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# Galling insects as bioindicators of land restoration in an area of Brazilian Atlantic Forest

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**Abstract**
Galling insects may represent an excellent tool to evaluate habitat quality and restoration. We used galling insect species richness to evaluate the success of a project on reforestation in an Atlantic Forest area in southeastern Brazil. We selected 18 study sites from three distinct environments under succession: early stage (3-5 years old abandoned pasture), intermediate stage (10-15 years old), and intermediate stage sites under *Myracrodruon urundeuva* trees (10-15 years old). The highest galling species richness was found in the intermediate stage sites, followed by areas of early stages, while intermediate sites under *M. urundeuva* trees supported the lowest richness. The significant difference between areas under *M. urundeuva* and the other two suggests that this plant negatively impacts the plant community. Personal observations suggest an allelopathic activity of *M. urundeuva*, decreasing native species establishment, consequently reducing associated herbivore richness. Our results indicate that galling species were efficient tools to evaluate environmental quality in a degraded area of Atlantic Forest.

**Keywords:** bioindicators, degraded area, insect galls, restoration ecology.

## Introduction

Studies addressing the richness of galling insects have been increasing astonishingly, perhaps owing to the many advantages in their usage in elucidating ecological and environmental differences among habitats (e.g., Gonçalves-Alvim & Fernandes, 2001; McGeoch & Chown, 1997a; Fernandes et al., 1995; Fernandes & Price, 1988; 1992; Julião et al., 2005). On the other hand, the importance of galling insects in programs of conservation and environmental impact has not been fully explored (Roech *et al.* 2001). Advantages in the use of this guild of herbivorous insects in monitoring studies are clear because of their extreme specificity with their host plants (e.g., Floate et al., 1996), and their strong response to habitat change (e.g., McGeoch & Chown, 1997b; Fernandes et al., 2005; Julião et al., 2005). Furthermore, there is a relatively good taxonomic knowledge in this guild as each gall is species-specific, they are ecologically diverse, and their sessile habitat during the larval phase facilitates field sampling (Fernandes & Price, 1988; Gonçalves-Alvim & Fernandes, 2001; Fernandes et al., 2001; Cuevas-Reyes et al., 2003). The use of galling species to evaluate ecosystems process restoration may increase the quality of the analyses as this herbivore guild is highly influenced by abiotic factors such as humidity and soil quality. Not surprisingly, Price et al. (2004) suggested the use of galling insects to test broad ecological concepts.

The Brazilian Atlantic Forest is considered a biodiversity hotspot given its high levels of biodiversity and endemism under severe threat (Myers et al., 2000). Less than 100,000 km$^2$, or about 7% of its forest remains (Tabarelli et al., 2005) and occurs mostly in isolated remnants scattered throughout a landscape dominated by agriculture. The city of Aimorés, in Minas Gerais state, southeastern Brazil, was not long ago covered by a luxuriant Atlantic Forest, which was logged for timber and later mostly transformed into pastureland. The forest destruction was accelerated by the construction of the Vitória-Minas railway that added more environmental disturbance due to the high demand for firewood and fires caused by sparks thrown out by locomotives. The loss of forest cover has been most fast and severe in the past two decades leaving only fragments of the original Atlantic Forest (Instituto Terra, 2001).

In an effort to provide input into land restoration in Atlantic Forest, the Instituto Terra has been using native seedlings in the restoration of an experimental farm, Fazenda Bulcão (Instituto Terra, 2001). Before the reforestation project began, Fernandes & Negreiros (2006) evaluated the richness of galling species in the farm in 2001 in an attempt to provide follow-up studies using this insect herbivore guild as an indicator of habitat restoration and quality. They reported that the community of galling insects was very poor but argued that the result should be expected given the degree of forest destruction in the area. In

