Gehlhausen et al., 2000). There were no differences in the minimal temperature, soil moisture and canopy openness among anthropogenic edges, natural edges and forest interior. The low maximal temperature seen at NE was probably caused by the stream water that buffered or lowered the high temperature in this habitat, as recorded in New Zealand (Meleason and Quinn, 2004).

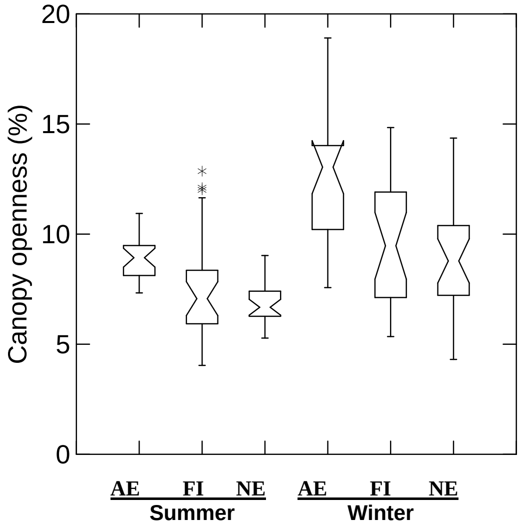

Figure 5 - Canopy openness (%) for an anthropogenic edge (AE), forest interior (FI) and natural edge (NE), at Hotel Fazenda Serra da Castelhaña (SC) (summer and winter of 2003). The box plot presents the median, 25th and 75th percentiles (box), and the minimum and maximum values (whiskers). The asterisks indicate values outside the acceptable range. The boxes are notched at the median values and return to full width at the lower and upper confidence interval (95%) values.

Other studies have shown spatial variability in some microclimatic variables between edges and the forest interior, depending on the orientation of the forest fragment, relative to the angle of the sun incidence (Young and Mitchell, 1994; Renhorn et al., 1997), or because some edges were buffered by the heterogeneity of the vegetation structure in adjacent habitats (Williams-Linera et al., 1998; Gehlhausen et al., 2000; Mourelle et al., 2001; Newmark 2001). The age of the fragment formation (Turton and Freiburger, 1997) and the extent of deforestation (Giambelluca et al., 2003) along the edge could also influence the microclimatic variables.

All of the microclimate variables examined here showed temporal variations. Other studies have also reported temporal microclimatic differences in fragmented edges over years (Camargo and Kapos, 1995; Kapos et al., 1997), seasons (Murcia, 1993 *apud* Restrepo and Vargas, 1999) and even hours (Newmark, 2001; Giambelluca et al., 2003) caused by the grown of vegetation and natural oscillation within a day. The seasonal variation in sunlight could contribute to seasonal microclimatic variations (Young and Mitchell, 1994), as could oscillations in vegetation growth in the daily light intensity.

The canopy openness did not differ among the habitats, probably because of the great variation among the sample plots within the habitats. The forest canopy may vary in species composition, deciduousness, height above the soil, and in thickness and foliage density (Lieberman et al., 1989; Bianchini et al., 2001). The heterogeneity observed probably reflected variation in the forest structure (tree diameter and height) in each sample plot (M. T. Ribeiro et al., unpublished data), in the number of deciduous tree species and in the presence of small gaps.

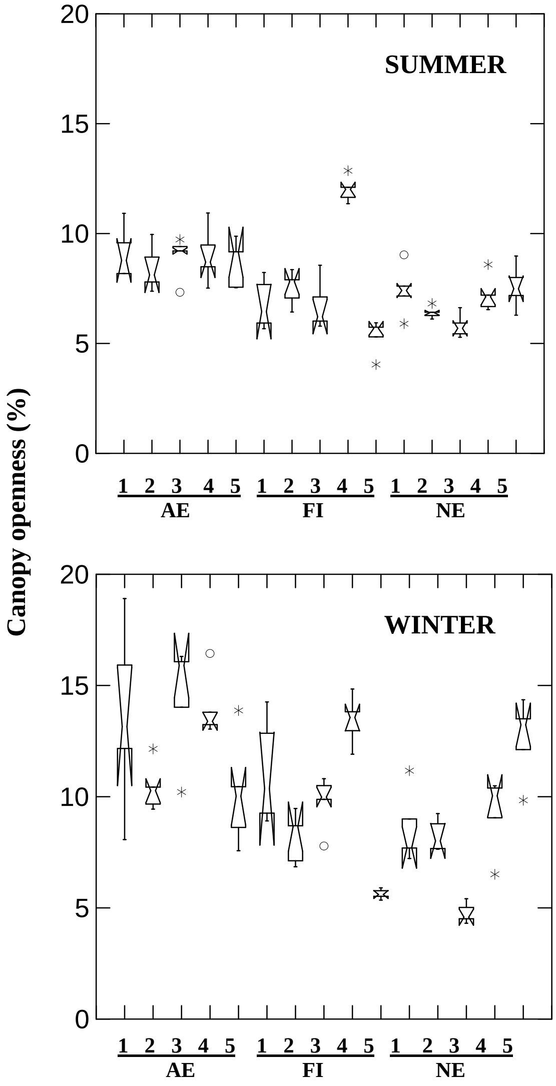

Figure 6 - Canopy openness (%) in each sample plot of an anthropogenic edge (AE), forest interior (FI) and natural edge (NE) in the summer and winter of 2003. The legends for the boxes are given in figure 4.

According to Smith et al. (1989), the aggregation of crowns in the canopy depends on the spatial distribution of the individuals and on gap formation.

The variability of microclimatic gradients found in this study was probably common to forest edge microclimatic gradients in general. However, the insufficient number of replicates in most studies probably accounted for the reported lack of microclimatic heterogeneity in the fragments. According to Murcia (1995), the lack of consensus in the microclimatic differences between edges and the fragment interior reflected differences in methodology used and the absence of replicates and adequate controls. However, the greater heterogeneity in microclimate variables seen among the sample plots of each habitat in this study indicated that other factors, such as edge age, matrix type, or the proximity of gaps, might have more influence on these variables than the proximity to the edges.

Thus, it could be recommended to incorporate more edges and/or fragment replications in future studies of fragmentation, in order to obtain more natural heterogeneity within fragments and to avoid erroneous conclusions about the influence of fragmentation on resident or persistent organisms.

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RESUMO

O objetivo deste trabalho foi investigar se (i) os organismos dentro de diferentes fragmentos, em escala regional (separados por até 100 km), podem ser submetidos a condições climáticas similares (pluviosidade e temperatura) e se (ii) a formação de borda em fragmentos florestais pode estimular mudanças microclimáticas (abertura de dossel, temperatura do ar e umidade do solo), em escala regional. O estudo foi conduzido em cinco fragmentos (escala regional) no Rio de Janeiro, sudeste do Brasil, e em escala local, dentro de um deles. Os organismos dentro dos diferentes fragmentos, em escala regional, foram submetidos a diferentes condições climáticas, e a formação de borda nos fragmentos florestais estimulou mudanças climáticas, de maneira heterogênea. Não apenas a distância das bordas tem influencia nas diferenças microclimáticas. Provávelmente, a idade e localização da borda, a estrutura da matriz, assim como a proximidade de clareiras pode modificar o microclima mesmo entre bordas.

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