ANDRÉ LUIZ BATISTA TAVARES

LOCAL AND LANDSCAPE PROSPECTS FOR DUNG BEETLE CONSERVATION IN TROPICAL FRAGMENTED LANDSCAPES: AN ATLANTIC FOREST ESSAY

LAVRAS – MG
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Prof. Dr. Júlio Louzada
Orientador

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ANDRÉ LUIZ BATISTA TAVARES

LOCAL AND LANDSCAPE PROSPECTS FOR THE DUNG BEETLE CONSERVATION IN TROPICAL FRAGMENTED LANDSCAPES: AN ATLANTIC FOREST ESSAY

PERSPECTIVAS LOCAIS E DE PAISAGEM PARA A CONSERVAÇÃO DE BESOUROS ROLA-BOSTA EM PAISAGENS FRAGMENTADAS: UM ESTUDO SOBRE A MATA ATLÂNTICA

Tese apresentada à Universidade Federal de Lavras, como parte das exigências do Programa de Pós-Graduação em Entomologia, área de concentração em Entomologia, para a obtenção do título de Doutor.

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RESUMO

Perda de habitat e as mudanças no uso do solo são umas das grandes ameaças a biodiversidade em paisagens tropicais. Por conta disso, é importante investigar qual a influência que esses ecossistemas modificados têm sobre a diversidade nativa. Ainda, esses efeitos devem ser avaliados em diferentes escalas, uma vez que escalas diferentes trazem novas informações para estabelecimento de estratégias de conservação. Essa tese teve como objetivo avaliar em escala local e de paisagem os efeitos que as mudanças do uso da terra apresentam sobre as comunidades de besouros rola-bosta na região do domínio Mata Atlântica. No primeiro capítulo nós investigamos em escala local quais ecossistemas modificados podem ajudar na conservação de espécies nativas e se o nível de modificação interfere no valor de conservação. Nós encontramos que plantações de eucalipto tem um maior valor de conservação do que pastos para espécies, e, que sua condição de ecossistema híbrido permite que esse valor de conservação seja aprimorado, caso esse ecossistema seja devidamente manejado com fins conservacionistas. Já no segundo capítulo, usando de uma abordagem de paisagem, nós vimos que besouros rola-bostas florestais são mais sensíveis a perda de habitat que besouros tipicamente encontrados em áreas de pastagens. Encontramos também que a heterogeneidade da paisagem pode influenciar positivamente a abundância desses insetos nas florestas. Os besouros coletados em pastos não responderam as variáveis de paisagem, evidenciando que essa comunidade pode ser mais influenciada em escala local ou por hipóteses biogeográficas. Com esses resultados concluímos que besouros rola-bosta são um excelente grupo para testar questões relacionadas a conservação em escalas locais e de paisagem. Também evidenciamos que os remanescentes de floresta nativa têm valor incomparável e insubstituível na conservação da biodiversidade e que a remoção de florestas leva a uma grande perda de espécies. Pastagens exóticas na região da Mata Atlântica tem um baixo valor de conservação e plantações de eucalipto podem ser manejadas para fins adicionais de conservação. Por fim, salientamos o quão fundamental é a investigação da matriz para um real entendimento dos efeitos das paisagens modificadas pelo homem na diversidade biológica.

Palavras-chave: Florestas tropicais. Paisagens antropizadas. Rola-bosta. Valor de Conservação.

ABSTRACT

Habitat loss and land use changes are some of the most threats for biodiversity in tropical landscapes. Because of this, it is important investigate what the influence that modified ecosystem presents on native diversity. In addition, these effects should be assessed in distinct scales since different scales bring a variety of information that it is helpful in the conservation strategies development. Therefore, this thesis has aimed to evaluate, at local and landscape scales, the effects of land use change on dung beetles communities in Atlantic Forest domain. In the first chapter, we investigated at local scale which modified ecosystems might help in native species conservation and whether the alteration level of this ecosystem has any influence in its conservation value. We found that *Eucalyptus* plantations have greater conservation value than pastures for forest species. The hybrid condition of these ecosystems allows an improvement of this conservation value if they are properly managed. In the second chapter, using a landscape approach, we found that forest dung beetles are more sensitiveness to habitat loss than dung beetles associated with pastures. We also found that landscape heterogeneity can influence positively the abundance of these forest communities. Dung beetles sampled in pasture sites did not respond to landscape attributes, evidencing that these dung beetle communities might be more related to local scale variables or biogeographic factors. With these results, we conclude that dung beetles are an excellent group to test ecological hypothesis related to biodiversity conservation in both local and landscape scale. Also, we highlight that native forests have an incomparable and irreplaceable conservation value and their destruction has led to species extinctions. Exotic pastures placed in Atlantic Forest region have a low conservation value and *Eucalyptus* plantations could be more useful. Finishing, we emphasize that it is fundamental investigate matrix components in order to understand the real effects of distinct land use on biological diversity living in human-modified landscapes.

Keywords: Conservation value. Dung beetle. Human-modified landscapes. Tropical forest.

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PRIMEIRA PARTE

1 GENERAL INTRODUCTION

Tropical forests are important and irreplaceable ecosystems (GIBSON *et al.*, 2011). They harbour most of Earth's terrestrial biodiversity (DIRZO; RAVEN, 2003), stock large amount of carbon (PAN *et al.*, 2011), are source of medicine, food and wood (SHEIL; LISWANTI, 2006), and support indigenous and rural communities (HEUBACH *et al.*, 2011). At the same time, tropical forests are one of the most threatened ecosystems (LAURANCE, 2015). Nowadays, less than 9 million km^2 of tropical rainforest remains from the 19 million km^2 that originally existed worldwide, whereas it was estimated an increase in forest loss of 2101 km^2/year between 2000 and 2012 (LAURANCE, 2010; HANSEN et al. 2013). Beyond this, around 70% of remaining forest is within 1-km of the forest's edge, subject to the degrading effects of fragmentation (HADDAD *et al.*, 2015). The impact of all this disturbance has estimated an extinction of 41% of the animal and trees in tropical forests and the forecast becomes worse since the conversion of native vegetation into other land use classes tend to keep happening (ALROY, 2017; LAURANCE, 2015a; MALHI *et al.*, 2014). Hence, human-modified landscapes are emerging from places once dominated by old-growth forests (FISCHER; LINDENMAYER, 2007). Therefore, future of tropical biodiversity will depend on the capacity of native species to persist in human-dominated landscapes within and outside protected areas (DENT; JOSEPH WRIGHT, 2009; LAURANCE *et al.*, 2012; MELO *et al.*, 2013).

In this human-dominated world, – classified as Anthropocene epoch by many researchers – tropical forests remnants are scattered within highly heterogeneous landscapes where coexist with modified and anthropic ecosystems (MALHI *et al.*, 2014). These adjacent environments will present different effects on forest biodiversity, since the availability of resources and shelter in these ecosystems as well as species capacity to move through them will determine which species are able to remain in small and degraded forests patches (ARROYO-RODRÍGUEZ *et al.*, 2017; KUPFER; MALANSON; FRANKLIN, 2006). For this reason, researchers are concerned that conservation practices must be performed considering a properly management not only for natural ecosystems but also for modified ecosystems surrounding the natural areas in order to enhance the conservation value for these ecosystems (BHAGWAT *et al.*, 2008; BROCKERHOFF *et al.*, 2013; CHAZDON *et al.*, 2009; CHESTER; ROBSON, 2013; MELO *et al.*, 2013; RÖSCH *et al.*, 2013; SOLAR *et al.*, 2016; TSCHARNTKE *et al.*, 2014). The proper management will depend on whether those modified ecosystems are in novel or hybrid state (HOBBS *et al.*, 2014). Hybrid ecosystem will share species with historical ecosystem whereas novel ecosystem will not, thereby, each state has different aims and management strategies (ACREMAN *et al.*, 2014; HOBBS; HIGGS; HARRIS, 2009). Therefore, to have effectiveness on conservation planning, it is important to know the state of the most commons modified ecosystems within the landscape as well as understand how those ecosystems help forest remnants to hold native biodiversity.

In human-modified landscapes is also critically needed to understand the relationship between species and spatial scale to improve managements strategies (BANKS-LEITE; EWERS; METZGER, 2012; TSCHARNTKE *et al.*, 2014). Specie occurrence and permanence in a given forest site will depend on local (ecological filters) and landscape (migration and emigration events) conditions (BRUDVIG, 2011). Both local and landscape scale attributes have strong relationship with community structure (AUDINO *et al.*, 2017; SÁNCHEZ-DE-JESÚS *et al.*, 2016). However, to have effectiveness in conservation strategies it is critical to find what are the main conditions that drive the specie persistence and use this information to improve or mitigate environmental and/or landscape conditions (AUDINO *et al.*, 2017; DAUBER *et al.*, 2005; HILL; HAMER, 2004; PHILPOTT *et al.*, 2014; WILLIAMS; WINFREE, 2013). Therefore, biological diversity conservation in human-modified landscapes will require understanding about the conservation value of modified ecosystems in different states and spatial scales (GONTHIER *et al.*, 2014; KENNEDY *et al.*, 2013).

The Brazilian Atlantic Forest is one of the most threatened tropical rainforest worldwide and a convenient model to test the effects of conversion of continuous forest into human-modified landscapes (SLOAN *et al.*, 2014). Starting in 1950s, the massive wave of industrialization, population growth and environmental degradation reduced to only 12% the total forest original cover (JOLY *et al.*, 2014; RIBEIRO *et al.*, 2009). Hence, the combination between the small fraction of the original forest cover, high deforestation rates (57,7% between 2015 and 2016), and extremely high levels of endemism ranked the Brazilian Atlantic Forest among the top five biodiversity hotspots (MELO *et al.*, 2013; MYERS, NORMAN *et al.*, 2000; SOS MATA ATLANTICA, 2015). Nowadays Atlantic Forest region is highly fragmented with all those threatened species living in small and sparse forest remnants (<50 ha) immerse within a human-modified matrix (RIBEIRO *et al.*, 2009). Thus, it is extremely important investigate the effects of the Atlantic forest destruction and land use changes at local and landscape scales in order to understand, mitigate and protect all biodiversity that remains in this biome.

An efficient tool to assess and monitor the effects of habitat modification and their consequences on biodiversity it is the use of bioindicators (HEINK; KOWARIK, 2010). Dung beetles (Coleoptera: Scarabaeidae) are recognized to be good bioindicators due to their high sensitiveness to environmental changes and capacity to highlight the cascade effects from mammals loss in different spatial scales (BICKNELL *et al.*, 2014; CULOT *et al.*, 2013; FEER; BOISSIER, 2015; SPECTOR, 2006). Dung beetle are widely used to investigated the effect of land use changes (BARLOW, J. *et al.*, 2007; COSTA *et al.*, 2017; KORASAKI; BRAGA; *et al.*, 2013), restoration process (AUDINO *et al.*, 2017; AUDINO; LOUZADA; COMITA, 2014) and habitat loss and fragmentation (FILGUEIRAS; IANNUZZI; LEAL, 2011; SÁNCHEZ-DE-JESÚS *et al.*, 2016). Besides, they are a bioindicator group with high cost-benefit and have a well-established taxonomy (GARDNER; BARLOW; *et al.*, 2008; LARSEN, T.; FORSYTH, 2005). Dung beetles communities also play important ecological functions in the ecosystems. Through their nest and feed behaviour, they promote the soil bioturbation, nutrient cycling, secondary seed dispersal, parasites and pest control (NICHOLS *et al.*, 2008). Habitat disturbance also reduce these ecological function provision what allow us to use dung beetles as an integrated assessment of ecosystems health (BRAGA *et al.*, 2013; KENYON *et al.*, 2016).

Therefore, in this thesis we will present, in two chapters, a comprehensive evaluation of the effects of the forest loss and land use change in Atlantic Forest biome by local and landscape perspectives using dung beetle communities as a biodiversity proxy. In the first chapter we will present a local evaluation of the land use changes effects on the Atlantic Forest diversity. We used dung beetles to test if *Eucalyptus* plantations are novel or hybrid ecosystems and discuss the consequences of this classification for biodiversity conservation. At the second, we present an evaluation of the habitat loss and fragmentation effects on Atlantic Forest diversity at landscape perspective. In this case, we investigated the relationship between dung beetles communities from forest and pasture sites with landscape components (habitat amount and matrix heterogeneity). We also discuss the relevance of this relationships for biodiversity conservation at landscape scale.