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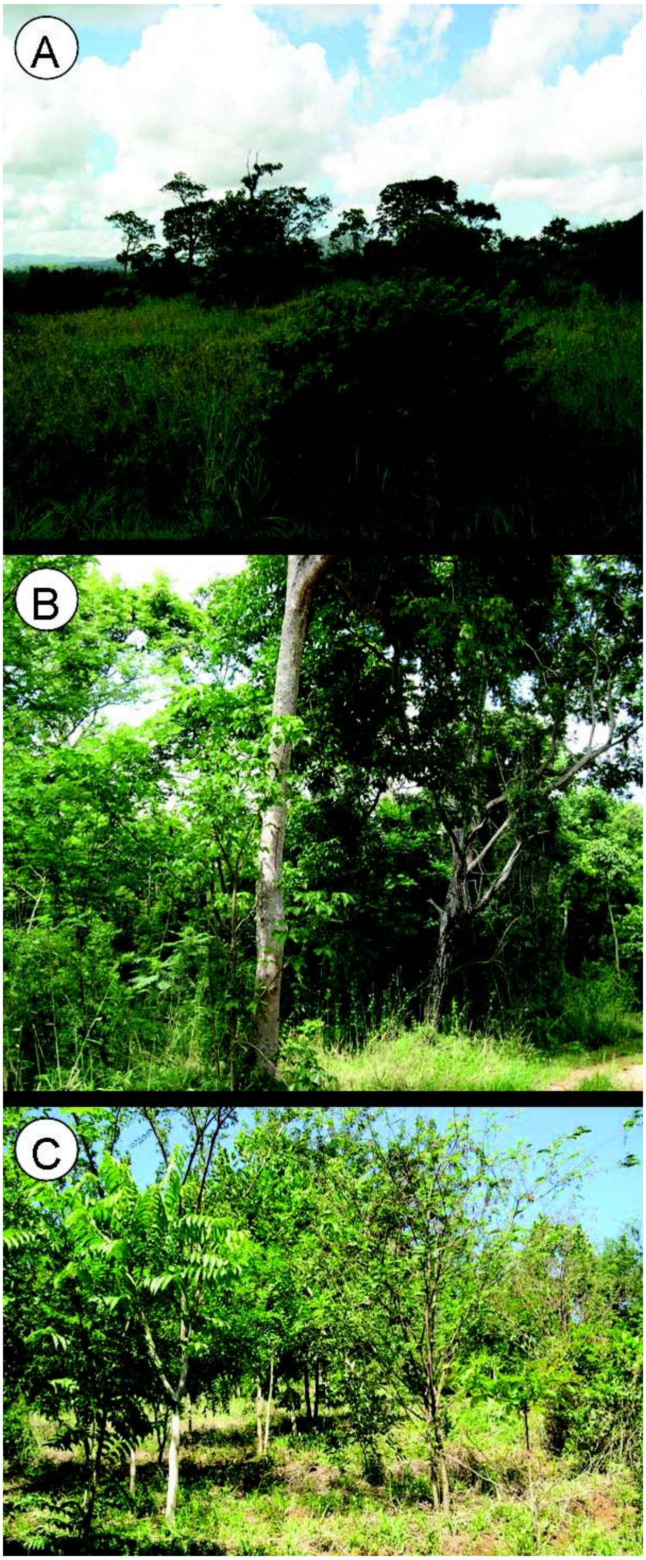



**Figure 1 -** Succession stage areas on 2004 at the Bulcão Farm, Aimorés, Minas Gerais, Brazil. a) early succession (abandoned pasture); b) intermediate succession; c) intermediate succession under *M. urundeuva* dominance.

this study, we report on the richness of galling insects in the experimental farm, five years after the restoration project had started. Furthermore, we aimed to evaluate the differences of galling species richness between areas of three distinct environments easily observed in the farm: early succession (abandoned pasture), intermediate succession, and intermediate succession under the native but now invasive tree species *Myracrodruon urundeuva* (Anacardiaceae). We expected greater richness of galling insects at sites at intermediate succession stages due to several better habitat conditions, including higher diversity of potential host plants.

