

**University of São Paulo  
“Luiz de Queiroz” College of Agriculture  
Center of Nuclear Energy in Agriculture**

**Use of silvicultural landscapes by small mammals in the state of São Paulo,  
Brazil**

**Lina Cristina Vásquez Uribe**

Dissertation presented to obtain the degree of Master in  
Science. Area: Applied Ecology

**Piracicaba  
2018**

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*“Our loyalties are to the species and the planet. We speak for Earth. Our obligation to survive is owed not just to ourselves but also to that Cosmos, ancient and vast, from which we spring”.*

**Carl Sagan**  
Cosmos, 1980

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## RESUMO

### Uso de paisagens silviculturais por mamíferos de pequeno porte do estado de São Paulo, Brasil

Estudos em paisagens agrícolas têm mostrado que ambientes antrópicos podem ser relevantes para muitas espécies selvagens. Dada a extensão destas áreas, são necessários métodos eficientes de pesquisa para avaliar seu valor ecológico em termos de diversidade local, tais como o uso de indicadores biológicos. O presente estudo teve como objetivo geral avaliar a possível relação entre a biomassa de vegetação nativa e a diversidade de mamíferos de pequeno porte em uma paisagem silvicultural do estado de São Paulo. O estudo foi desenvolvido na Fazenda Três Lagoas, que é parte do Núcleo Angatuba do Programa de Pesquisa em Biodiversidade (PPBio), no município de Angatuba, Estado de São Paulo e teve a duração de nove meses. De maio de 2015 a março de 2016, foram realizadas campanhas mensais de amostragem em uma grade amostral com 15 conjuntos de armadilhas de interceptação e queda (*pitfall*), sendo cinco nas plantações de *Eucalyptus spp.*, cinco em vegetação nativa e cinco em pasto abandonado. No Capítulo 1 foram avaliados os padrões de distribuição e abundância de pequenos mamíferos em uma paisagem silvicultural ao início do segundo ciclo de plantações de *Eucalyptus* no Sudeste do Brasil. Um total de 672 indivíduos de 15 espécies das ordens Rodentia (9 spp.) e Didelphimorphia (6 spp.) foram capturados e cinco novas espécies foram detectadas na área de estudo em relação ao primeiro ciclo. Embora as espécies presentes sejam predominantemente generalistas, houve diferença na abundância de pequenos mamíferos nos três ambientes. A presença de fragmentos de vegetação nativa associados a áreas ripícolas e pasto abandonado e o papel dos pequenos mamíferos como recurso alimentar para predadores em uma estrutura trófica, atribui um valor de conservação às paisagens silviculturais no sudeste do Brasil. No Capítulo 2, o objetivo foi avaliar a relação entre métricas da paisagem e padrões de diversidade, distribuição e abundância de pequenos mamíferos em uma paisagem silvicultural. A riqueza de espécies e a diversidade de famílias dos pequenos mamíferos tem sido predominantemente determinada pela área porcentual de vegetação nativa. No entanto, a abundância de pequenos mamíferos pode ser determinada por uma estimativa indireta da biomassa da vegetação nativa (e.g., NDVI), que pode ser considerada uma métrica de paisagem 3D, pois está relacionada ao volume. Portanto, para ter sucesso na avaliação do valor da paisagem agrícola, os estudos futuros devem considerar o contexto da paisagem, bem como as métricas da paisagem associadas à análise dos dados geoespaciais e as distintas respostas das espécies.

Palavras chaves: Monitoramento da biodiversidade, Roedores, Marsupiais, Paisagens agrícolas, Métricas da paisagem

