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Effects of habitat fragmentation on the spider community (Arachnida, Araneae) in three Atlantic forest remnants in Southeastern Brazil

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Abstract:
This work was developed in three remnants of Atlantic forest in southeastern Brazil. We aimed to assess edge effects in the spider community in a well conserved fragment and to study the variation of spider diversity among fragments of different sizes. The spider families with the highest richness were Theridiidae (38 sp), Araneidae (31 sp) and Salticidae (25 sp). The control area showed the highest diversity (D=0.98*)* and exclusive species (58.9%). We concluded that spider richness is higher in the large and best preserved fragment. In addition, we found that species richness and abundance increased towards the interior.
Key words: Atlantic forest, spiders, diversity, fragmentation and edge effect.

Efectos de la fragmentación de hábitats en la comunidad de arañas (Arachnida, Araneae) de tres remanentes de bosque tropical atlántico en el sudeste brasilero.

Resumen:
Este trabajo fue realizado en tres áreas relictas de bosque tropical atlántico en el sudeste de Brasil. El objetivo fue evaluar el efecto de borde sobre una comunidad de arañas en un área bien conservada, así como la variación en la diversidad de arañas entre fragmentos de diferentes tamaños. Las familias más diversas fueron Theridiidae (38 sp), Araneidae (31 sp) y Salticidae (25 sp). El área control presentó la diversidad más alta (D=0.98) y número de especies exclusivas (58.9%). Se concluyó que la riqueza de especies de arañas es mayor en el fragmento más grande y mejor conservado. Igualmente encontramos que la riqueza y abundancia de especies fueron mayores en el interior del fragmento con respecto al borde.
Palabras clave: Mata Atlántica, arañas, diversidad, fragmentación y efecto de borde.

Introduction

The Brazilian Atlantic forest holds a high number of flora and fauna endemisms and it has been considered a high priority area for biological conservation (*hotspots*) due to its species diversity and richness (Myers *et al.*, 2000). However, as a consequence of deforestation, and human activities, the Atlantic forest today represent less than 7% of its original extension and about 70% of the Brazilian population inhabit this biome threatening its conservation (Tabarelli *et al.*, 2005).

Fragmentation, a mosaic pattern of natural vegetation set in a matrix of land under different types of human use, is currently one of the processes that most contributes to species extinction and loss of biodiversity (Tscharntke *et al.*, 2002). Fragmentation involves the reduction of the amount of habitats, an increase in the number of habitat patches, a decrease in the size of the habitat remnants and an increase in the degree of fragment isolation (review in Fahrig, 2003). Incident light, temperature and humidity influence the richness, distribution and abundance of species inside natural vegetation fragments (Murcia, 1995). Deforestation modifies environmental features and interespecific interactions causing an edge effect in the interface between the forest and the surrounding matrix (Murcia 1995, Horváth *et al* 2002).

Studies have suggested that species richness is positively correlated with fragment size and is influenced by the surrounding matrix, the edge effects and the connectivity with other forest patches (Laurance *et al.*, 2002). Few surveys have analyzed the effects of fragmentation on spider communities considering the effects of edge and patch size (Baldissera *et al.*, 2004). While some studies found an increase in species richness from the interior to the fragment edge (Horváth *et al.,* 2002), others found an increase from the edge to the interior (Cortés & Fágua, 2003; Baldissera *et al.,* 2004). Nogueira (2004) found no relationship between the web spider distribution and fragment size. However, Miyashita *et al.* (1998) found a positive relationship of spider richness with fragment size, while Bolger *et al.* (2000) and Gibb & Hochuli (2002) found a negative correlation between those variables.

Spiders are excellent indicators of habitat disturbance, not only for being animals extremely common in almost all ecosystems, but also for depending on the physiognomy of the landscape for the construction of their webs, and for foraging in the case of the wandering species (Uetz, 1991). Most of them are strictly carnivorous, with some exceptions of alternative use of nectar and pollen (Romero & Vasconcellos-Neto, 2007). Currently the Order Araneae includes 40.024 species distributed in 108 families (Platnick, 2008), being the seventh largest diversity among animal Orders (Coddington & Levi, 1991).