## Material and methods

This study was conducted in the private reserve named Reserva Particular do Patrimônio Natural Bulcão (RPPN Bulcão), that is managed by the Instituto Terra in Aimorés, Minas Gerais state, Brazil, between March and November 2004. It represents the first biological reserve created in a degraded area of Atlantic Forest in Brazil (Instituto Terra, 2001) with the aim of restoring native forest. The soil is compact, with low organic matter and several erosion foci. Besides the progressive reduction in outflow of water sources, the incorrect area management has caused local extinction of many species of the fauna and flora (Instituto Terra, 2001). According to the Köppen classification the weather is Aw, with rainy summers, dry winter and at least one month with less than 60mm precipitation (Instituto Terra, 2001).

The three most common succession habitats found in the farm were studied (Fig. 1): i) four sites of early stage (3-5 years old abandoned pasture dominated by herbaceous species with scattered trees and shrubs); ii) six sites of intermediate stage (10-15 years old areas dominated by shrubs and trees of several ages -including those enriched with native species in the reforestation process), and iii) eight sites of intermediate stage dominated by

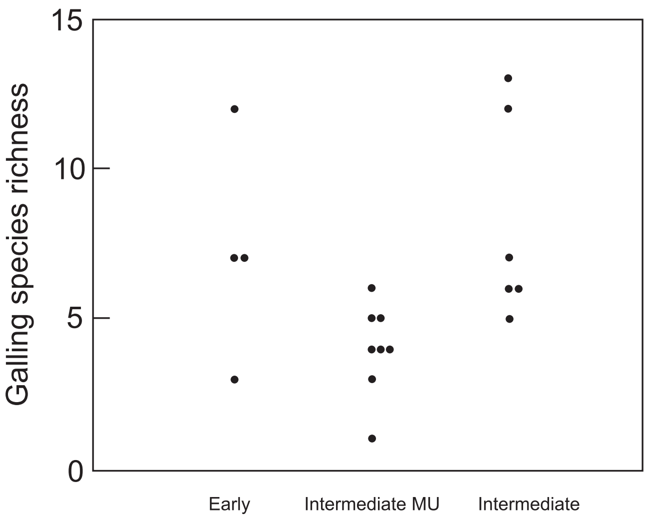
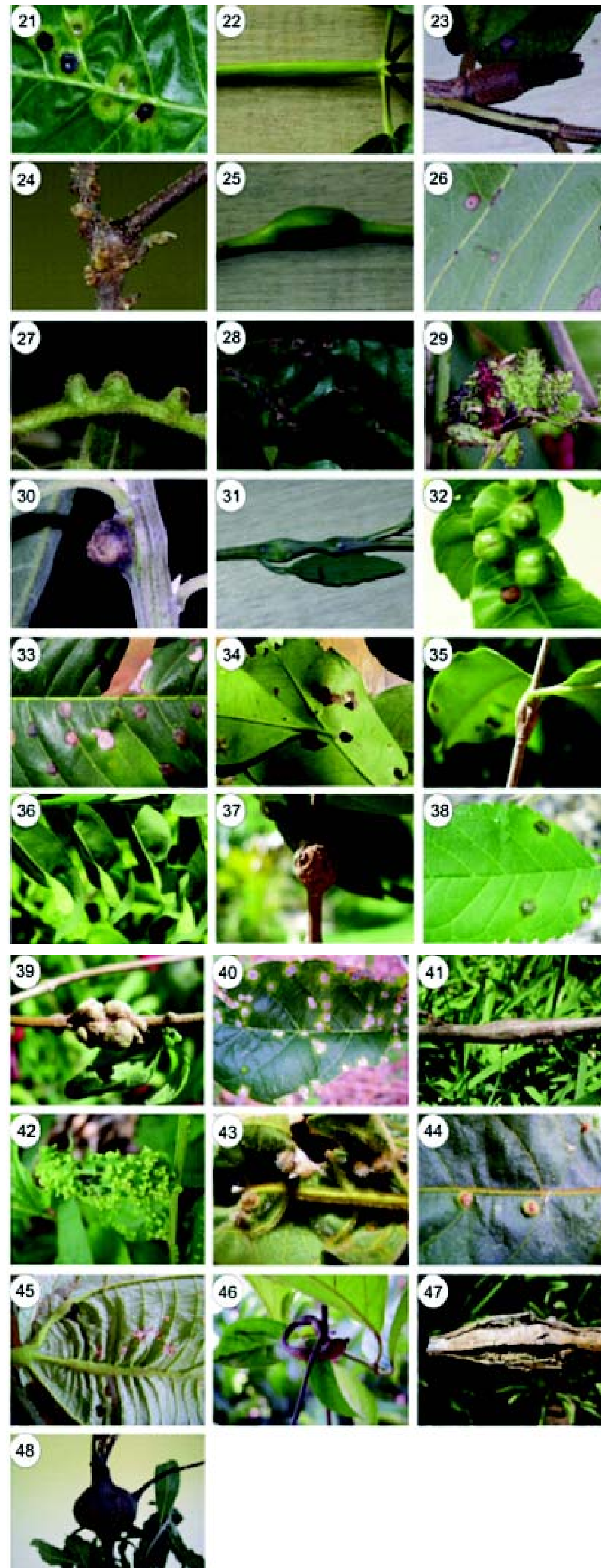