## ABSTRACT

### Use of silvicultural landscapes by small mammals in the state of São Paulo, Brazil

Studies in agricultural landscapes have shown that anthropogenic environments may be relevant to wildlife species. Given the extent of these areas efficient research methods are needed to assess its ecological value in terms of local diversity, such as the use of biological indicators. The main goal here was to evaluate the possible relationship between the native vegetation biomass and diversity of small mammals in a silvicultural landscape of São Paulo. The study was developed at Fazenda Três Lagoas, which is part of the “Programa de Pesquisa em Biodiversidade” (PPBio), at Angatuba municipality, State of São Paulo, and lasted nine months. From May 2015 to March 2016 nine sampling campaigns were carried over a grid of 15 pitfall traps, five in *Eucalyptus* plantations, five in native vegetation and five in abandoned pastures. In the Chapter 1 the distribution and abundance patterns of small mammals on a silvicultural landscape during the early second cycle of *Eucalyptus* plantation in Southeastern Brazil was evaluated. A total of 672 individuals from 15 species of the orders Rodentia (9 spp.) and Didelphimorphia (6 spp.) were captured and five new species were detected in the study area in comparison to the first cycle. Although these species are predominantly generalists, there were differences in the abundance of small mammals in the three environments. The presence of native vegetation patches associated with riparian areas and abandoned pastures and the role of small mammals as a food resource for predators on a trophic structure, gives a certain conservation value to silvicultural landscapes in southeastern Brazil. In the Chapter 2 the relationship between landscape metrics and patterns of diversity, distribution and abundance of small mammals in a silvicultural landscape were evaluated. The species richness and family diversity of small mammals have been predominantly determined by the percentage of native vegetation. However, the abundance of small mammals can be determined by an indirect estimate of the native vegetation biomass (i.e., NDVI), which can be considered a 3D landscape metric as it is related to volume. Therefore, to succeed in assessing the value of agricultural landscape, future studies should consider landscape context, as well as the landscape metrics associated with geospatial data analysis and the distinct responses of species.

Keywords: Biodiversity monitoring, Rodents, Marsupials, Agricultural landscapes, Metrics landscapes.



## 1. GENERAL INTRODUCTION

It was less than 10,000 years ago when humans first began to cultivate plants and domesticated animals. Thus, natural ecosystems have been replaced by agroecosystems managed in order to suppress wild vegetation and renew soil fertility and the management of resources (MAZOYER; ROUDART, 2006). These functions, ensure the internal circulation of matter and energy within the agroecosystem and surrounding ecosystems. For example, water supply and drainage, erosion and deposition of sediments and transfers, of wild or domestic species (MAZOYER; ROUDART, 2006).

In this way, agriculture has become a major factor in the transformation of the ecosphere, where agroecosystems replaced pristine ecosystems worldwide, creating agricultural landscapes with their own history, geography and ecology (VERDADE *et al.*, 2016). Tropical forests are often destroyed to clear land for agriculture or to harvest forestry products, such as timber (CARRASCO *et al.*, 2017), as the growing global demands for food and biofuels generate pressures for deforestation across the tropics (GIBBS *et al.*, 2010). Thus, land use change and agricultural practices have been impacting patterns of wildlife distribution and abundance and the ecological and evolutionary processes that mold them (VERDADE *et al.*, 2016). Also, land use change results in direct habitat loss, increases in local extinction rates and declines in  $\alpha$ - to  $\gamma$ -diversity (JAKSIC *et al.*, 2002; MOONEY; HOBBS, 2000). Agricultural intensification has also been associated with the introduction of invasive species of plants and animals which lead to environmental impacts such as biodiversity homogenization (MAGNUSSON, 2006), the spread of diseases (TOMPKINS *et al.*, 2011; Lafferty, 2014) and competitive pressure on native species (FERRONATO *et al.*, 2009; VERDADE *et al.*, 2016).

In addition, agroecosystems present a spatial-temporal variation, which creates “pulses” in biomass production across the landscape, possibly affecting the use of space and trophic relations of wild species. For these reasons, agroecosystems (i.e. the matrices of agricultural landscapes) should no longer be considered as “non-habitats” and they are important providers of ecosystem services at the landscape level (BONECKER *et al.*, 2009). “It is not only necessary to include agriculture in the context of wildlife management, but also wildlife management in the context of agriculture” (VERDADE *et al.*, 2016, p. 6). Also, some wildlife populations appear to benefit from intensive agriculture while others may be reduced or eliminated; thus, there is a need to understand how differing population responses

shape wildlife communities and ultimately the integrity of the ecosystem in agricultural landscapes (HURST *et al.*, 2014).