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SEGUNDA PARTE

ARTIGO 1- *Eucalyptus* plantations as hybrid ecosystems: Implications for species conservation in Brazilian Atlantic Forest

Preparado de acordo com as normas da revista Forest Ecology and Management.

Versão Preliminar.

Eucalyptus plantations as hybrid ecosystems: Implications for species conservation in Brazilian Atlantic Forest

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Abstract

Novel and hybrid ecosystems present different conservation values for native species. Therefore, the classification of modified ecosystems into a novel or hybrid state is an essential step to assist conservation strategies for biodiversity. In the last decades, plantations of *Eucalyptus* have increased in the highly threatened Atlantic Forest region, highlighting the importance of defining this ecosystem as novel or hybrid. In this study, we evaluated whether *Eucalyptus* plantations are novel or hybrid ecosystems by contrasting biotic components (dung beetle communities) and abiotic components (local environmental variables) within historical (Atlantic Forest remnants) and non-historical (pasture) environments in the Atlantic Forest biome, located in Bahia state, Brazil. Our results show that *Eucalyptus* plantations should be classified and managed as a hybrid ecosystem in this biome. Of the 19 dung beetle species found in *Eucalyptus*, ten were shared with primary forests (52.6% of *Eucalyptus* species) and 6 with pastures (31.5%). *Eucalyptus* plantations have environmental aspects similar to both primary forests and pastures. Despite presenting similar components to historical and non-historical ecosystems, *Eucalyptus* plantations are sufficiently distinct to be not classified as either one of them. Our results highlight the potential conservation value of *Eucalyptus* plantations in the Atlantic Forest region as habitat for historical species, and we discuss how alternative management at landscape and stand (local) scales might increase this value.

Keywords: Dung beetles; tree plantations; forest management; novelty concept.

1 – Introduction

Anthropogenic activities have altered around 83% of the planet's land surface, resulting in a range of disturbed, modified or secondary ecosystems (Sanderson et al., 2002; Vitousek et al., 1997). Novel ecosystems are those that have been highly and irreversibly modified by human activities, presenting biotic and abiotic components that differ substantially from the historical ecosystem. These novel ecosystems are relatively stable, functional, tend to self-organize, and are unable to return to their historical conditions. In contrast, hybrid ecosystems exhibit a combination of novel components and elements from the original system, making a return to the original state possible (Hobbs et al., 2009, 2006). Hybrid ecosystems can potentially include a range of disturbed, secondary and introduced systems that share species with primary systems and exhibit similar ecological functioning (Kasari et al., 2016).

Both novel and hybrid ecosystems have been extensively studied and monitored in order to understand and improve their value for biodiversity conservation (Lindenmayer et al. 2015; D. B. Lindenmayer and Hobbs 2004; Tscharntke et al. 2005). Novel ecosystems have demonstrated a conservation value for new groups of species and ecosystem services performed by this biodiversity (Acreman et al., 2014; Perring et al., 2013). For this reason, they need to be actively managed in order to sustain their high species richness and ecosystem services (Nájera and Simonetti 2010; Lindenmayer et al. 2015), however they may have low value in terms of native species, and even to original services (Acreman et al., 2014; Nájera and Simonetti, 2010; Perring et al., 2013). In contrast, hybrid ecosystems are able to conserve local species from the historical ecosystem, thus maintaining part of the original biodiversity and ecological functions (Acreman et al., 2014; Kasari et al., 2016; Perring et al., 2013). Consequently, in recent years some authors have emphasized the importance of considering the "novelty concept" as a premise to improve conservation strategies at local and landscape scale (Acreman et al. 2014;

Doley and Audet 2013; Hobbs et al. 2014; Lindenmayer et al. 2015; Perring, Standish, and Hobbs 2013).

Eucalyptus plantations have well-documented conservation value for biodiversity, often supporting some of the species present in the original pool, regardless of the taxon (Barlow,et al. 2007a, Boelter, Zartman, and Fonseca 2011; Brockerhoff et al. 2008; Calviño-Cancela, Rubido-Bará, and van Etten 2012; Gardner et al. 2008). However, the novel or hybrid nature of these ecosystems is still inconclusive (Barlow et al. 2007c; Calviño-Cancela, Rubido-Bará, and van Etten 2012; Rocha et al. 2013). This ambiguity becomes of utmost importance to biodiversity conservation since these plantations are increasing worldwide (FAO, 2015). In 2015, 291 million hectares were covered by cultivated forests, increasing at a rate of 3.3 million hectares per year over the last five years (FAO, 2015). The growth rate of planted forests has remained constant in Africa, North-West Asia, South America and Oceania, regions in which many of the countries are considered megadiverse (FAO, 2015).

In this study we used dung beetles as a model group to investigate the status of Eucalyptus monocultures as novel or hybrid ecosystems within the Atlantic Forest biome. The Atlantic Forest is considered a biodiversity hotspot (Myers et al., 2000), and is being constantly threatened by its replacement for *Eucalyptus* plantations (Joly et al., 2014). Today, in many regions, small remnants of Atlantic Forest are immersed in a matrix of *Eucalyptus*-based by pulp companies (Fonseca et al., 2009; Joly et al., 2014). In order to verify the status of *Eucalyptus* plantations as novel or hybrid ecosystems, we compared its biotic and abiotic components with a historical (primary Atlantic Forest) and non-historical modified ecosystem (introduced pastures). Therefore, our two alternative hypotheses are: 1) *Eucalyptus* plantations are hybrid ecosystems that share biotic and abiotic components with the historical forest ecosystem and/or other ecosystems; 2) *Eucalyptus* plantations are novel ecosystems that do not share biotic and abiotic components with the historical forest ecosystem.

Dung beetles (Coleoptera, Scarabaeidae) are an excellent study model due to their high sensitivity to environmental change (Bicknell et al., 2014; Spector, 2006) and extensive use in determining the conservation value of land uses (Barlow et al. 2010; Korasaki et al. 2013). Furthermore, these beetles offer great potential to examine the cascade effects of mammal loss, allowing an integrated assessment of ecosystem health (Culot et al., 2013; Feer and Boissier, 2015). Ultimately, our goal is to discuss management practices for *Eucalyptus* plantations in order to increase their biodiversity conservation value.

2 – Material and methods

2.1 – Study region

We carried out the study in the northeastern part of the Atlantic Forest biome, in the municipalities of Eunápolis (16°22′S, 39°34′W) and Porto Seguro (16°27′S, 39°3′W), Bahia, Brazil (see Appendices Figure A.1). The area is considered a highly biodiverse region of the Atlantic Forest (Rocha et al. 2013; Thomas et al. 1998). However, during the 1960's and 1970's, most of the Atlantic Forest was cleared for cattle grazing. At the beginning of the 1990's, cellulose companies began to be established in the region, primarily due to its high potential for *Eucalyptus* plantations. The landscape now comprises a mosaic of a few primary forest fragments and patches of regenerating forest (at varying different stages of regeneration) immersed in a matrix of human-managed habitats, mainly pastures and *Eucalyptus* plantations (Galindo-Leal and Câmara, 2003).

The studied region presents a tropical rainforest climate type Af, according to the Köppen classification, with rains well-distributed across the year and high and fairly constant temperatures (Kottek et al., 2006). It receives approximately 1600 mm of precipitation annually, with temperatures ranging from 18.9–27.9°C, achieving an average of 22.6°C (Veracel, 2007).

2.2 – Studied ecosystems

We sampled dung beetles in five areas in each of the following ecosystems: i) adult *Eucalyptus* plantation areas (~10 years old), ii) primary Atlantic Forest (historical ecosystem of the region), and iii) introduced exotic pastures (non-historical ecosystem with both biotic and abiotic features contrasting from the historical one). Each sampling area was separated by a distance of at least 1 km, and contained four independent sampling points, resulting in 20 sample points per ecosystem type.

2.3 – Biotic components: dung beetle sampling

We used pitfall traps baited with 25 g of human faces, carrion (bovine spleen) or rotten banana, in order to attract coprophagous, necrophagous and carpophagous dung species, respectively. The pitfalls consisted of a plastic container (11 cm height, 19 cm diameter) buried flush with the ground, and a bait recipient (5 cm diameter, 5 cm height) suspended in the centre of the trap. To protect the trap from rain and sun a plastic lid cover was held 20 cm above it using wooden stakes. Dung beetles attracted by the bait fell into a saline and detergent solution.

The four sample points per area were spaced 100 m apart, positioned along a 300 m linear transect (placed 50 m from the area edge, whenever possible). Each sample point received three pitfall traps, one for each bait type, that were placed 3 m away from each other. Traps were left in the field for 48h. Sampling was performed between May 12th and June 3th, 2012. Dung beetles were identified to the species level by Dr. Fernando Z. Vaz-de-Mello (Universidade Federal do Mato Grosso).

2.4– Abiotic components: environmental conditions

We characterised the *Eucalyptus* plantation, primary forest, and pasture areas according to six environmental aspects: canopy cover, understory density, distance among trees, tree basal area, leaf litter depth and percentage of sand in soil samples. Vegetation variables were used as a proxy for microclimate and habitat heterogeneity. We recorded canopy cover above each sample point of three traps using hemispherical photographs taken with a Nikon D40 coupled with a fisheye hemispherical lens 0.20 x, and measured canopy openness using Gap Light Analyzer 2.0 software (Frazer et al., 1999). To measure understory cover we took photographs of the understory at each of the sample points using a black sheet (1 x 1 m) as background, placed perpendicular to the ground. The photographs were analysed with the software Sidelook 1.1 (Nobis, 2005). We calculated the distance among trees and basal area by recording the distance from the centre of each sample point to the nearest four trees (with circumferences higher or equal to 10 cm at 1.3 m above the soil) and measuring the perimeter of those trees. Distance among trees was estimated as the average distance (in cm) between each tree and the centre of the sample points. Basal area relates to the mean size of the trees and was calculated using the following formula: $AB = P^2/4\pi$, where AB is the tree basal area and P the perimeter. Leaf litter depth was measured within 3 m from the sample points using a digital vernier calliper. The sand percentage in the soil was quantified through the collections of soil samples (took from 10 to 20 cm depth), obtained at each sample point, in each study area. These samples were analyzed for texture (proportion of sand, silt, and clay) at the Universidade Federal de Lavras, Departamento de Ciências do Solo (Department of Soil Science).

2.5 – Statistical analysis

To test if the environmental conditions of *Eucalyptus* plantation were different to primary forest and pasture areas, we performed a NMDS and an ANOSIM analysis. All measured environmental conditions were used to calculate a triangular matrix based on

Euclidean distance. We standardized the environmental data prior to analysis as they present different base units of measurement.

We also built generalized linear models (GLMs) to test for environmental differences between systems. We used ecosystem type (primary forest, *Eucalyptus* plantation, and pasture) as an explanatory variable and the environmental variables (canopy cover, distance among trees, basal area, leaf litter, understory cover, and sand content) as responses. We used a Gaussian error distribution to perform GLM analyses and subsequently performed a contrast analysis to verify which categories were distinct in relation to the response variables. To check for the error distribution and adequacy of the model we performed a residual analysis.

To verify if dung beetle species composition of *Eucalyptus* plantation was different or similar to primary forest and/or pasture areas, we performed a non-metric multidimensional scaling (NMDS) and an analysis of similarity (ANOSIM). The similarity matrix of the species composition was calculated based on presence and absence of species using the Jaccard similarity index. The NMDS was used to graphically represent similarity between sites and ANOSIM to test for significant differences in species composition between the three groups of ecosystems. We also evaluated the number of shared species between the systems and plotted it in an infographic.

All statistical analyses were performed using R v.3.4.2 (R Core Development Team 2017). NMDS and ANOSIM analyses were implemented using the *vegan* package (Oksanen et al. 2017).

3 – Results

3.1 – Biotic components: dung beetles

In total we recorded 5355 dung beetle individuals representing 45 different species across the three land use types. The highest numbers were found in the historical ecosystem (primary forest) with 4467 individuals and 29 species, while in the non-historical ecosystem (introduced pastures) we registered 13 species and 551 individuals, and in *Eucalyptus* plantations 21 species and 337 individuals were recorded.