**Figure 2 -** Galling species richness per site in three different restored areas of Atlantic Forest in Aimorés, Minas Gerais, Brazil. Early (early succession); Intermediate MU (intermediate succession under *M. urundeuva* dominance); Intermediate (intermediate succession).

**Figures 3 - 48 -** Galling insect morphospecies in restored areas of Atlantic Forest in Aimorés, Minas Gerais, Brazil. For plant identification see Table 1.



the native but invasive species *Myracrodruon urundeuva* (Anacardiaceae). In these areas - shrubs and other tree species were less common because of the dominance and perhaps allelopatic effect of *M. urundeuva*.

In each site, galling insects were sampled by two people following the methodology of 60 minutes random walking (see Julião et al., 2002; Fernandes & Negreiros, 2006). To avoid pseudo-replication inside the areas, a distance of at least 300m were established among the sites sampled (Fernandes & Price, 1988). Every gall and host plants (up to 3 meters height) found were collected, packed in plastic bags, and then taken to a laboratory for photographic registration and description of the external morphology. Host plants were classified in to morphospecies in the field, and later at the species level. In general, each species of insect induce a gall on a specific tissue of a certain plant species (Dreger-Jauffret & Shorthouse, 1992; Floate et al., 1996). Therefore, galls were characterized as reported by Fernandes et al. (1988): presence or absence of trichomes, type

**Table 1 -** Galling insect morphospecies and host plants found at Bulcão Farm in the wet season (March) and dry season (November) of 2004.
Pub. – Pubescense, ES - Early Succession, IS - Intermediary Succession, MU - Under *M. urundeuva* dominance, Fig. – Figure.