Agricultural landscapes of Southeastern Brazil present substantial diversity of many taxonomic groups, including mammals (GHELER-COSTA *et al.*, 2016). Small mammals are an important component of many ecosystems and landscapes. They prey on a large variety of insects playing an important role in pest control and reduce the spread of insect-vector diseases. In addition, they graze on the foliage of grasses and forbs and consume as well as disperse seeds. They are also a major food source for numerous species of carnivores and generalist predators (PASITSCHNIAK-ARTS; MESSIER, 1998). Additionally, some small mammals also live in underground galleries, contributing to soil fertilization and aeration and therefore increasing the system's productivity (GONÇALVES *et al.*, 2012). In this way, small mammals are an ideal taxonomic group for assessing the impacts of different forestry practices as they can occupy different habitat niches (STEPHENS *et al.*, 2012).

Studies with *Eucalyptus* in Brazil began at 1904 by Edmundo Navarro de Andrade, who introduced several species of the genus in Jundiá Garden, São Paulo (CASTRO *et al.*, 2016). This genus is considered one of the most important planted in Brazil and other tropical and subtropical regions of the world (CASTRO *et al.*, 2016). In addition, although *Eucalyptus* plantations are less relevant to species conservation than native environments, according to CARRILHO *et al.*, (2017) maintenance of understory in these plantations is a crucial management strategy that promotes small mammal abundance. Thus, by maintaining understory patches in plantations, managers assure that such anthropic environments may still hold small mammals, thus contributing to the preservation of key ecosystems functions (CARRILHO *et al.*, 2017). In this way, when working at the landscape scale, several factors can influence biodiversity and the ecological functions it performs. Recent mammal studies incorporate landscape metrics as explanatory variables for traditional measures (e.g., species richness and diversity), such as Shape Index, Fractal Dimension Index, Normalized Difference Vegetation Index and percentage of biomass (MAGIOLI *et al.*, 2016). In such context, the main objective in this study was to evaluate the possible relationship between the native vegetation biomass and diversity of small mammals in a silvicultural landscape of São Paulo. In the Chapter I, develops the topic of diversity of small mammals on a silvicultural landscape during the early second cycle of *Eucalyptus* plantation is presented. In Chapter II, the relationship between landscape metrics and patterns of diversity, distribution and abundance of small mammals is discussed.

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## 2. CHAPTER 1: DIVERSITY OF SMALL MAMMALS ON A SILVICULTURAL LANDSCAPE DURING THE EARLY SECOND CYCLE OF *EUCALYPTUS* PLANTATION IN SOUTHEASTERN BRAZIL

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### Abstract

As agriculture expands, agroecosystems become a likely habitat for wildlife, like small mammals in different regions of the world. However, the impact and suitability of such habitat for wildlife is still unknown. This study evaluated the distribution and abundance patterns of small mammals on a silvicultural landscape during the early second cycle of *Eucalyptus* plantation in Southeastern Brazil. From May 2015 to March 2016 we carried out monthly sampling campaigns over a grid of 15 pitfall traps, five in *Eucalyptus* plantations, five in native vegetation and five in abandoned pastures. A total of 672 individuals from 15 species of the orders Rodentia (9 spp.) and Didelphimorphia (6 spp.) were captured. However, three species of rodents (*Oligoryzomys nigripes*, *Oligoryzomys flavescens* and *Calomys tener*) represented 82.4% of the total population. Five new species were detected in the study area in comparison to the first cycle. *Eucalyptus* plantations had a smaller species richness and abundance than the abandoned pasture and the remaining fragments of native vegetation. Although the species are predominantly generalists, there were differences in the abundance of small mammals in the three environments. Although a relationship between species richness and border/water distance in *Eucalyptus* plantations was not detected, riparian habitats, given their resource availability, were found to have a positive effect on species composition. The temporal variation (considering pattern of colonization) was similar for some species for each environment in the two cycles and the relative abundance are affected by seasonal variations and changes to vegetation structure, influencing the ecosystem structure and functioning. The presence of native vegetation patches associated with riparian areas and abandoned pastures and the role of small mammals as a food resource for predators on a trophic structure, gives a certain conservation value to silvicultural landscapes in southeastern Brazil.