Eucalyptus plantation, primary forest, and pasture were organized in three distinct species composition groups according to NMDS (Figure 1b) and ANOSIM (R= 0.868; p<0.001). Dung beetles in *Eucalyptus* plantation was more similar to pastures (mean Jaccard similarity = 17.62%) than to primary forest (mean Jaccard similarity = 11.21%; Figure 1b). As expected, primary forest and pastures presented completely distinct dung beetle communities, with a mean Jaccard similarity of only 0.54%. According to ANOSIM, all land uses were significantly different in relation to species composition (see Appendices Table A1).

Most of the species found in *Eucalyptus* plantations also occur in primary forests and/or pastures. Of the 19 species found in *Eucalyptus*, ten were also sampled in primary forests (52.6% of *Eucalyptus* species), six in pastures (31.5% of *Eucalyptus* species), and one species was shared with both primary forests and pastures (5.2% of *Eucalyptus* species). Only four species were exclusive to *Eucalyptus* plantations (21% of *Eucalyptus* species). Primary forests presented 29 dung beetle species, of which 18 were exclusive to this system. About 34% of all species sampled in primary forests were also found in *Eucalyptus* plantations. In pastures, six of the 13 recorded species were exclusive to this system. Around 46% of all species sampled in pastures also occur in *Eucalyptus* plantations. Primary forests and pastures did not share any species, with the exception of the one species that was found in all systems (Figure 2).

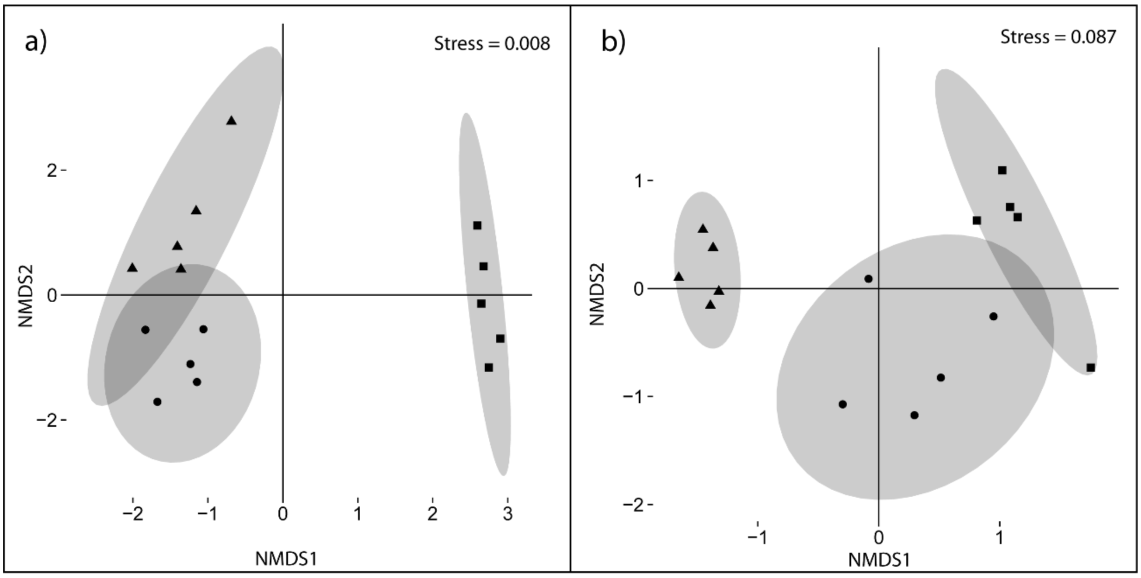

Figure 1. Non-metric multidimensional scaling (NMDS) of a) the environmental conditions (Canopy cover, Tree basal area, Understory density, Distance among trees, Leaf litter depth, and Sand percentage) using a triangular matrix constructed from Euclidian distances (Abiotic components) in three different ecosystems b) dung beetle species composition using a similarity matrix constructed from Jaccard similarity index (Biotic component) in three different ecosystems. Historical Atlantic Forest (triangles); Eucalyptus plantations (circles) and Non-historical pastures (squares).

3.2 – Abiotic components

According to NMDS, the ecosystems can be organized into three distinct groups in relation to the environmental variables. This pattern was confirmed statistically by ANOSIM analysis (R= 0.907; p< 0.001) (Table A1). However, in NMDS, it is possible to visualize that *Eucalyptus* plantations are more similar to primary forest than to pastures, indicating a higher abiotic similarity with the historical forested system (mean Euclidian distance = 2.84) compared to the open non-historical system (mean Euclidian distance = 4.29) (Figure 1a).

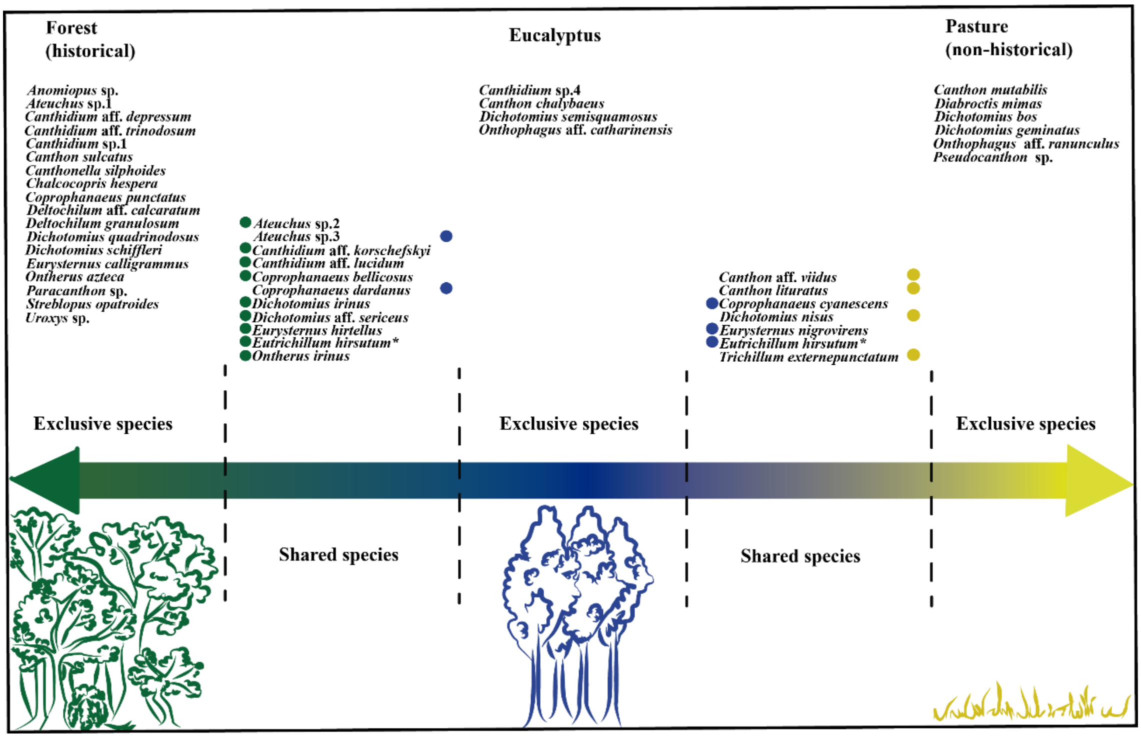

Figure 2. Shared dung beetle species among the three ecosystems evaluated. For each shared species, the coloured circles indicate in which ecosystem the species present higher relative abundance.

When environmental variables are analysed individually, it is possible to verify that *Eucalyptus* share environmental characteristics with both primary forests and pastures (Figure 3). Nonetheless, the systems were statistically different in relation to canopy cover ($F_{12,14}$= 1630.200; $p < 0.001$), tree basal area ($F_{12,14}$= 28.643; $p < 0.001$), distance among trees ($F_{12,14}$= 506.360; $p < 0.001$), understory density ($F_{12,14}$= 5.309; $p = 0.022$) and litter depth ($F_{12,14}$= 52.073; $p < 0.001$; Figure 3). Percentage of sand in the soil was the only environmental variable that did not differ statistically among the systems ($F_{12,14}$= 1.742; $p = 0.217$; Figure 3). Canopy cover was higher in primary forest than in *Eucalyptus*; and with 0% canopy cover, pastures unsurprisingly had significantly lower canopy cover than the other land use types (Figure 3). Tree basal area and leaf litter depth did not differ between forest and *Eucalyptus*, but both systems were markedly different from pastures in relation to these variables (Figure 3). Sampled pasture areas did not present any trees, for this reason, there was little leaf litter, and it was not possible to obtain values for tree basal area. Distance among trees was higher in *Eucalyptus*, followed by forest and pastures (Figure 3). Understory density was higher in primary forest in relation to *Eucalyptus* plantations and pastures, while the latter two were found to be similar according to this variable (Figure 3).

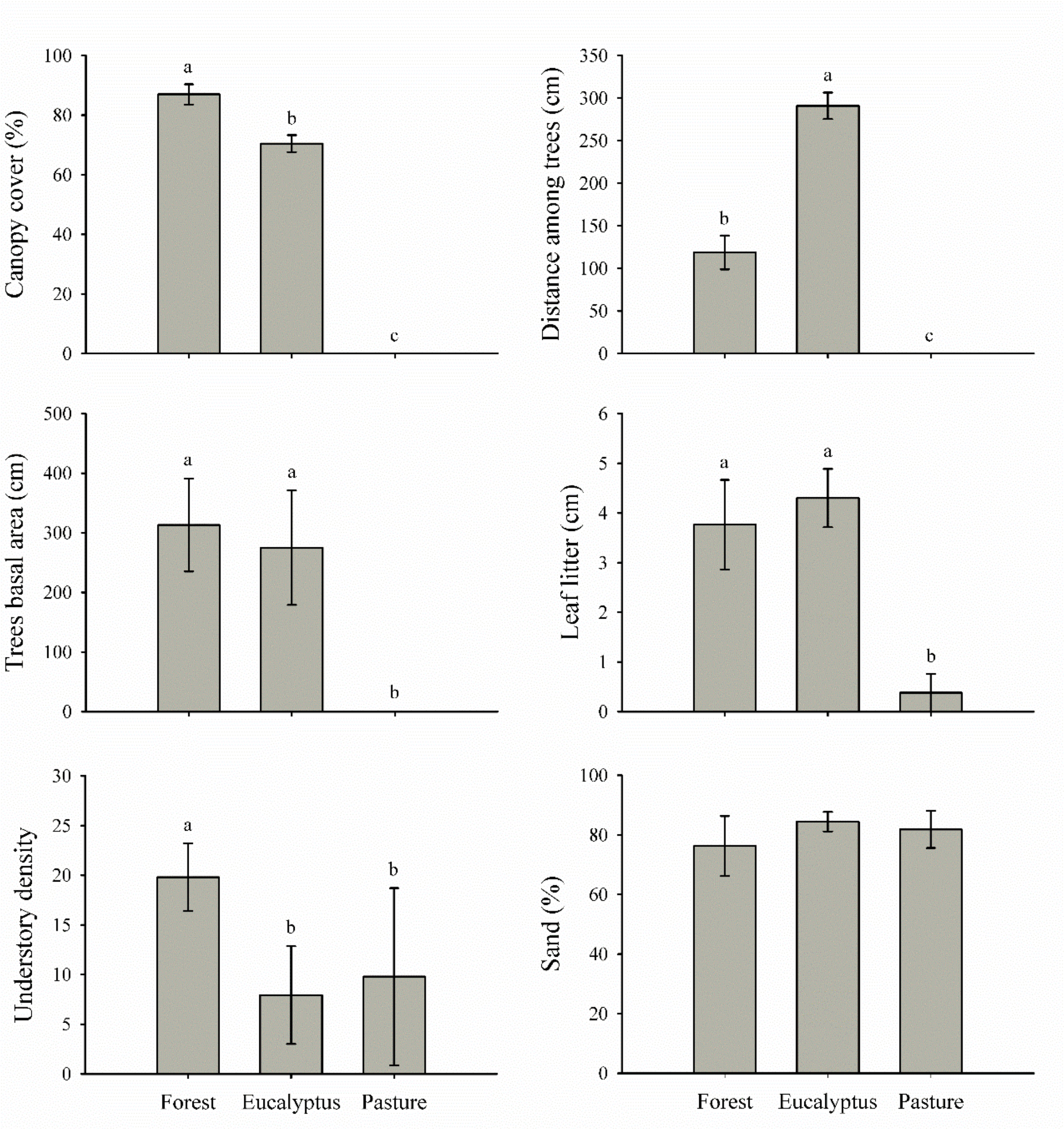

Figure 3- Mean ±SE of abiotic components sampled in three different ecosystems: historical Atlantic Forest remnants (Forest), Eucalyptus plantations (Eucalyptus) and non-historical pastures (Pasture). Different letters above the bars indicate statistically significant difference (p<0,005) among the ecosystems.