Our work represents a first approach to analyze the edge effect in spiders communities in the Atlantic forest of southeastern Brazil. For the Atlantic forest of Espírito Santo state, few studies with spiders have been carried out so far, including inventories (e.g, Mello-Leitão, 1940; Santos, 1999) and studying some ecological features (Santos, 1999; Romero & Vasconcellos-Neto, 2004). Furthermore, spider studies in Brazil are scarce and it is estimated that about 40-50% of the spider specimens collected in the Neotropics are new species (Coddington & Levi, 1991; Brescovit *et al.*, 2002). In this study, we evaluated the spider richness and abundance of three remnants of Atlantic forest, one well conserved and two disturbed, in order to analyze features such as edge effects and the variation of spider richness among fragments to answer research questions like: (1) are there any differences in species richness and composition among fragments of different size? (2) Are there any differences in species richness and abundance between the edge and the interior of a well conserved fragment?

Material and Methods

STUDY SITE

Field work was carried out in three Atlantic forest remnants in the Central mountain region of Espírito Santo State, located in the city of Santa Teresa (19°57'S, 40°31'W). The study site ranges between 100 and 1.143 m with climate Cwa according to Köppen classification, i.e., humid and mesothermic, with dry winters (June-

August) and rainy summers (December-February). Mean annual temperature is 20°C and annual rainfall ranges from 1300 to 1900 mm. June is the driest month and a small water deficit may take place (Mendes & Padovan, 2000).

The area of Santa Teresa was originally covered by Atlantic forest vegetation, classified as montane and submontane rainforest highly reduced by coffee cultures and Eucalyptus plantation since the decade of 1940 (Mendes & Padovan, 2000). Thereafter efforts of reforestation, conservation and environmental policies enhanced the regeneration of natural vegetation (IPEMA, 2005). Actually, about 33% of the city area is protected and in a well state of conservation (SOS Mata Atlântica & INPE, 2006).

The first disturbed remnant sampled, known as "Nova Valsugana" (NVAL) (19°54'09"S, 40°39'31"W), is a 2-ha fragment located at 648 m of altitude, at a distance of 12 km southeast from the city's downtown. The vegetation patch is dominated by Myrtaceae, Lauraceae and Melastomataceae species in a medium stage of succession. The understorey posses a sparse herbaceous vegetation with Asteraceae as the main component, highly affected by a surrounding matrix of grassland used for raising cattle (cattle use to forage inside the fragment), fact that was used as an important criterion for its inclusion in the present study. The second disturbed remnant, is located inside the "Museu de Biologia Prof. Mello Leitão" (MBML) (19°56'10"S, 40°36'06"W) within the city's downtown. The patch expands for 4.3 ha and ranges from 670 to 750 m in altitude, with a well preserved original forest vegetation dominated by *Tibouchina granulosa* (Melastomataceae) and *Senna macranthera* (Fabaceae). The understorey includes dense vegetation dominated by scandent plants and vines (mainly Passifloraceae, Sapindaceae and Nyctaginacea) (Mendes & Padovan, 2000). This fragment has not been altered extensively for more than 50 years. Nevertheless, it suffers from the influence of a road used to access neighborhood plantations and an adjoining matrix of *Eucalyptus,* as well as the pressure from the city. The last remnant (control) is the "Estação Biológica Santa Lúcia" (ESBL) (19°57'10"S, 40°31'30"W), consisting of a 440-ha area of well protected Atlantic forest, which ranges from 600 to 900 m in altitude (Mendes & Padovan, 2000). The main vegetation includes members of Myrtaceae, dominated by the genus *Eugenia*, followed by *Ocotea* (Lauraceae), *Pouteria* (Sapotaceae) and some Rubiaceae, Melastomataceae, Fabaceae and Arecaceae. The soil at the station is mostly dystrophic, i.e. highly acidic and with a high content in aluminum (for more details see Mendes & Padovan, 2000 and references therein).

SPIDER SAMPLING

Sampling was carried out monthly between April and September of 2005. Field work was planned within the time available for the first author, since this work was part of his monographic dissertation. Thus, unfortunately, no replication could be done. Adult specimens

were identified by specialists and deposited in the spider collection of the Butantan Institute (curator: A.D. Brescovit).