| Family | Species | Gall | Shape | Color | Tissue/side | Pub. | Chambers | Galler | ES | | IS | | MU | | Fig. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Wet | Dry | Wet | Dry | Wet | Dry | |
| Anacardiaceae | *Anacardium occidentale* L. | 1 | Conical | Yellow | Leaf, adaxial | No | 1 | Cecidomyiidae | | | | | X | | 8 |
| | *Myracrodruon urundeuva* All. | 1 | Discoid | Green | Leaf, both | No | 1 | Cecidomyiidae | | | | X | | | – |
| Asteraceae | *Vernonia polyanthes* Less | 1 | Amorphous | Green | Leaf, shoot | No | 1 | Cecidomyiidae | X | X | X | X | X | | 7 |
| | | 2 | Globoid | Green | Stem | No | 1 | Cecidomyiidae | | X | X | X | | | 30 |
| | | 3 | Globoid | Green | Stem | No | >1 | Tephritidae | | | | X | | | 48 |
| | *Vernonia* sp. 1 | 1 | Conical | Green | Leaf | No | 1 | Not identified | | X | | X | | | 42 |
| | | 2 | Elliptical | Green | Stem | No | 1 | Coleoptera | | X | | | | | – |
| | Sp. 1 | 1 | Globoid | Green | Stem | No | 1 | Cecidomyiidae | | X | | | | X | 39 |
| | Sp. 2 | 1 | Elliptical | Green | Stem | No | 1 | Cecidomyiidae | | | X | | | | 31 |
| Bignoniaceae | *Arrabidae chica* (H. & B.) Verlot | 1 | Cylindrical | Green | Leaf, both | Yes | 1 | Cecidomyiidae | X | X | | X | | | 29 |
| | | 2 | Elliptical | Brown | Stem | No | >1 | Cecidomyiidae | X | | X | | | | 47 |
| | *Tabebuia chrysotricha* Mart. | 1 | Amorphous | Brown | Leaf, shoot | Yes | – | Cecidomyiidae | X | | X | | X | X | 6 |
| | Sp. 1 | 1 | Elliptical | Brown | Stem | No | 1 | Cecidomyiidae | | | X | | | | 13 |
| | | 2 | Conical | Green | Leaf, adaxial | Yes | 1 | Cecidomyiidae | | | X | | | | 14 |
| | | 3 | Globoid | Green | Stem | No | 1 | Lepidoptera | X | | | | | | 25 |
| | Sp. 2 | 1 | Elliptical | Brown | Gavin | No | 1 | Cecidomyiidae | | X | | | | | 46 |
| Bombacaceae | Sp. 1 | 1 | Discoid | Green | Leaf, Both | No | 1 | Cecidomyiidae | X | | X | | | | 21 |
| | Sp. 1 | 2 | Elliptical | Green | Petiolo | No | 1 | Lepidoptera | X | | | | | | 22 |
| Boraginaceae | *Cordia* sp. | 1 | Discoid | Green | Leaf | No | 1 | Cecidomyiidae | | | X | | | | 40 |
| Euphorbiaceae | *Manihot* sp. | 1 | Cylindrical | Green | Leaf, adaxial | No | 1 | Cecidomyiidae | X | X | X | | | | 10 |
| Lecythidaceae | *Lecytes lurida* Miers | 1 | Discoid | Green | Leaf | No | 1 | Cecidomyiidae | | | | X | | | 33 |
| Fabaceae | *Acacia polyphylla* D.C. | 1 | Elliptical | Brown | Stem | No | >1 | Cecidomyiidae | | | | | X | X | 16 |
| | *Acosmium cardenasii* H.S. Irwin & Arroyo | 1 | Flattened | Green | Leaf | No | 1 | Cecidomyiidae | | | | X | X | | 17 |
| | *Dalbergia nigra* Benth. | 1 | Discoid | Green | Leaf | No | 1 | Cecidomyiidae | | | | X | | | – |