**Keywords:** Agricultural landscapes, Conservation, Marsupials, Rodents

## 2.1 Introduction

According to Edmundo Navarro de Andrade, it was in Chile that *Eucalyptus* possibly first arrived in South America in 1823. It is difficult to know how and when the *Eucalyptus* entered for the first time in Brazil, but Navarro de Andrade mentioned that of *Eucalyptus globulus* trees may have been planted in São Paulo, between 1861 and 1863 (Andrade, 1961). Initially in Brazil the trees were planted for decorative purposes and for their essential oil. However, in other countries, they were already recognized as wood producers (Foelkel, 2005). For this reason, Navarro de Andrade considered them as a potential timber resource for the São Paulo Railways Company, which needed wood, sleepers, poles and fence posts. In 1910, Navarro planted in Rio Claro his first major collection and in 1919, had already about 123 species of the genus planted. The introduction of other species occurred later (Foelkel, 2005). In 1950, Brazil was internationally recognized as the country with the most extensive eucalypt plantations worldwide (Leão, 2000).

Currently, the sector has about 30 thousand companies with investments and infrastructure for the production of pulp and paper in Brazil (Leão, 2000). The coverage of plantations for the pulp and paper industry currently represents 2.63 million hectares (34% of the total planted trees) (IBÁ, 2015). Additionally, there are currently about 5.56 million hectares of *Eucalyptus* plantations in Brazil that are used to produce timber, biofuels and charcoal. Minas Gerais (25.2%), São Paulo (17.6%), and Mato Grosso do Sul (14,5%) are the states with highest production (IBÁ, 2015). Also, the production of charcoal from wood of *Eucalyptus* occupies an area of three million hectares in Brazil and belongs to the group of biofuels used in the steel industry (Kohlhepp, 2010). In the state of São Paulo grazing areas with low productivity are being replaced by forestry, especially *Eucalyptus* plantation (Kronka et al., 2003).

As agriculture expands, agroecosystems have been shown to be viable habitat for wildlife like small mammals in different regions of the world (Bonecker et al., 2009; Heroldová et al., 2007; Prevedello & Vieira, 2010; Martin et al., 2012). Small mammals (small rodents and marsupials) are a model-group which have ecological characteristics/strategies (r-reproductive strategies with short reproductive cycles) that allow a faster response to the frequent disturbance associated with forestry (Martin et al., 2012). Likewise, small mammals respond quickly to changes in environmental conditions (food and shelter availability), which are crucial to their reproduction and survival (Hansson & Hansson, 1979; Hansson, 1982; Angelstam et al., 1987; Jensen et al., 2003; Marques et al., 2015). In

addition, they have been associated with ecological functioning, environmental health and zoonotic diseases (Davis et al., 2005; Hill & Brown, 2011; Halliday et al., 2012; Oliveira et al., 2013; Bovendorp et al., 2017). Thus, small mammals have a crucial role in ecosystem functionality and food webs, thereby increasing the conservation value of agroecosystems (Verdade et al., 2011). Additionally, given that protected areas only represent around 12% of the world's land, conservation efforts must look beyond these areas in order to maintain global biodiversity (Foley et al., 2005; Verdade et al., 2014). It has been shown that wildlife are able to inhabit and utilize areas such as coffee plantations in Mexico (Moguel & Toledo, 1999), banana plantations and coconut in Costa Rica (Harvey et al., 2006; Harvey & González Villalobos, 2007), subsistence farming in Nepal (Acharya, 2006) and, in the case of Brazil, cocoa, *Eucalyptus* and sugarcane plantations (Faria et al., 2006; Lyra-Jorge et al., 2008; Dotta & Verdade, 2007, 2009, 2011; Gheler-Costa et al., 2012; Timo et al., 2014; Millan et al., 2015).

Furthermore, several authors have pointed out that landscape connectivity depends on the distance between remnant patches, the presence of corridors and the permeability of the different types of matrix habitats which may differ between species (Taylor et al., 1993; Åberg et al., 1995; Jules & Shahani, 2003; Murphy & Lovett-Doust, 2004). Also, the role of the matrix in maintaining diversity in fragmented landscapes, acting as a mosaic of units with varying permeability to different species has also been demonstrated (Umetsu & Pardini, 2007). Further, the ability to occupy or disperse through the matrix is a key ecological attribute in determining species vulnerability to habitat fragmentation (Henle et al., 2004), especially in the tropics (Laurance, 1991; Gascon et al., 1999; Renjifo, 2001; Viveiros De Castro & Fernandez, 2004; Antongiovanni & Metzger, 2005; Umetsu & Pardini, 2007). For example, Brazilian *Eucalyptus* plantations are considered a permeable matrix to some small mammals by some authors (Stallings, 1990; Lyra-Jorge & Pivello, 2001; Umetsu & Pardini, 2007a; Umetsu et al., 2008; Biz et al., 2017) and a viable habitat by other authors (Gheler-Costa et al., 2002, 2012; Martin et al., 2012; Rosalino et al., 2013; Timo et al., 2014; Millan et al., 2015).