Spiders were sampled in 11 plots, each one of 40 m², totaling 440 m². To evaluate the distribution of spiders from the edge to the core of the fragment, five plots were established in the control area (EBSL), settled at 5, 25, 50, 100 and 150 m. The forest edge was delimited within the first 10 m of forest, where the major changes in vegetation structure and density occur. The forest interior was considered to be at 150 m from the edge.

To compare the spider community in the three fragments we took into account the total species richness and abundance sampled in the five plots of EBSL and in three plots on each disturbed areas (NVAL and MBML) placed at 5, 25 and 50 m from the edge to the interior.

In every plot we collected spiders with two methods, beating-trays during the day and nocturnal hand collecting (modified from Santos, 1999). The nocturnal sampling was done between 21:00 and 22:30 (n = 16.5 hours of sampling), while diurnal sampling was from 10:00 to 12:00 (n = 22 hours of sampling). In each plot we sampled using beating-trays during 2 hours and 1.5 hours using nocturnal hand collecting. Thus, in total, in NVAL and MBML we completed 6 hours of beating-trays and 4.5 hours of nocturnal hand collecting, and in EBSL we completed 10 hours of beating-trays and 7.5 hours of nocturnal hand collecting. Coddington *et al.* (1996) recommended varying collecting methods because it results in a more representative sample of the spider community, allowing to capture spiders species in a wide range of habitats and microhabitats (see Santos, 1999). Therefore, due to limited time and resources, we chose the above sampling methods.

DATA ANALYSIS

Species richness, abundance and diversity were estimated for each study site using the data from the total number plots in each area (EBSL n=5, MBML and NVAL n=3) as described above. Diversity was calculated using the Simpson index ($D = 1 - \Sigma p_i^2$), that ranges from 0 (low diversity) to almost 1 (1-1/s; where s is the number of species in the sample), with observed species richness values (Krebs, 1998), and 95% of confidence for this index was calculated with a bootstrap procedure. The Simpson's index is particularly efficient in detecting dominance but may be affected by sample size (Krebs, 1998). To control the sample size effect, we conducted a Simpson analysis with both an unbalanced and a balanced sampling design (i.e.; excluding the 100 and 150 m plots from the largest, EBSL remnant).

To compare the spider species richness among fragments with an equal sampling effort, species accumulation curves were generated using the method of rarefaction (Simberloff, 1972; Krebs, 1998). For our purpose of comparing species richness we used, in particular, the individual-based rarefaction curves because this method standardizes each of two or more samples on the basis of the number of individuals (Gotelli & Colwell, 2001).

We calculated the expected number of species E (Sn) using the following formula:

$$E(S_n) = \sum_{i=1}^{S} \left[1 - \frac{\binom{N-Ni}{n}}{\binom{N}{n}} \right]$$

where N is the total number of individuals in the sample, S the total number of species, N_i the total number of individuals of species i^{th}, and n the size of the smaller sample (Krebs, 1998). The rarefaction procedure and Simpson analysis were performed using PAST (Hammer *et al.*, 2001).

Results

SPIDER ALFA-DIVERSITY

After 38.5 hours of sampling effort, a total of 2610 specimens, 469 adults (18%) and 2141 young (82%) were collected. In previous studies the number of species in the Santa Teresa county was 29, distributed in 8 families (A.D. Brescovit, *pers. obs.*). We recorded 196 species, distributed in 30 families, increasing the number of species in 675%. Spider families with the highest numbers of species were Theridiidae (38), Araneidae (31), Salticidae (25), Pholcidae (12) and Tetragnathidae (11). Families as Hahniidae and Miturgidae were represented by two species and Amaurobiidae, Anapidae, Dictynidae, Deinopidae, Hersiliidae, Ochyroceratidae, Pisauridae, Scytodidae, Selenopidae, Sicariidae, Synotaxidae and Zodariidae, represented by one. The most abundant species was *Episinus* sp.01 (Theridiidae) with 22 specimens, *Chrysometa* sp.01 (Tetragnathidae) with 20 specimens, *Thwaitesia affinis* Cambridge, 1882 (Theridiidae) and *Dipoena pumicata* Keyserling, 1886 (Theridiidae) with 12 specimens each. In the nocturnal sampling we collected 286 individuals distributed in 132 species (63.4% exclusive species), with beating trays we achieved 196 individuals from 80 species (Table I).