4 – Discussion

By using an ecosystem level approach and a spatially replicated experiment, our study provides evidences that *Eucalyptus* plantations can be categorised as a hybrid ecosystem. Biotic and abiotic components of *Eucalyptus* plantations were statistically different from the historical (primary forest) and non-historical (exotic pasture) ecosystems. However, *Eucalyptus* plantations still share biotic and abiotic components with these systems. For this reason, it should not be considered a novel ecosystem. Our findings contrast with the findings of Lindenmayer et al. (2015), which suggested that commercial tree plantations, such as *Eucalyptus* plantations, should be classified and managed as novel ecosystems. We present empirical evidence that these plantations are not novel ecosystems and that these systems present a potential to sustain historical species. We recommend that conservation planning should establish management strategies for *Eucalyptus* plantations that seek an equilibrium between conservation and production.

4.1 – Biotic components

Ecosystems with similar abiotic conditions may also present similar biological communities and share more species (Baker, French, and Whelan 2002; de Bello et al. 2013; Evans et al. 2016; Liu, Tang, and Fang 2015; Zhang et al. 2014). Indeed, *Eucalyptus* plantations harbour a mixture of species from both primary forests and pastures. Community assembly is mainly driven by the combination of abiotic (environmental and management) and biotic (interactions among groups) filters, which determine the establishment of populations into new areas (Lebrija-trejos et al., 2010; Pakeman and Stockan, 2014; Stegen et al., 2012). We found some exclusive species in *Eucalyptus* plantations possibly evidencing certain exclusive conditions of this system in relation to forest and pasture, such as uniform distance among trees and homogeneous forest cover (Gardner et al., 2008). Therefore, while *Eucalyptus* plantations show similar conditions to surrounding ecosystems, they are sufficiently distinct to not be classified as either of them, reinforcing its designation as a hybrid ecosystem.

As previously reported in the literature, *Eucalyptus* plantations share more species with historical forests than with cleared agricultural lands (Korasaki et al. 2013; Lindenmayer and Hobbs 2004; Solar et al. 2016). This pattern is reinforced by our results highlighting the forested nature of *Eucalyptus* plantations. Thus, it is suggested that *Eucalyptus* plantations present potential habitat or corridors for certain tolerant species, evidencing their conservation value when contrasted to other agroecosystems (Barlow et al. 2007a; Barlow et al. 2007b; Biz, Cornelius, and Metzger 2017; Hawes et al. 2009; Rocha et al. 2013).

4.2 – Abiotic conditions

Eucalyptus plantations share abiotic components with primary forest (historical ecosystem) and pastures (non-historical ecosystem) and this aspect allows us to classify these plantations as hybrid ecosystems, being in an intermediate state between both historical and non-historical ecosystems (Hobbs et al., 2009, 2006). These similar characteristics between historical and modified ecosystems may be a starting point to understand whether modified ecosystems will progress towards historical or novel conditions (Hobbs et al., 2014; Perring et al., 2013).

In this study, *Eucalyptus* plantations presented a tree basal area and leaf litter depth similar to primary Atlantic forests. These aspects are important to biodiversity conservation in forested ecosystems; tree basal area has been considered an important metric to assess habitat quality (Arroyo-Rodríguez and Mandujano, 2006), biodiversity maintenance (Bradford and Bell, 2017) and carbon storage (Gilman et al., 2016), while leaf litter depth is related to nutrient cycling and is an important variable to assess ecosystem functioning (Aerts, 1997; Pei et al., 2017). In contrast, *Eucalyptus* plantations also presented some abiotic conditions similar to pastures, such as low understory density. Traditionally, understory vegetation has been considered a limiting factor in planted trees ecosystems in terms of production, because understory plants compete with overstory species for nutrients and water (Nambiar and Sands, 1993). For this reason, understory vegetation is typically removed in *Eucalyptus* plantations (Chang et al., 1996; Nambiar and Sands, 1993; Zhou et al., 2017). This type of management of *Eucalyptus* plantations decrease habitat provisioning capacity for native species (Millan et al., 2015; Simonetti et al., 2013; Teixeira et al., 2017) and reduce the ecosystems services provided by soil microorganisms (Wu et al., 2011; Zhao et al., 2013) which make this system impoverished and similar to pastures.

4.3 – Implications for biodiversity conservation

Modified ecosystems are classified following the degree of irreversibility in their biotic and abiotic conditions (Acreman et al., 2014; Hobbs et al., 2014; Hobbs and Cramer, 2008; Morse et al., 2014). Ecosystems classified as novel can no longer naturally return to their original condition, while any restoration efforts towards a historical condition would be costly and inefficient (Hobbs and Cramer, 2008; Miller and Bestelmeyer, 2016; Seastedt et al., 2008). Hence, in such situations, the only strategy is to improve the local abiotic conditions in order to enhance species diversity, maintain ecological functions and provide more ecosystem services (Acreman et al., 2014; Doley and Audet, 2013; Hobbs and Cramer, 2008; Perring et al., 2013).

Once an ecosystem is in a hybrid condition, the strategies for conservation may be more complex (Miller and Bestelmeyer, 2016). Hybrid is a dynamic condition in an intermediate state between novel and historical conditions (Hobbs et al., 2009). Primarily, the direction in which a hybrid ecosystem changes depends on whether anthropic disturbances are intensified or mitigated (Acreman et al., 2014). Subsequently, the direction of ecosystem change may also be determined by decision makers, in accordance with the scientific community, that must identify and define feasible restoration strategies for each situation (Hobbs and Cramer, 2008; Jackson and Hobbs, 2009; Miller and Bestelmeyer, 2016). Therefore, whether the main goal of management is the conservation of historical and/or threatened species or maintenance and enhancement of ecosystems services, the decision must be made by several stakeholders (Acreman et al., 2014; Hobbs et al., 2014).

The hybrid condition of the *Eucalyptus* plantation can be a starting point to increase the conservation of Atlantic Forest remnants, not as an alternative habitat, but rather as a continuum for this habitat (Lindenmayer et al. 2015; Miller and Bestelmeyer 2016) (Figure 4). If properly managed, these hybrid ecosystems could increase the habitat extent for historical species (Kasari et al. 2016; Lindenmayer et al. 2015). Appropriate management practices have the potential to maintain production, generate employment and conserve historical species, which are fundamental for the sustainable development in this region (Hartley, 2002). The huge economic interest in *Eucalyptus* plantations and the urgent necessity to preserve Atlantic Forest biodiversity highlights the importance of establishing effective measures that improve the conservative value for biodiversity and ecosystem services within these systems.

4.4 – Managing hybrid ecosystems

Currently, management applied in *Eucalyptus* plantations has resulted in ecosystems with low diversity, new species compositions, and a limited range of ecosystem services (Calviño-Cancela et al., 2012; Guo and Gifford, 2002; Solar et al., 2016; Zhou et al., 2017). However, even under conventional management, *Eucalyptus* plantations still share species with native ecosystems (Barlow et al., 2007b). Hence, we should classify them as hybrid ecosystems and suggest management alternatives that enhance the potential to maintain historical species in these modified environments. Particularly in highly threatened ecosystems, such as the Atlantic

Forest, hybrid ecosystems (such as *Eucalyptus* plantations) may be fundamental to the maintenance of native species and ecological functions.

Here, we provide some management suggestions for *Eucalyptus* plantations at two levels: forest stand and landscape level. In both cases, the goal is to integrate economic productivity and conservative value (Lindenmayer and Hobbs 2004). In general, management practices at each level aim to improve abiotic conditions. At a landscape level, abiotic conditions can be improved by altering the matrix quality in order to create an increased variety of habitats and allow connectivity between historical forest remnants (Costa et al., 2017). Landscapes with higher habitat heterogeneity, with native and exotic cultures adjacent to each other, will possess more resource availability, such as food, shelter and nests, for historical species (Fahrig et al., 2011). Habitat diversification can, thus, create a more permeable matrix to species with different dispersal capability (Brockerhoff et al. 2013; Lindenmayer and Hobbs 2004)

At a stand level, management of *Eucalyptus* plantations should aim to decrease the contrasting impacts of edge and matrix effects (e.g. luminosity, moisture, and temperature), establish plantations structurally similar to the historical ecosystem, and reduce harvesting impact, tending and pest control. All these goals can be achieved by leaving stand snags, fallen trees, foliage and branches on site after harvest, maintaining native vegetation and understory within stands (biological legacy), longer rotation periods, multicultural stands favouring native species when possible, and the use of selective pesticides to retain native/beneficial insects. Fertilizers and herbicides can be used conventionally since they benefit understory vegetation and individual trees. Fertilizers provide assimilable nutrients to native vegetation and *Eucalyptus*. Herbicides can reduce the competition among trees and invasive species. Fire management with controlled burning can also be an alternative to reduce competition (Brockerhoff et al. 2013; Hartley 2002; Lindenmayer and Hobbs 2004).

5 – Conclusion

We conclude that *Eucalyptus* plantations in the Atlantic Forest region should be classified and managed as a hybrid ecosystem. The hybrid condition of *Eucalyptus* plantations in the Atlantic Forest region shows that this system offers the potential to serve as a complementary habitat, allowing the conservation of historical species. Changes in conventional management may enhance the conservation value of this ecosystem and maintain productivity. Evidently, these results do not equate historical ecosystems to hybrid ecosystems in terms of biodiversity value. Since *Eucalyptus* plantations are not a viable habitat for all forest species, we impress the urgent need to protect primary forest remnants and their historical species. Nonetheless, in an increasingly anthropogenic world, pragmatic and effective management of human-modified habitats/landscapes is perhaps just as important for successful conservation.

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Appendices

Tables

Table A1. ANOSIM results for the comparison of biotic and abiotic components among *Eucalyptus* plantations, primary forest and pastures. '*' means statistically significant results (p value is <0.05).

	Biotic		***Abiotic***	
Source of variation	**R**	**p**	**R**	**p**
Land use systems	0.868	0.0001*	0.907	0.0001*
Post hoc comparison of systems				
Eucalyptus plantations vs. primary forest	0.924	0.008*	0.784	0.008*
Eucalyptus plantations vs. pasture	0.588	0.02*	1	0.008*
Primary forest vs. pasture	1	0.008*	0.98	0.008*

Figures

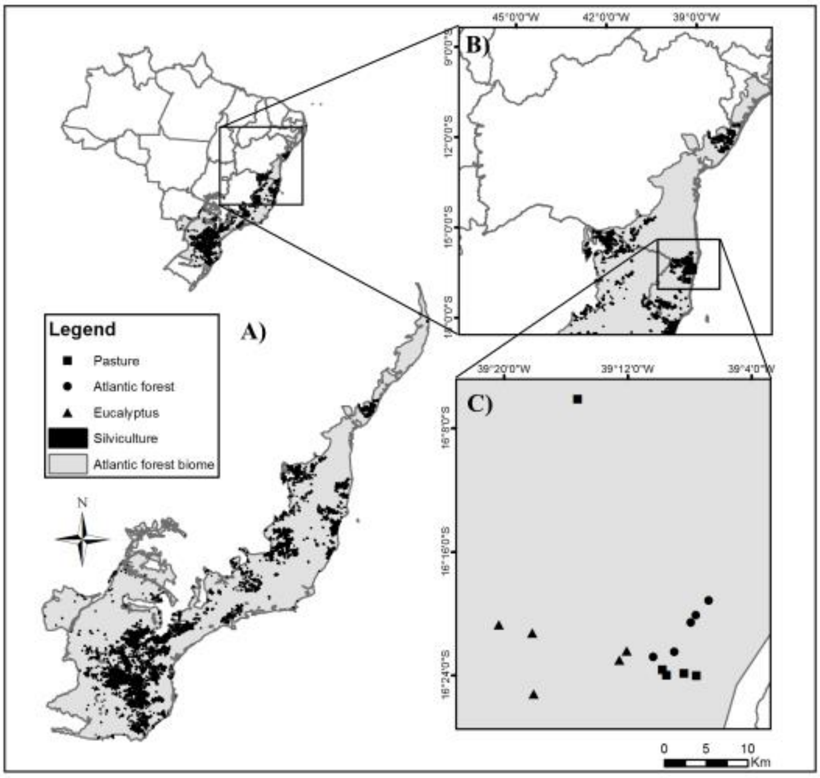

Figure A1. Map of the study region. A) Distribution of silviculture areas in the Atlantic Forest biome; B) The southern Bahia state, Atlantic Forest northeastern region, where was carried out the study; C) Distribution of the sampling units in the historical ecosystem (circles – primary forest), non-historical (squares - pastures) and Eucalyptus plantations (triangles).