| | *Dalbergia* sp. | 1 | Conical | Green | Leaf, adaxial | No | 1 | Cecidomyiidae | | | X | | | | 11 |
| | *Machaerium fulvo-nervis* | 1 | Discoid | Green | Leaf | No | 1 | Cecidomyiidae | | | | X | | | 36 |
| | *Machaerium* sp. 2 | 1 | Elliptical | Brown | Stem | No | 1 | Cecidomyiidae | | | | X | | | 41 |
| | *Mimosa* sp. | 1 | Amorphous | Green | Leaf, shoot | No | >1 | Cecidomyiidae | | | X | X | | | 18 |
| | *Stylosanthes* sp. | 1 | Globoid | Brown | Stem | No | 1 | Not identified | | | | X | X | X | 5 |
| Malpighiaceae | Sp. 1 | 1 | Spheral | Green | Leaf, abaxial | Yes | 1 | Cecidomyiidae | | X | | | | | 43 |
| | | 2 | Cylindrical | Green | Leaf, adaxial | Yes | 1 | Cecidomyiidae | | X | | | | | 44 |
| Moraceae | *Maclura tinctoria* L. | 1 | Discoid | Green | Leaf, both | No | 1 | Cecidomyiidae | | | | | | X | 38 |
| Myrtaceae | *Myrcia itambensis* O. Berg. | 1 | Cylindrical | Green | Leaf, adaxial | No | 1 | Cecidomyiidae | | | | X | | | 34 |
| | | 2 | Elliptical | Brown | Stem | No | 1 | Cecidomyiidae | | | | X | | | 35 |
| | *Psidium guajava* L. | 1 | Globoid | Brown | Stem | No | >1 | Hymenoptera | | | | | | X | 37 |
| Nyctaginaceae | *Bougainvillea praeox* | 1 | Cylindrical | Green | Leaf, both | No | 1 | Cecidomyiidae | X | X | | X | X | X | 9 |
| Sterculiaceae | *Waltheria indica* L. | 1 | Conical | Yellow | Leaf, adaxial | Yes | 1 | Cecidomyiidae | X | X | X | X | X | X | 3 |
| Tiliaceae | *Luehea grandiflora* Mart. | 1 | Elliptical | Green | Leaf | No | 1 | Cecidomyiidae | | X | | | | | 45 |
| | | 2 | Elliptical | Brown | Stem | No | 1 | Lepidoptera | X | X | | | | | 23 |
| Verbenaceae | *Lantana camara* L. | 1 | Conical | Green | Leaf, adaxial | Yes | 1 | Cecidomyiidae | | | X | X | | X | 15 |
| Not identified | Sp. 1 | 1 | Globoid | Green | Stem | No | >1 | Cecidomyiidae | | | | | X | | 4 |
| | Sp. 2 | 1 | Spheral | Green | Leaf, adaxial | No | 1 | Cecidomyiidae | | | X | | | | 12 |
| | Sp. 3 | 1 | Elliptical | Brown | Stem | No | 1 | Cecidomyiidae | | | X | | | | – |
| | Sp. 4 | 1 | Conical | Green | Leaf, both | No | 1 | Cecidomyiidae | | | X | | | | 19 |
| | Sp. 5 | 1 | Spheral | Green | Leaf, adaxial | Yes | 1 | Cecidomyiidae | X | | | | | | 20 |
| | Sp. 6 | 1 | Globoid | Brown | Stem | No | – | Not identified | X | | | | | | 24 |
| | Sp. 7 | 1 | Discoid | Brown | Leaf, adaxial | No | 1 | Cecidomyiidae | X | | | | | | 26 |
| | Sp. 8 | 1 | Conical | Green | Petiole | Yes | 1 | Cecidomyiidae | X | | | | | | 27 |
| | Sp. 9 | 1 | Globoid | Green | Leaf, both | No | 1 | Cecidomyiidae | X | | | | | | 28 |
| | Sp. 10 | 1 | Spheral | Green | Leaf, adaxial | No | 1 | Cecidomyiidae | | | X | | | | 32 |