Fifty three percent of species of the biological station (EBSL) were singletons and 23% were doubletons. Likewise, the MBML remnant included 58% of singletons and 17% of doubletons and the NVAL remnant included 58% of singletons and 18% of doubletons (Table I).

EDGE EFFECT IN A WELL CONSERVED FRAGMENT

Figure 1 shows the differences of spider richness and abundance according to the sequence edge-interior in the EBSL fragment. There was substantial variation in species richness and abundance from the edge (5m) to the interior (150m) with a patent increase of the above parameters in the direction of the fragment core (Fig. 1). However, in the first 50 m no substantial differences in spider abundance and richness were recorded.

In the interior of the fragment the richest families were Anapidae, Araneidae, Ctenidae, Deinopidae, Linyphiidae, Miturgidae, Ochyroceratidae, Oonopidae, Sparassidae, Synotaxidae, Theridiosomatidae, Thomisidae
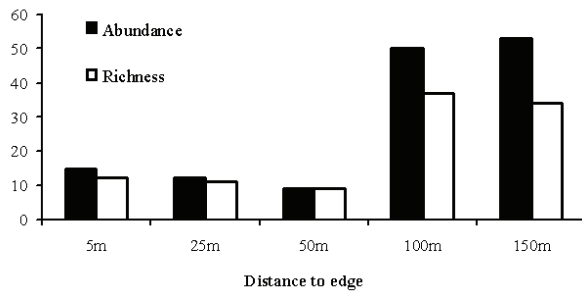
Figure 1 – Changes in abundance and richness of spider species at 5 distances from the edge to the interior in the control area at Estação Biológica Santa Lúcia, Santa Teresa, southeastern Brazil.

near pattern from the largest to the smallest remnant is recorded.

Discussion

Spiders inhabiting fragments with different size and forest edge and or interior in the Atlantic Rainforest respond in different ways to habitat changes specially because they depend on landscape physiognomy for feeding and web construction. Our study show that spider community differs in fragments with different size and state of conservation. Furthermore, edge effect is probably an important factor that affects spider richness and abundance.

and Uloboridae, while in the edge the richest families were Hahniidae, Mimetidae, Pholcidae, Salticidae and Theridiidae (Fig. 2).

SPIDER DIVERSITY AMONG FRAGMENTS
The forest remnant of the biological station (EBSL), revealed the highest diversity index (D=0.982, n=5), followed by the fragment of the MBML (D=0.976, n=3) and the NVAL (D=0.970, n=3) as expected. Moreover, the highest number of exclusive species was found in the EBSL (58.9%), while 44.3% and 38.7% of them were found in the MBML and NVAL, respectively (Table I). Similarly, the rarefaction analysis showed that, at n=75 the EBSL was the richness fragment followed by the MBML and NVAL, as expected (Fig. 3 and Fig. 4). Both for the rarefaction analysis and the expected variation (95% confidence), as well as for the Simpson index, the EBSL was the richest fragment followed by MBML and NVAL. Nonetheless, no significant differences were found between MBML and NVAL in observed richness using the Simpson index (Fig. 4) in the unbalanced sampling design. Similarly, when we excluded the plots 100 and 150 m of EBSL (i.e., the balanced sampling design), the same pattern was observed (Fig. 5). However, a decreasing clear li-

SPIDER SPECIES COMPOSITION IN THE ATLANTIC FOREST
The data set as a whole shows that Theridiidae, Araneidae and Salticidae were the richest and most abundant families. Several studies have found similar results (e.g., Silva & Coddington, 1996; Santos, 1999; Scharff *et al.*, 2003) using different methods such as beating-trays, pitfall traps, Berlese funnels and day and nocturne hand collecting. These similar patterns for different biomes (e.g., Amazonian forest, Atlantic forest and temperate deciduous forests) seem interesting because of their distinct environmental traits.