ARTIGO 2- Effects of landscape composition on dung beetle community in tropical forests and exotic pastures

Preparado de acordo com as normas da revista Landscape Ecology.

Versão Preliminar.

Effects of landscape composition on dung beetle community in tropical forests and exotic pastures

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Abstract

Context: Habitat loss is converting continuous native tropical forest into highly heterogeneous landscapes. In this context, both forest cover and matrix components are important to evaluate the impact of habitat modification and landscape fragmentation on native biological diversity. Furthermore, the contribution of landscape attributes on beneficial diversity in the matrix is also important and, thus, the relation between landscapes components and biodiversity conservation need to be understood better.

Objectives: In this study, we evaluated the effects of landscapes composition and habitat amount (forest and pasture) on both forest and pasture's dung beetle communities in tropical fragmented landscapes.

Methods: We sampled dung beetles in adjacent pastures and forests sites located in Brazilian Atlantic Forest region. The sites were placed within 1-km radius landscapes in which were used to measure the landscape variables (forest cover, pasture cover and landscape heterogeneity)

Results: Forest dung beetles were more sensitiveness to the landscape changes, with richness and biomass being positively influenced by the enhancement of forest cover whereas number of individuals by landscape heterogeneity. Pasture dung beetles were not sensitiveness to landscape modification.

Conclusions: Forest presented an irreplaceable role for forest dung beetles and should be preserved. Pastures showed a low conservation value and management at local scale might be an efficient option. Biodiversity conservation in Atlantic Forest region should consider both habitat and matrix heterogeneity when developing landscape management strategies.

Keywords: Conservation value; Habitat amount; Landscape Heterogeneity; Matrix.

Introduction

Habitat loss and fragmentation of tropical forests are some of the main threats to global biodiversity and ecological processes (Fischer & Lindenmayer, 2007; Laurance, 2015). One of the reasons is that tropical forests store the largest amounts of carbon (Baccini et al. 2017) and hold over half of the terrestrial species (Dirzo and Raven 2003). Yet, between 1990 to 2010, there was a 62% acceleration in net deforestation in the humid tropics (Kim et al. 2015) and this rapid reduction of the native and pristine forests brought broader negative consequences for global biodiversity and ecosystem services (Haddad et al. 2015). In addition, this forest loss and degradation have led to the expansion of fragmented environments and consequently emergence of human-modified landscapes (Ewers and Didham 2006; Fischer and Lindenmayer 2007; Haddad et al. 2015)

Most human-modified landscapes are composed by both the amount of native/primary forests in the landscape and the components of the matrix surrounding the remaining forest patches (Fahrig et al. 2011; Perović et al. 2015). Although forest loss is known to have negative impacts on biodiversity (Andrén, 1994; Fahrig, 2003, 2013) is still unclear whether tropical biodiversity is more strongly affected by forest loss or by the increment of the others anthropogenic environments in the landscape (Kupfer et al. 2006). The variety of the land use and land cover resultant of the forest loss may affect the species persistence in the fragmented landscapes by different ways (Tscharntke et al. 2012; Lindsay et al. 2013; Perović et al. 2015). Different types of habitat surrounding a forest patch – or landscape heterogeneity- affect the connectivity between patches because each land use may pose different levels of resistance of the matrix for the species moving through them (Stasek et al. 2008; Estavillo et al. 2013; Silva et al. 2016). Similarly, a more heterogeneous landscape might support more species due to more resource availability, as well as by attenuating the edge influence (Kupfer et al. 2006; Fahrig et al. 2011; Tscharntke et al. 2012). Therefore, evaluating not only how the amount of the habitats in the landscape but also the diversity of the surrounding habitats may influence tropical biodiversity may enhance our understanding of the impacts from forest loss and fragmentation in tropical landscapes (Dauber et al. 2003; Kupfer et al. 2006; Fahrig et al. 2011; Estavillo et al. 2013).

The maintenance of the biodiversity within fragmented landscapes is also crucial for many agricultural systems (Ricketts et al. 2004; Fahrig et al. 2011). Many ecosystem services (e. g. pollination and pest control) are provided by species that inhabit native environments and obtain resources in agricultural systems and have been shown to be influenced by the landscape composition (Rand and Tscharntke 2007; Andersson et al. 2013). A higher forest amount has been positively related to more diversity of beneficial fauna in apple orchards (Martins et al. 2015), biofuel crops (Bennett and Isaacs 2014) and coffee plantations (Karp et al. 2013), whereas landscape heterogeneity increases beneficial insects in wheat crops (Medeiros et al. 2018) and field beans (Andersson et al. 2014). Despite this knowledge brought by previous research, still unclear the effect of the landscape composition on pasture biodiversity and ecosystem services. Understanding the role of the pastures in fragmented landscapes is essential for biodiversity conservation because they are dominant in many landscapes, have relevant economic importance, and are driving deforestation in tropical regions (Barona et al. 2010). In addition, it is important to investigate the effects of the pasture systems on tropical biodiversity and, at the same time, to evaluate whether the amount and/or diversity of the habitats in the landscape results in more biodiverse pastures (Melo et al. 2013).

The Brazilian Atlantic Forest is among the most important global biodiversity hotspots (Loyola et al. 2013), presenting higher rates of biodiversity and endemism when compared to some forest regions of the Amazon (Morellato and Haddad 2000). In Brazil in the 1950s, a massive wave of industrialization, economic development, and environmental degradation reduced the Atlantic Forest original cover by 88% (Tabarelli et al. 2005; Ribeiro et al. 2009). Today, with 70% of the Brazilian population living in the Atlantic Forest region and high deforestation rates (57,7% between 2015 and 2016), the biodiversity of this ecosystem is highly threatened becoming this biome a good example to test the effects of conversion of continuous forest into human-modified landscapes. (Melo et al. 2013; SOS Mata Atlantica 2015).

Here, we investigate the effects of landscape components (forest cover, pasture cover, and landscape heterogeneity) on dung beetle (Coleoptera: Scarabaeidae) species richness, abundance, and biomass in human-modified landscapes from the Atlantic forest biome. Dung beetles are a good bioindicator group because of their high sensitiveness to habitat modification (Spector 2006; Bicknell et al. 2014; Filgueiras et al. 2015; França et al. 2016). Furthermore, dung beetles are easily sampled and have a strong contribution to ecosystem functioning, through their dung recycling activity (França et al. 2018), making them an excellent group for biodiversity monitoring and assessment (Gardner et al. 2008). Specifically, we addressed the following questions: 1) Are there any relationship between landscape components and dung beetle communities from native forests and exotic pastures? 2) How habitat and matrix modulate the dung beetle communities in forests and pastures?

Material and Methods

Study region

The study was carried out in a region between the *Cantareira* and *Mantiqueira* mountains, in São Paulo state, Brazil (Fig. 1). This Atlantic Forest region serve as an important biodiversity corridor between these two forested mountains (Boscolo et al. 2017). The climate, according to Koppen-Geiger, is warm temperate with dry winter and hot summer (Cwa) (Kottek et al. 2006). This region lies in the Atlantic Forest domain subdivision, nominated Interior Atlantic Forest, with the prevalence of tropical seasonal semi-deciduous forests (Galindo-Leal and Câmara et al., 2003). Overall, the landscape consists of an agro-mosaic with small patches of old-growth forest remnants, secondary and regenerating forests, agroforestry patches, and plantations of exotic trees such as *Pinus* spp. and *Eucalyptus* spp.; as well as large areas of croplands and exotic pastures (Ribeiro et al. 2009).

Landscapes selection

We used high resolutions images (30 m resolution and 1:5000 scale) available in Basemap extension (ArcGIS 10.2) to obtain land use data at the landscape level and to select the areas for dung beetle sampling. We mapped 10 buffers of 5km radius, where we selected 30 landscapes with 1km radius (three landscapes per 5-km buffer). Within each 1-km landscape, we measured the proportion of forest and pasture cover, as well as the landscape heterogeneity (Fig.1). These 1-km radius landscapes were selected following an orthogonal relationship between forest cover and heterogeneity (correlation R<0.5). Landscape heterogeneity was calculated by Shannon’s index (McGarigal et al., 2012, Shannon and Weaver, 1949). For heterogeneity, eight land cover categories were examined: natural forest remnants (with canopy closure), early successional natural forest regrowth, forestry areas (tree plantations), pastures (grazed and abandoned), cultivated land (mainly crops), swamps, water bodies and urban areas (see Appendix Table A1 in supplementary material for full details of each category). This analysis was performed using GRASS 7.0 (GRASS development team, 2015).

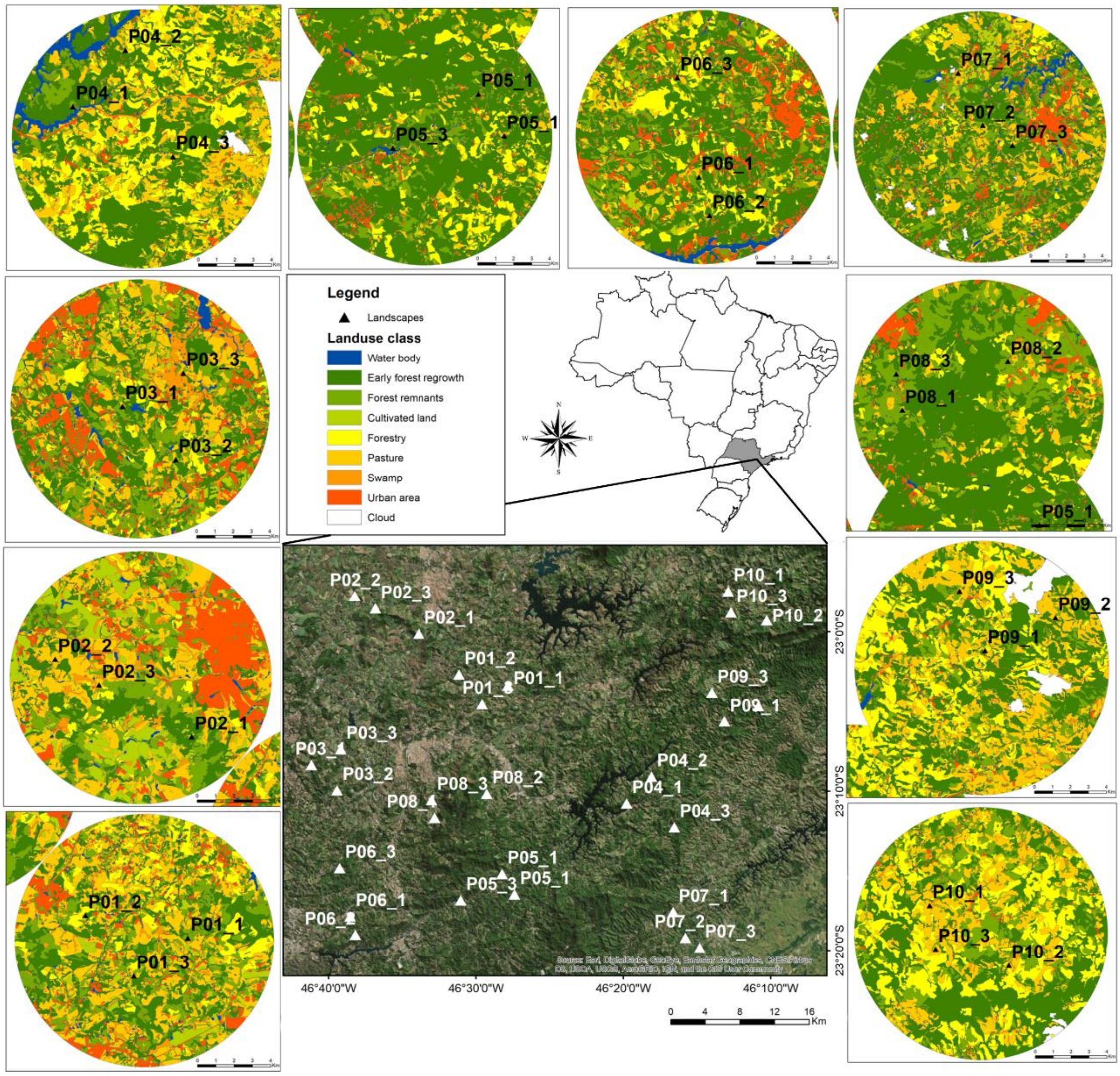

Fig. 1 *Cantareira-Mantiqueira* study region. The 10 colored circles are the maps of land cover within 5 km radius buffer. In each of these buffers, triangles show the location of the three 1-km radius landscapes where dung beetles were sampled.