of occurrence on the host organ (isolated or grouped), color, shape, host tissue attacked, and host plant. The use of morphospecies to represent the galling species richness has been used in some studies (Price et al., 1998; Cuevas-Reyes et al., 2004). To compare the richness of galling species among the three habitat types, we used the Kruskal-Wallis test because the data did not present a normal distribution (Wilkinson, 1999).

## Results

The richness of galling insects differed statistically among all three habitats of different succession ages (Kruskal-Wallis $H = 7.636$, $p = 0.022$, Fig. 2). Figure 2 shows a dot-plot graphic, in which each point represents the number of galling species richness in each site sampled. The most speciose habitats were those at intermediate succession. Twenty six species of host plants and 31 galling insect morphospecies were recorded in this habitat. Early succession habitats (abandoned pasture areas) supported 18 species of host plants and 24 galling insect morphospecies, while intermediate succession habitats under *M. urundeuva* trees supported only 13 species of plants and 13 galling insect morphospecies. The richest galling fauna was found in the families Fabaceae (eight galling species), Asteraceae, and Bignoniaceae (both with four galling species each) (Fig. 3 – 48).

Most species of galling insects were exclusive to some habitats. We found 13, 18, and 5 galling insect morphospecies exclusively in the early succession, intermediate succession, and intermediate stage under *M. urundeuva*, respectively (Table 1). Only four galling insect morphospecies occurred in all three studied habitats, namely, the gall inducing insects on *Vernonia polyanthes*, *Tabebuia chrysotricha*, *Bougainvillea praeox,* and *Waltheria indica* (Table 1). Six galling insect morphospecies were common to both early succession and intermediate succession while one galling insect morphospecies was common to both early succession and intermediate stage under *M. urundeuva*. Three galling insect morphospecies were common to both intermediate succession and intermediate stage under *M. urundeuva* (see Table 1). The numbers of galling species recorded in the wet and dry seasons were similar, but the morphospecies were not the same. Despite the record of 33 galling species in the wet season, only 20 morphospecies were exclusively found in this period. During the dry season, we recorded 30 galling insect morphospecies, of which 17 were found only in this period (Table 1).

Approximately 88% of the galls were induced by flies (Diptera: Cecidomyiidae). Among the 50 galling morphospecies found, approximately 66% were induced on leaves while the remaining 34% were induced on stems (Table 1). Most galls were of elliptical shape (24%), followed by globoid (18%), discoid and conical (16%), and cylindrical (10%). *Vernonia polyanthes* and an unidentified species of Bignoniaceae (Bignoniaceae sp. 1) were the host plants that supported the largest number of galling species, each one with three galling morphospecies.

## Discussion

Studies on galling insect communities are still rare in the Brazilian Atlantic Forest, notwithstanding the diversity of galling insects in this Neotropical biome. Only two studies could be found in a literature survey about galling insect in the Atlantic Forest and associated ecosystems. Fernandes et al. (2001) evaluated galling species richness in the Rio Doce basin, while Maia et al. (2001) studied gall richness in three areas of "restinga" in Rio de Janeiro. The richness of galling species in our study in a restored area was much lower when compared to the native area of Rio Doce Valley with 273 galling morphospecies. Except for the galls found on *V. polyanthes, T. chrysotricha,* and *L. camara*, all galling morphospecies recorded here may represent new species yet to be described. For instance, the first galling adult reared represented a new genus and new species of Cecidomyiidae (Diptera) (see Maia & Fernandes, 2005).

The decrease in galling species richness towards sites of intermediate succession under *M. urundeuva* dominance can be explained by the diminished habitat complexity and host plants richness. Habitats under the influence of *M. urundeuva* were remarkably less diverse in plant species (G. W. Fernandes, unpub. data) probably because of allelopathic effects of *M. urundeuva*. The most species-rich habitats were those at intermediate succession, while habitats at early succession showed an intermediate number of galling species. Otherwise, detailed studies must be performed to evaluate *M. urundeuva* effects on the flora and associated fauna in habitats under its dominance. If *M. urundeuva* represents a threat to the conservation of biodiversity it is ought to be studied in more detail in the future as it seems to be spreading to the entire region.

Many recent studies have shown that communities at intermediate succession stages are more speciose than communities at climax (Kessler, 1999; Molino & Sabatier, 2003; Sheil & Burslem, 2003; Tsai et al., 2006). The mechanisms responsible for such trend may be related to competitive exclusion events (see Connell, 1979). Although we did not gather such data, the higher richness of galling insects at the intermediate succession stage may be related to the rich flora. For instance, Fernandes (1992) and Gonçalves-Alvim et al. (2001) have reported on the importance of plant species richness for the patterns in galling species richness and distribution.

An increase of 66% in the richness of galling species was observed since the study of Fernandes and Negreiros (2006) performed in the same area five years before our study. We suggest that the community of galling species become richer with habitat succession due to the increased number of host plants and habitat complexity (see Oyama, 2003). Although our results must be viewed with caution, given the defaunated nature of the habitats studied, the use of galls as indicators of habitat recovery was positive and promising as it may prove to be another important tool to understand the restoration mechanisms in the Atlantic Forest.

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