The family Araneidae, belongs to the guild of orb weavers and is commonly found in a range of microhabitats from litter to canopy. Salticidae, in the stalkers guild, can be also found in several microhabitats especially during the day (Silva & Coddington, 1996), frequently foraging on the vegetation and litter (Rego, 2003). Theridiidae, classified in the guild of space web builders, is a family with a wide niche variation as solitary hunters, colonies and orb weaver kleptoparasits, and also occupy different microhabitats (for more details in spider guild structure see Uetz *et al.*, 1999). The above patterns suggest that Araneidae, Salticidae and Theridiidae are the most abundant and diverse because they occupy several niches and microhabitats.
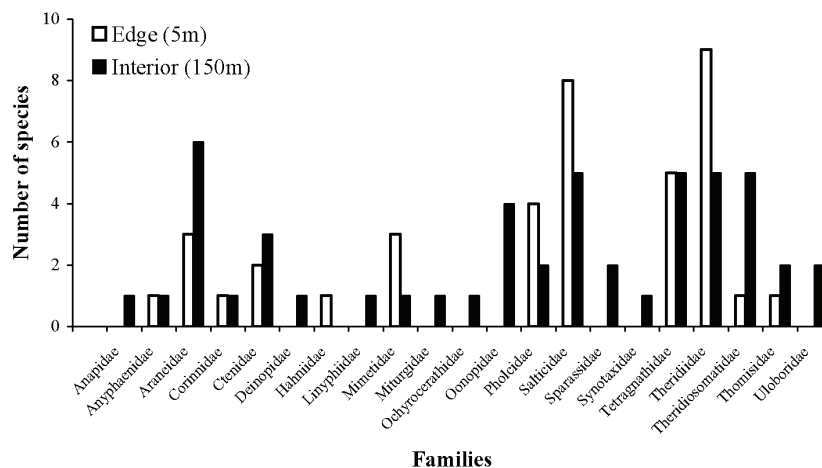
Figure 2 – Number of species per family found in the edge (5m) and interior (150m) at the "Estação Biológica Santa Lúcia".
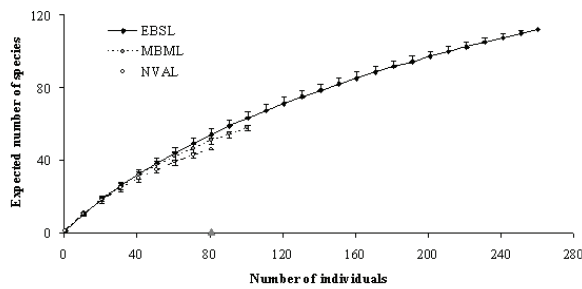
Figure 3 – Individual-based rarefaction curves for the expected number of species for "Estação Biológica Santa Lúcia (EBSL)", "Museu de Biologia Mello Leitão (MBML)" and "Nova Valsugana (NVAL)".
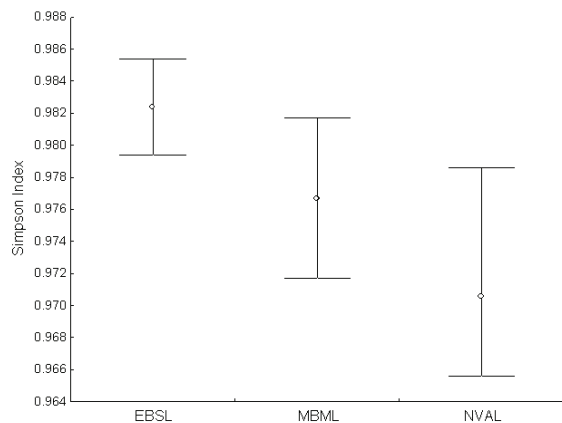
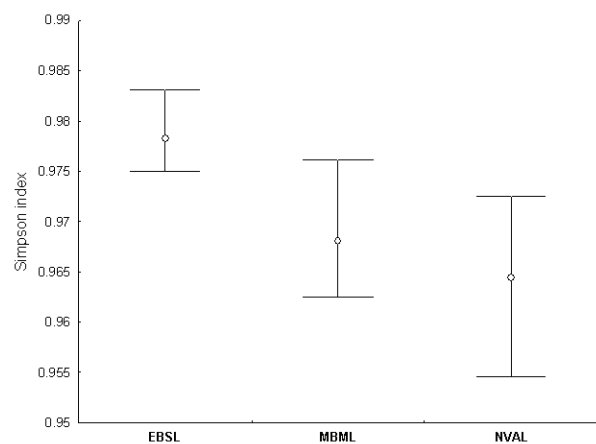
Figure 4 – Simpon index (unbalanced sampling design; i.e., including plots at 100 and 150 m for EBSL) for "Estação Biológica Santa Lúcia (EBSL)", "Museu de Biologia Mello Leitão (MBML)" and "Nova Valsugana (NVAL)". Error bars represent 95% confidence intervals. Non-overlapping error bars indicate significant differences. There is clear linear pattern from the largest (left) to smallest (right) remnant.