Dung beetle sampling

At each of the 30 landscapes, we sampled dung beetles in a forest and a pasture, whenever possible, adjacent to each other. Forests sites were characterized by closed canopy (natural forest remnants in the land cover map) with some level of human intervention (e.g. hunting, recreation and domestic animal presence). Pasture sites were predominantly dominated by exotic grasslands such as *Urochloa* sp., alternating from constantly managed to abandoned. All forest-pasture pairs were sampled together, between February 2016 and January in 2017 (see Appendix Table A2 in supplementary materials for full details).

Dung beetles were sampled with baited pitfall traps placed in a linear transect within each sampled site. Pitfall traps consisted of plastic containers (depth = 11 cm; diameter = 19 cm) buried into the ground and protected against the rain by a plastic cover suspended above the trap. Each trap was partially filled with a killer solution of water, salt, and detergent. In forests, we installed four pitfall traps, 50-m apart, and baited with 50 g mixture of human and pig feces (Marsh et al. 2013). In pastures, we selected three sampling points 100 m apart where, at each sampling point, two traps were placed 1-m far from each other. The first trap was baited with 50g of human/pig dung mixture, while the other was baited with 500g of cattle dung. Forest pitfalls were exposed to beetle communities for 48 hours, while pasture traps were collected after 24 hours of exposition. The slightly different sampling protocol between forests and pastures was carried out to ensure that a good representation of the dung beetle assemblage associated with each habitat was collected, based on their resource preferences (Larsen and Forsyth 2005), while maintaining sampling effort constant.

All collected beetles were preserved in ethanol 70% and were sent to the Universidade Federal de Lavras (Lavras, Minas Gerais, Brazil) where they were sorted, dried and stored for further identification. Dung beetles were identified to species level by Dr. Fernando Z. Vaz-de-Mello and voucher specimens were deposited at the Coleção Zoológica da Universidade Federal de Mato Grosso (Cuiabá, Mato Grosso, Brazil). To determine the biomass for each species, wherever was possible, 15 individuals of each species were weighted in precision balance (0.001g) and, thereafter, determined the mean by species.

Statistical analyses

In order to verify the response of the dung beetle species richness, number of individuals and biomass to landscape components we built Generalized Linear Mixed Models (GLMMs) (Zuur et al., 2009). Due to sampling effort discrepancy between pasture and forest communities, the data set was analyzed separately to each one. We used binomial negative errors distribution for all response variables. To the predictors variables, we set forest cover, pasture cover, and heterogeneity as fixed effect parameters and year as random effect parameter. The landscape composition data were standardized prior to analysis because they present different base units of measurement. To assess collinearity among fixed predictors variables we performed Pearson's correlation test. Predictor variables with a Pearson's coefficient > 0.6 or $p<0.05$ were considered correlated and the models were carried out separated for these cases (see Appendix Table A3 in supplementary material). All models were checked for a random distribution of residuals and homogeneity of the variance and all models shown met the model assumptions. The GLMMs were performed in the software R 3.4.3 using lme4 package (R Development Core Team 2018).

Spatial scale selection

To avoid confounding factors and misinterpretation of the dung beetle community responses to landscape components, we performed a model selection in order to choose the best spatial scale for each response variable. Thus, for species richness, number of individuals and biomass we built 24 models each, in which represent the spatial scales separated by 30m (starting from 300m until 990m). Each scale has measures of proportion of forest and pasture cover. Thus, we selected the scale for each response variable by comparing the AICs models among the scales and land use class measurements (see Appendix Fig. A1 in supplementary material). The best spatial scale was the scale with the lowest AIC. Thereafter, the analyses were carried out using the landscape measures of the best scales (see Table 1).

Table 1. The best spatial scales for each dung beetle community variable response.

Variable response	Best spatial scale effect	
	Forest community	Pasture community
Species richness	300 m	650 m
Number of individuals	1000 m	600 m
Biomass	300 m	1000 m

Results

We collected 3525 individuals belonging to 74 dung beetle species. In the forest sites, we sampled 3280 individuals from 58 species, whereas 245 individuals from 26 species were found in pasture sites. There were 47 species associated only with forest sites, 18 species only found in pastures, and 9 species occurring in both ecosystems.

For forest communities, the dung beetle richness and biomass were the only variables influenced by forest cover ($\chi^2 = 4.77$ and 3.87, respectively; all $p<0.04$), increasing in landscapes with higher forest amount (Fig. 2-a, 4-a). The number of individuals did not have a significant response to the amount of forest in the landscape ($\chi^2 = 3.74$; $p=0.053$; Fig. 3-a) but increased significantly with landscape heterogeneity ($\chi^2 = 5.44$; $p=0.019$; Fig. 3-e). Species richness and biomass in forest communities were not influenced by landscape heterogeneity ($\chi^2 = 0.84$ and 1.72, respectively; all $p> 0.19$; Fig. 2-e, 4-e). Finally, pasture cover did not show any influence on forest communities (Fig. 2-c, 3-c, 4-c), and pasture communities were not influenced by any of the explanatory variables (Fig. 2-b-d-e, 3-b-d-e, 4-b-d-e). See Appendix Table A4, in supplementary material, for further details.

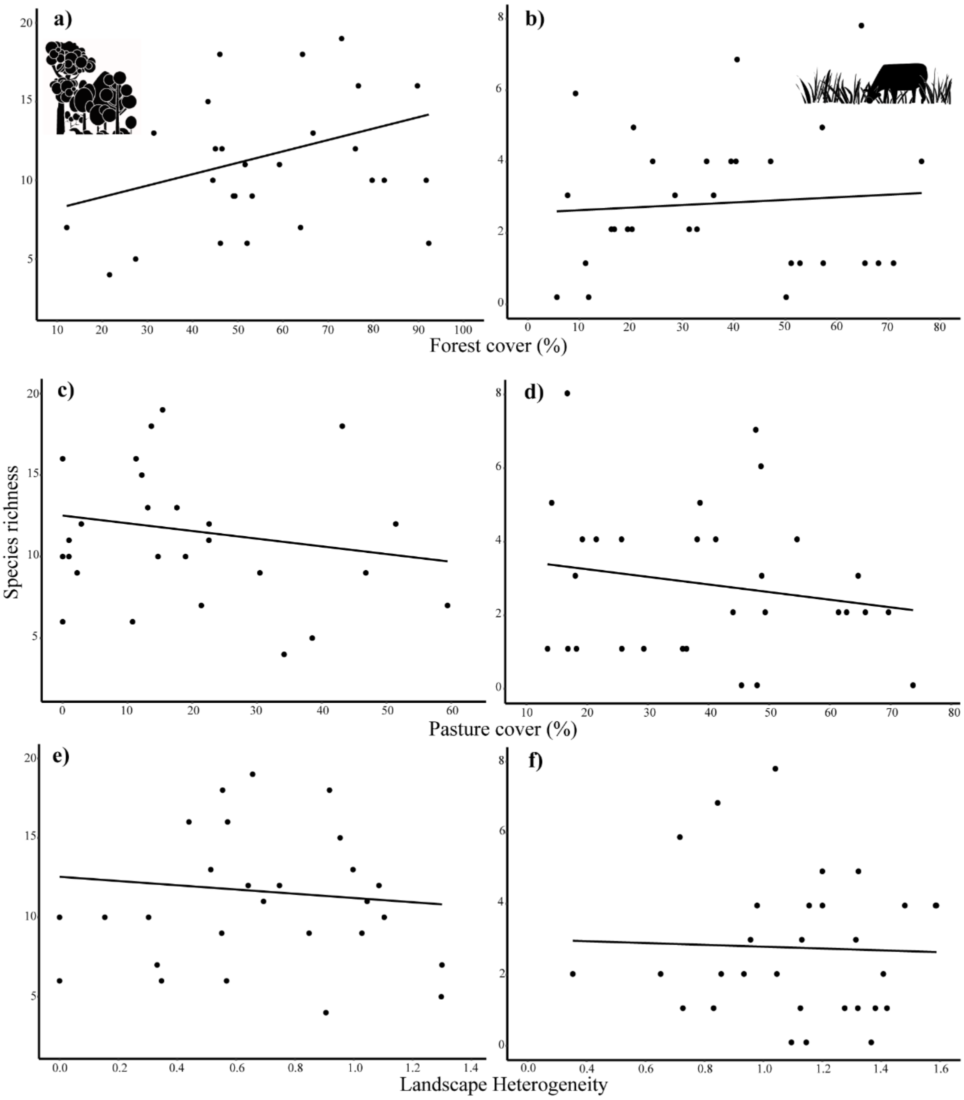

Fig. 2 Relationship between dung beetle species richness and landscape components. a), c) and e) represent forest community whereas b), d) and f) represent pasture community.

Discussion

Addressing our first question about the relationships between dung beetle communities and landscape composition, we found that only forest dung beetle communities being influenced by landscape components. The forest loss resulted in decreased species richness and biomass, whereas the number of individuals within forest patches increased with landscape heterogeneity. The matrix homogenization resulting from the increased pasture cover at the landscape did not have any effect on forest dung beetle, while dung beetle communities from pastures were not influenced by the landscape composition. The lack of influence from forest cover on pasture communities underline the low conservation value of the pastures sites in the Atlantic Forest region, emphasizing how the substitution of forests by pastures is harmful to tropical biodiversity. Surprisingly, landscape heterogeneity did not show any relationship with pasture dung beetle communities.

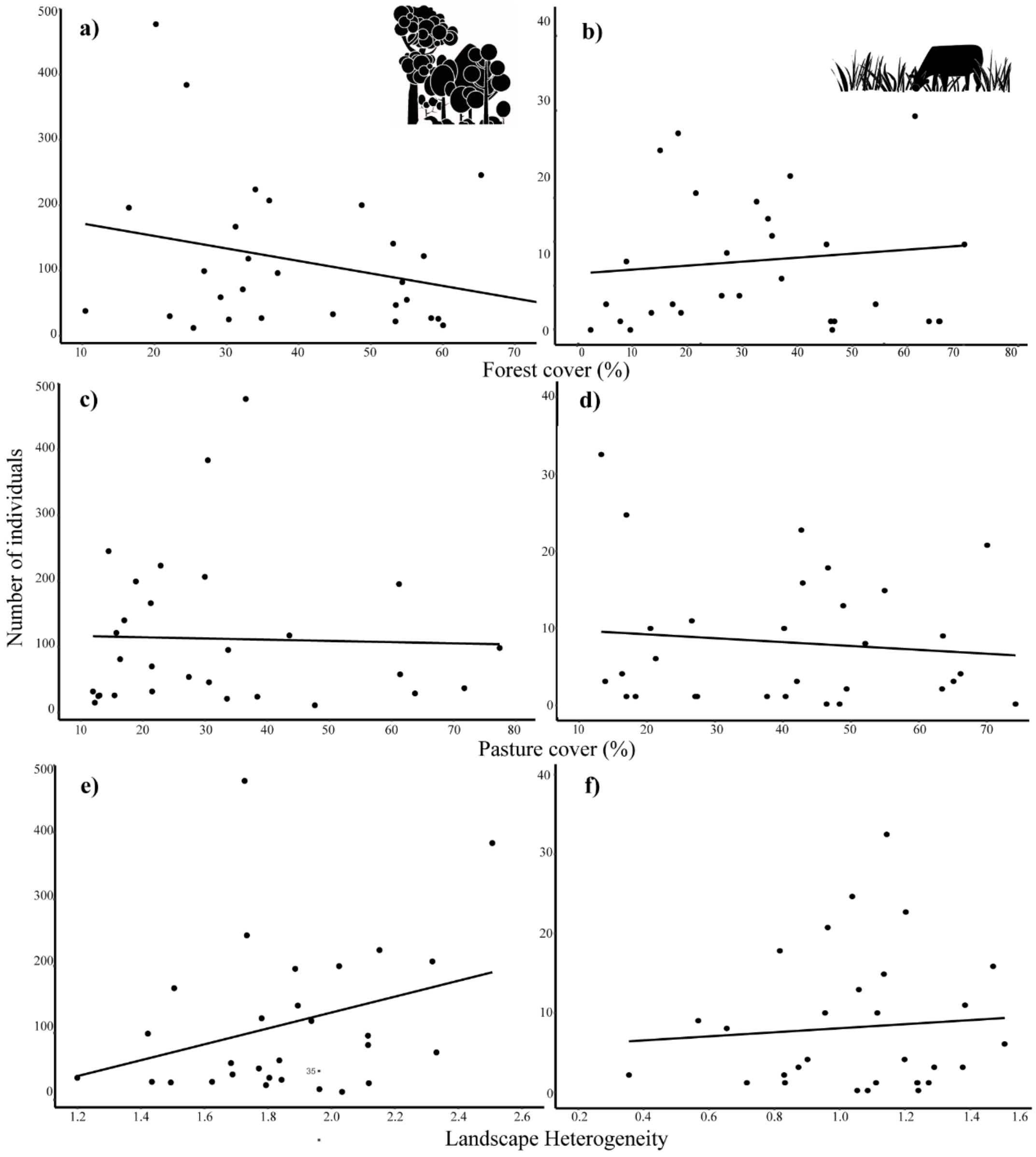

Fig. 3 Relationship between dung beetle individuals and landscape components. a), c) and e) represent forest community whereas b), d) and f) represent pasture community.

Forest cover and dung beetle diversity

The positive relationship that we found between the forest amount in the landscape and the beetle species richness and biomass demonstrates the importance of forest habitat for maintaining the biodiversity at the landscape level (Sánchez-de-Jesús et al. 2016). By showing that the conversion of native Atlantic Forest into pastures brings negative consequences on the dung beetle communities, our research corroborates to previous studies demonstrating the impacts of tropical forest loss on biodiversity (Escobar et al. 2008; Larsen et al. 2008; Sánchez-de-Jesús et al. 2016). At landscape level the reduction in forest area is related with two main consequences for biodiversity, which may likely explain our findings: (1) reduction in the range of habitats types, resulting in fewer species, and (2) a decline in resources followed by smaller populations that are, consequently, more vulnerable to extinction (Fahrig 2003a; Kupfer et al. 2006). On the contrary, landscapes with more forest areas are likely to have a higher richness of mid- and large-sized mammal species (Beca et al. 2017; Regolin et al. 2017), whose biomass has been related to increase dung beetle richness and biomass (Culot et al. 2013).

We did not find any relationship between forest cover and pasture dung beetle communities. The pasture cover or amount of other land use tend to be lower in landscapes with higher forest cover, and, consequently, a decreased distance is expected between agricultural systems and forest edges (Fischer and Lindenmayer 2007). This proximity to the edge benefits the cross-edge spillover, which means that more species could be moving through the forest/matrix boundaries (Boesing et. al. 2017; Estavillo, Pardini, and Rocha 2013). For this reason, as found by other studies (Rand et al. 2006; Lucey and Hill 2012; Estavillo et al. 2013; Lucey et al. 2014), we could expect that more dung beetle diversity in pastures would be related to higher forest cover at the landscape (Rand et al. 2006; Lucey and Hill 2012; Estavillo et al. 2013; Lucey et al. 2014). However, only 12.2% of total species were shared between both habitats, indicating a low species spillover between forests and pastures. This low cross-edge dispersal ability of the forest dung beetles into pasture sites may indicate that the latter offers a strong resistance for dung beetle dispersal (Numa et al. 2009; Díaz et al. 2010; Silva et al. 2016). Furthermore, this low species spillover may indicate that resources in pastures are unattractive for forest dung beetles since dung cattle is less attractive than other dung resources (omnivore and carnivore feces) (Whipple and Hoback 2012; Bogoni et al. 2014). Such predominance of dung cattle in pastures may allow that just generalist species, which may be able to use feces containing a large amount of fibres will remain in this environment (Bogoni et al. 2014). These are likely explanations for why forest cover did not present effect on pasture beetle communities, regardless whether these pastures are close or not to forest patches (Horgan 2007; Díaz et al. 2010).

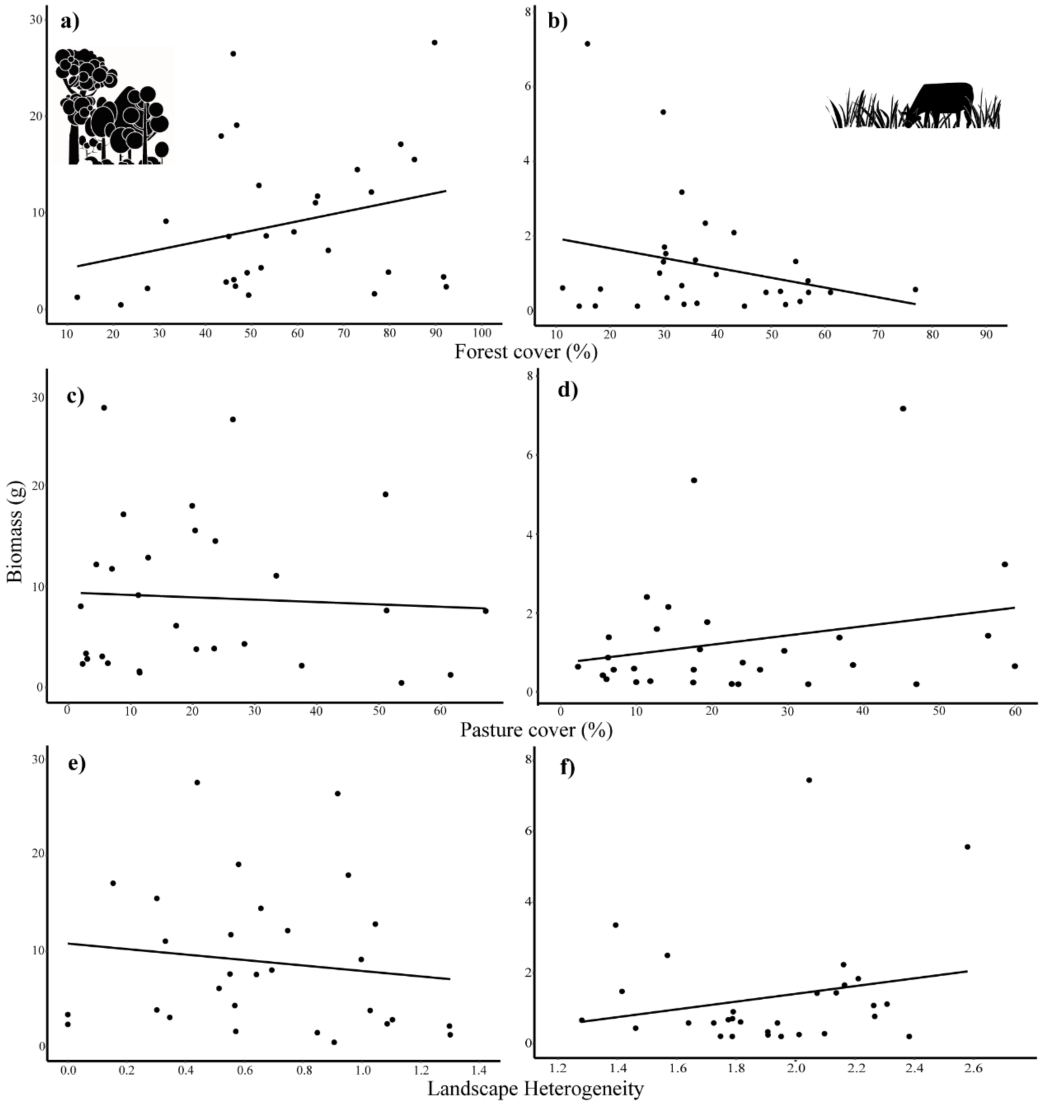

Fig. 4 Relationship between dung beetle biomass and landscape components. a), c) and e) represent forest community whereas b), d) and f) represent pasture community.

Matrix composition and dung beetle diversity

Landscape heterogeneity demonstrated to be a better attribute than the proportion of pasture cover when assessing the matrix effects on forest dung beetle diversity. The homogenization of the landscape resulting from the increase in pasture cover did not present any influence on forest dung beetle communities. These results disagree with other previous studies that found a negative effect of the homogenization by the increase of open-areas at the landscape (Horgan 2007; Numa et al. 2009; Sánchez-de-Jesús et al. 2016). This lack of effect may result from the simultaneous increment of pasture cover and landscape heterogeneity (Pearson’s coefficient = 0.55,

Appendix Table A3). As the forest cover declines within a landscape, another land use class emerge in its place. So, the landscape becomes more heterogeneous due to the new land uses that are turning up and, at the same time, more homogeneous as the new land use classes become preponderant in relation to the others (Fischer & Lindenmayer, 2007; Laurance, 2015). For this reason, the influence of landscape heterogeneity on forest dung beetle may be overlapping the effects of matrix homogenization. In fact, some studies have found a greater influence of landscape heterogeneity on bee species richness, abundance and mutualistic interactions (Moreira et al. 2015; Boscolo et al. 2017). Each land use type, even without canopy closure, will present different levels of matrix permeability and resources availability, bringing more alternatives for the communities living within fragmented landscapes (Tscharntke et al. 2012; Estavillo et al. 2013; Perović et al. 2015).

Landscape composition did not show any influence on pasture dung beetles. Pasture areas are semi-habitat for dung beetle communities associated with natural savannas (e.g. Brazilian Cerrado) and this result might be due to the distance from these ecosystems to pastures sites (Almeida et al. 2011). Silva and collaborators (2016) have found that the replace of forest by pasture reduce dung beetle species richness, however, due to proximity and connectivity with Cerrado patches, pastures also presents a high species richness. Moreover, the connectivity between pastures allow that only generalist and high dispersal capacity dung beetle species are able to reach pastures installed far the habitat source (Horgan 2007). For this reason, for pasture dung beetles the biogeographic context seems be relevant (Silva et al. 2016). Also, the lack of response may be related to the majority of dung beetle species inhabiting pastures are more sensitivity to local condition, for example, dung availability (Lobo et al., 2006).

Implication for dung beetle conservation

It is undeniable that the forest loss is the major threat to tropical biodiversity (Dirzo & Raven, 2003; Fahrig, 2003; Newbold et al., 2015). Around the world, deforestation led about 41% of tree and animal species to be absent in the tropics (Alroy 2017). For dung beetles in the tropical region, fragmentation and habitat loss have shown the same impact on dung beetles community at local (Filgueiras et al. 2011; Sánchez-de-Jesús et al. 2016), regional (Horgan 2007) and global-scale (Nichols et al. 2007). Our results reinforce the irreplaceable role of forest remnants for maintaining dung beetle communities in the Atlantic Forest hotspot (Filgueiras et al. 2011; Gibson et al. 2011; Joly et al. 2014). Even when considered the whole landscape under the best scale effect, forest cover was the main explanation of the dung beetle maintenance within forest patches. Although landscape heterogeneity has a strong positive influence on number of individuals, this result should be viewed with attention. More than increasing the abundance of forest species, landscape heterogeneity seems to benefit the hyperdominant species (Korasaki et al. 2013b; Steege et al. 2013). For example, the *Onthophagus haemathopus* species represented around 40% of the individuals sampled within forests, which may indicate a negative impact of the landscape heterogeneity on forest biodiversity. For this reason, we highlight the importance of maintaining and protecting the Atlantic Forest remnants, while advertising the impacts of the matrix composition on tropical biodiversity (Loyola et al. 2013; Melo et al. 2013; Joly et al. 2014).