As other researches have shown (e.g., Coddington *et al.*, 1991; Silva & Coddington, 1996; Santos, 1999; Scharff *et al.*, 2003), nocturnal collection resulted in estimates of higher spider species richness and abundance, perhaps due to the higher effectiveness of the visual methods (Santos, 1999). Moreover the use of the two chosen methods enhanced the efficiency of our sampling effort and allowed us to collect hunting (i.e., ground and foliage runners) and web building spiders. The families Anapidae, Ctenidae, Deinopidae, Hahniidae, Miturgidae, Ochyroceratidae, Pisauridae and Synotaxidae were only found at the EBSL. This may be explained as an influence of the sampling effort (Rego, 2003) or by their specific micro-environmental requirements such as shady microhabitats, close vegetation as a protection against predators (Santos, 1999), temperature, humidity and light intensity (Foelix, 1996).

The higher richness of the spider community found in the control area relative to the disturbed ones are probably due to the size of the area, as suggested by

Greenstone (1984) and Santos (1999), because large areas hold more microhabitats. Nevertheless, the vegetation structure as well as the continuing pressure factors could explain our findings. In fact, in "Nova Valsugana" cattle use the fragment to foraged affecting the understorey vegetation and litter, probably modifying the structural composition of the microhabitats (Uetz, 1979; Bromham *et al.*, 1999; Borges & Brown, 2001). In the second fragment (MBML) illegal hunting activities, wood extraction and proximity with an urban center are the possible factors influencing the microhabitat structure and similarly, the spider richness (Guariguata & Ostertag, 2001; see Santos & Tabarelli, 2002).

The higher spider richness and abundance recorded in the ESBL suggested that area size do have a role in the increase of the diversity of the patch. Miyashita *et al.* (1998) for orb weaver spiders and Rego (2003) for the families Ctenidae, Pisauridae and Salticidae, found a positive correlation between richness and size area. On the other hand, Bolger *et al.* (2000) recorded a negative correlation, and they attributed these patterns to the higher abundance of non-native species (e.g., Argentine ants) in smaller remnants. Furthermore, Nogueira (2004) did not find a significant relationship between the richness of orb-weavers and area size, and he attributed the absence of correlation to the high connectivity between his sampled areas. Even though we have not tested the effects of bird predation on the spider community, an alternative explanation to the lower richness in the small remants could be attributed to intense predation by birds. Gunnarsson (2007) reviewed studies about bird predation on spiders and summarized experimental results at the community level. He concluded that bird predation often reduced spider densities. Since there is a positive relationship between density and richness (as it is higher in the EBSL fragment), we should expect bird predation to also reduce species richness.

Figure 5 – Simpon index (balanced sampling design; i.e., excluding plots at 100 and 150m for EBSL) for "Estação Biológica Santa Lúcia (EBSL)", "Museu de Biologia Mello Leitão (MBML)" and "Nova Valsugana (NVAL) . Error bars represent 95% confidence intervals. Non-overlapping error bars indicate significant differences. There is clear linear pattern from the largest (left) to smallest (right) remnant.