Here, we use our results to bring three main considerations related to pastures in fragmented landscapes within the Atlantic Forest region. First, pastures showed low potential of conservation value of the dung beetle detritivore fauna (Korasaki et al. 2013a; Costa et al. 2017). Second, because pastures showed low diversity, we expect lower provisions of ecosystems services (Braga et al. 2013; Kenyon et al. 2016). Third, the lack of landscape effects on pasture beetle diversity means that dung beetle in pastures may be mainly influenced by local environmental changes (Davis et al. 2004; Tonelli et al. 2018). For this reason, we support that alternative grazing cattle management should be adopted within this region in order to make pastures more permeable to forest beetle communities, as this would increase the connectivity between populations from distinct patches (Díaz et al. 2010) and also bring more benefits, through the beetle-mediated ecological functions (França et al. 2018) for the pasture environments. A good alternative could be the silvopastoral systems (Latawiec et al. 2014). Such systems combine woodland (trees) and the grazing of domesticated animals in a mutually beneficial way (Montagnini et al. 2013). They have great advantage on conventional systems, since they conserve nutrients and reduce soil erosion, reduce pest incidence, demonstrate compensation by carbon storage and benefit the biodiversity conservation (Montagnini and Nair 2004; Mcadam et al. 2007; Latawiec et al. 2014; Auad et al. 2015). Specifically, for dung beetles, these systems show increase abundance and ecological functions, like dung removal, soil bioturbation and seed secondary dispersal (Giraldo et al. 2011).

Conclusion

We assessed dung beetle communities in forest and pasture habitats in the Atlantic forest hotspot to explore the influence of landscape composition on tropical biodiversity. While forest dung beetles were clearly affected by habitat loss and landscape heterogeneity, pasture dung beetles did not show any significant response to landscape attributes. Therefore, dung beetles within forest remnants showed more sensitiveness to landscape changes than pasture communities. These results highlight that even in the same region, distinct communities can respond fully different to landscape attributes. For this reason, the management planning need to be flexible and take account both habitat and matrix before implementation in order to avoid strategies which is benefic for a specific ecosystem but is detrimental to another one.

Acknowledgement

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Supplementary Material

Appendices tables

Table A1. Land use classes definition used to extract landscape composition variables forest cover, pasture cover and landscape heterogeneity.

Land use class	Description
Waterbody	Include ponds, rivers, dams, and reservoirs.
Early forest regrowth	early successional natural forest regrowth. Include forestry areas after clear-cut management or forest regrowth with an open canopy.
Forest remnants	Include forest in different successional levels with canopy closure. Include mature forests with or without human interference (hunting, plant extractivism, and leisure or touristic activities)
Cultivated land	Any type of agricultural activity, including perennial or annual crops.
Forestry	Tree plantations in majority *Eucalyptus* plantations.
Pasture	Open areas with exotic introduced forage managed or abandoned. Presence or not of livestock. Include areas with shrubs or scattered trees.
Swamp	Wetlands with or without shrubs or scattered trees. Can include areas with canopy closure.
Urban area	Include cities, villages and large highways.
Cloud	Part of the image that is covered by clouds and masking the class beneath.

Table A2. Respective months and years of dung beetle sampling for both pasture and forest areas in *Cantareira-Mantiqueira* region, São Paulo, Brazil. '*' forest area absent.

Landscape 1-km	Month	Year	Rainy season	Landscapes per season	
				forest	pastures
P01_3	February	2016	2016	17	17
P02_2					
P03_1					
P03_2					
P04_2					
P04_3					
P05_1					
P05_2					
P06_3					
P08_2					
P07_1	March	2016			
P07_2					
P07_3					
P08_3	April	2016			
P09_1					
P09_2					
P10_1					
P09_3	December	2016	2017	12	13
P10_2					
P10_3					
P01_1	January	2017			
P01_2					
P02_1					
P02_3*					
P03_3					
P04_1					
P05_3					
P06_1					
P06_2					
P08_1					
Total				29	30

Table A3. Correlations between landscape variables for the all best spatial scale. The scales were previously defined for each variable response. Forest species richness and biomass= 300m, number of individuals = 1000m; Pasture species richness = 650m; number of individuals = 600m, biomass=1000m.

Explanatory variables	Habitat type			
	Forest		Pasture	
	Pearson's coefficient	p-value	Pearson's coefficient	p-value
FC vs. PC 300m	-0.65	<0.001*		
FC vs. LH 300m	-0.81	<0.001*		
PC vs. LH 300m	0.55	<0.01*		
FC vs. PC 600m			-0.71	0.001*
FC vs. LH 600m			0.05	0.809
PC vs. LH 600m			-0.37	0.043*
FC vs. PC 650m			-0.70	<0.001*
FC vs. LH 650m			-0.02	0.921
PC vs. LH 650m			-0.33	0.07
FC vs. PC 1000m	-0.75	<0.001*	-0.59	<0.001*
FC vs. LH 1000m	-0.34	0.11	-0.34	0.07
PC vs. LH 1000m	<0.001	0.99	-0.09	0.65

* means Pearson's coefficient >0.6 or p-value <0.05

FC forest cover, PC pasture cover, LH landscape heterogeneity.

Table A4. Generalized linear mixed-models on the effects of forest cover (FC), pasture cover (PC), landscape heterogeneity (LH) on dung beetle species richness, number of individuals and biomass for pasture and forest community.

Models		Habitat type			
		Forest		Pasture	
		χ^2	p-value	χ^2	p-value
Species richness	FC	4.77	**0.029***	0.1757	0.6751
	PC	1	0.316	1.0469	0.3062
	LH	0.84	0.359	0.0337	0.8544
	FC vs. LH	NA	NA	0.9676	0.8091
	PC vs. LH	NA	NA	1.6967	0.6377
N. individuals	FC	3.74	0.053	0.3786	0.5384
	PC	0.004	0.9491	0.2809	0.5961
	LH	5.44	**0.019***	0.2053	0.6505
	FC vs. LH	8.58	**0.035***	0.6671	0.8809
	PC vs. LH	7.09	0.069	NA	NA
Biomass	FC	3.8732	**0.0491***	3.1765	0.0747
	PC	0.3091	0.5783	1.1635	0.2808
	LH	1.7235	0.1892	2.0113	0.1516
	FC vs. LH	NA	NA	4.058	0.2552
	PC vs. LH	NA	NA	5.8733	0.1179

* means p-value<0.05, NA means models in which the explanatory variables were correlated and, thereby, did not were used to analyze the data.

Appendices figures

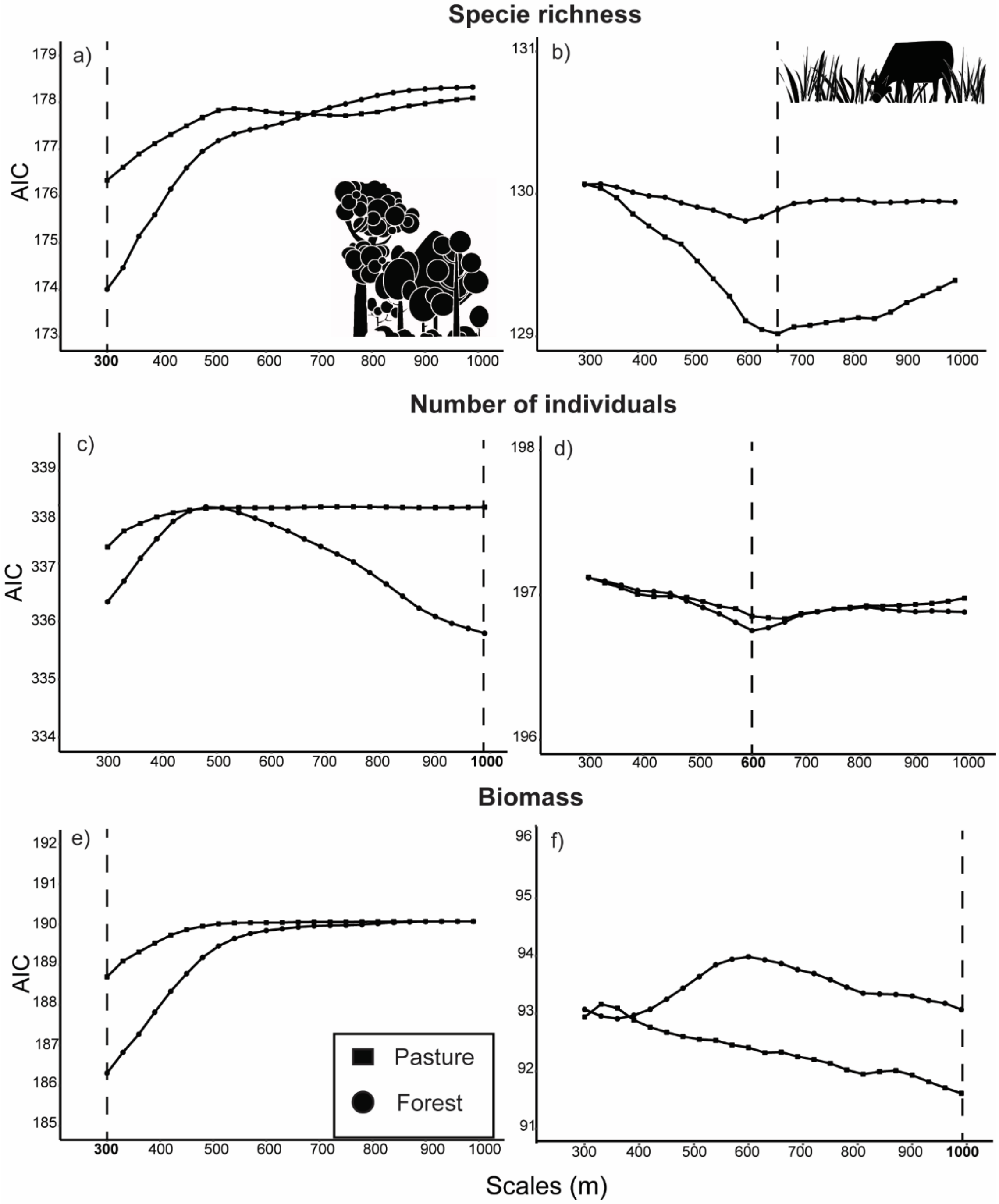

Fig. A1 Spatial scale selection for dung beetle species richness, individuals, and biomass by using the lowest AIC value. The dashed line points out the best spatial scale for forest community (a, c, e) and pasture community (b, d, f).

FINAL REMARKS

The general aim of this thesis was to evaluate how the conversion of tropical forests into modified ecosystems affect, at local and landscape scales, dung beetle communities in Atlantic Forest region. Secondly, we discuss the implications of our results for biodiversity conservation in human-modified landscapes. Therefore, we answer these issues splitting local and landscapes prospects in two distinct chapters.

First, as a local assessment, we evaluate the capacity of *Eucalyptus* plantations in Atlantic Forest region to harbour native species. Furthermore, we investigate if these plantations are novel or hybrid ecosystem according to their alteration level. Our results show that *Eucalyptus* plantations present all the characteristics of a hybrid ecosystem. *Eucalyptus* plantations share biotic and abiotic components with both historical and non-historical ecosystem, which allow us classifying them as hybrid. *Eucalyptus* plantations also hold many species from historical forest ecosystem which make a way for local and landscape management strategies that benefit conservation of native species. We highlight the importance of the classification of modified ecosystems regarding your alteration state since these categories (historical, hybrid and novel) may be used to define conservations planning.

Secondly, at landscape scale, we evaluated the effects of habitat loss and landscape heterogeneity on dung beetles communities that occurs in forest and pasture in Atlantic Forest region as a model group. We found that forest dung beetles were more sensitive to landscape changes, with richness and biomass being positively influenced by the increase of forest cover, whereas number of individuals by landscape heterogeneity. Pasture dung beetles were not influenced by any of the landscape attributes. Our results highlights that the maintenance of native forest in the landscape showed fundamental native dung beetles conservation. Higher heterogeneity levels may benefit species hyperdominance and should be warily considered. The lack of landscape influence on pasture communities might mean that these communities respond majorly to local conditions.

Summarizing, we demonstrated that dung beetle communities can respond to local and landscape scales and all those results are relevant to biodiversity conservation. At both scales, native forest remnants present an irreplaceable role for dung beetle conservation and replacement of these forests by other land uses can led to the loss native species. Pastures are ecosystems highly altered in Atlantic Forest region and have low conservation value potential.

Unlike, *Eucalyptus* plantations presents an intermediate alteration state and whether properly managed might be helpful as a habitat complement for native forests in human-dominated landscapes. Indeed, our results have indicated the fundamental contribution of the matrix on forest dung beetles communities and at the same time, that this contribution should be carefully investigated at local and landscape scales. Furthermore, our results are relevant because they are the first assessment of conservation value of *Eucalyptus* plantations using dung beetles in Atlantic Forest region. Also, we presented the first study that discuss about hybrid and novel ecosystem in tropical region. Lastly, we showed the first study using dung beetles in Atlantic Forest region using landscape approach to evaluate both native and cultivated lands.