Although we have surveyed more plots in the EBSL remnant, the highest number of exclusive species recorded in the control protected area (EBSL, Table I), may be related to the structural variation of the environment, as discussed by Greenstone (1984), McNett & Rypstra (2000), and Halaj *et al.* (2000), or a decrease in the edge effect (Didham, 1997). A lower quantity of exclusive species in small fragmented areas, such as NVAL and MBML, may be the consequence of pressures associated with fragmentation such as anthropogenic disturbances, isolation, loss of microhabitats, increase of temperature and/or luminosity (Foelix, 1996; Myashita *et al.*, 1998; Gibb & Hochuli, 2002).

Our results suggest that the variety of microhabitats occupied by Araneidae, Salticidae and Theridiidae makes them to be the most diverse families in the study sites. Similarly, because they use resources in similar ways, other families belonging to the same guilds may respond in similar ways to the effects of fragmentation. Fragmentation an impoverishment of plant diversity in the edge (Oliveira *et al.*, 2004), could lead to a decrease in the number of sites for spider web construction, resulting in lower spider richness (Santos 1999), unless fragmentation could favor spider families with preferences for sunny places.

SPIDERS IN THE EDGE AND INTERIOR OF THE FRAGMENT
We found variation in spider richness and abundance between the edge and the core of the studied fragment. It seems that edge effects do affect the spider community abundance and richness along the gradient from the border to the interior of the fragment, resulting in a lower number of individuals and species found in the edge. Our data indicate that an edge effect probably affects the spider community up to 50 m. In some studies with biotic and abiotic data, edge effects disappear at 50 m (Murcia, 1995). Nonetheless, Kapos (1989) shows that microclimatic changes near the edge, such as increase of light, temperature variability, and decrease of humidity could penetrate up to 60 m into the fragment interior.

Salticidae and Theridiidae were the most abundant families found in the edge. Salticidae is characterized by its visual acuity (Rego, 2003) and preference for sunny places (Romero & Vasconcellos-Neto, 2005a), thus, inhabiting edge habitats enhance the possibility of finding more food, sexual partners and shelters in brighter sites (Romero & Vasconcellos-Neto, 2004; Romero & Vasconcellos-Neto, 2005b). The Theridiidae are known to occupy a wide variety of niches (Silva & Coddington, 1996) which probably explains its presence in microhabitats such as the edge.

Previous studies correlating edge effects and spiders, presented conspicuous differences, probably due to employed methods, divergences in niche diversity (Murcia, 1995) or habitat structure (Greenstone, 1984). Like Cortés & Fágua (2003) our findings in the ESBL reveal an increase in species richness and abundance from the edge to the interior of the fragment. Horváth *et al.* (2002) describe a decreasing pattern and Gunnarsson (1988) did not find any difference at all. These diverse responses may result from either differential changes in the physical environment at the edge relative to the interior, as explained by Murcia (1995), or due to differences in the seasons in which the studies were carried out (Baldissera *et al.*, 2004). Furthermore, invertebrate responses to fragmentation vary often in a species-specific way (Didham, 1997) changing according to the biological level (Ribas *et al.*, 2005).

We conclude that edge effects and fragmentation processes influence the composition of spider community in our study site, although further replications will contribute to refine the patterns described here. The spiders seem to be a potential good taxon to evaluate edge effects and fragmentation in the Atlantic rainforest because they depend on the vegetation structure to attache their webs. Spiders could be also a functional group for understanding the influence of habitat modification (e.g., plant architecture, density) in the structure and organization of communities. We suggest that more accurate studies within guilds and niches should be done to improve our knowledge about the organization of spider communities, especially in highly diverse families.

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Table I -

Number of families, species, exclusive species, diversity index and abundance in "Estação Biológica Santa Lúcia", Museu de Biologia Mello Leitão" and "Nova Valsugana" (NVAL), and differences between the two collecting methods. Percentages of exclusive species for each sampled area and sampling method are shown in parentheses.

		Families	Species	Exclusive species (%)	Singletons	Doubletons	Abundance	Simpson index (D)
Area	EBSL	21	112	66 (58.9)	59	26	260	0.98
	MBML	16	60	26 (43.3)	35	10	108	0.97
	NVAL	11	45	17 (37.7)	26	8	81	0.97
Surveying methods	Beating trays	16	80	35 (43.7)	-	-	196	-
	Nocturnal collection	19	132	78 (63.4)	-	-	286	-