In addition, a common process that can explain changes in biodiversity and community structure is the presence of edge effects which can be highly variable across space and time (Hurst et al., 2013). Such effects are comprised of both biotic and abiotic changes related to the proximity of a habitat boundary (Murcia, 1995), which may exert strong influence on species distribution and abundance (Ries et al., 2004; Ewers & Didham, 2006;

Villaseñor et al., 2014). Specifically, the impact of the edge effect on the diversity of small mammals can be influenced by the type of matrix and the ecological characteristics of the mammalian species (Mendes-Oliveira et al., 2012). Likewise, the responses of species to edge effect are generally highly variable; with some small mammal species showing a population increase, while others may decrease in abundance near the edges (Ribeiro et al., 2016). Studies of edge effects on rodents are relatively rare (Delattre et al., 2009) and few studies have directly addressed this issue in Brazil (Napoli & Caceres, 2012). However, for example, Bayne & Hobson (1998) found that the types of habitat surrounding patches affected small-mammal abundance in agricultural edges. Other authors have investigated the impacts of edge effects on community composition (Butet et al., 2006; Bentley, 2008) and the abundance of certain species (Hansson, 1998).

*Eucalyptus*, due to its rapid growth, high productivity, great adaptability and wide range of uses, has been managed in 21-year rotations with three 7-years harvest cycles by the industry (Mora & Garcia, 2000). Consequently, its relatively high temporal heterogeneity can affect habitat quality (Monamy & Fox, 2000; Catling et al., 2001; Fox et al., 2003; Pinotti et al., 2015) and resource availability for wildlife (DeWalt et al., 2003; Pinotti et al., 2011). Specifically, previous studies carried out in Southeastern Brazil (Angatuba, São Paulo state) during the early first cycle of *Eucalyptus* plantation (0-3 years of implantation) between August 2007 and September 2009, showed a considerable temporal variation for small mammals diversity (Martin et al., 2012), which is possibly related to adaptive processes by small rodents (Rosalino et al., 2013). In addition, several studies have shown that changes in small mammals communities during vegetation succession are correlated with changes in vegetation composition structure (Hirth, 1959; Pearson, 1959; Atkeson & Johnson, 1979; Fox, 1982; Fox, 1990; Churchfield et al., 2009; Briani et al., 2004) and the species responses are related to their life histories (Friend, 1993; Kelly et al., 2013). At the beginning of succession, animal communities tend to be dominated by generalist species, while old growth forests are dominated by forest specialist species (Bowman et al., 1990; Lawton et al., 1998; Brook et al., 2003; Pardini et al., 2009; Uehara-Prado et al., 2009). Also, according to the successional niche model, higher productivity and abundant resources, allows some species to spread at the beginning of succession, while other species may be more efficient at using limited resources, on an apparent a trade-off between the ability to use abundant resources and the efficiency in using limited resources (Pacala & Rees, 1998; Rees, 2001; Amarasekare, 2003; Kneitel & Chase, 2004; Pinotti et al., 2015).

In this context, our main goal was to evaluate the distribution and abundance patterns of small mammals on a silvicultural landscape during the early second cycle of *Eucalyptus* plantation in Southeastern Brazil (0-3 years of implantation). To fulfill this aim, was tested three working hypotheses: (1) there are new species in the second cycle of *Eucalyptus* plantation, in relation to the first cycle; (2) There are edge effects within the matrix in relation to the richness/abundance of small mammal species; (3) the temporal variation in interspecific abundances of small mammals is different between the first and second cycle of *Eucalyptus* plantation.

## 2.2 Study area

This study was carried out in Angatuba municipality, São Paulo State in Southeastern Brazil, comprising Fazenda Três Lagoas (23°22'0''–23°20'41''S/48°28'0''–48°27'57''W), located in the Alto Paranapanema water basin and encompassing 3242 ha (Figure 1). The local climate is subtropical (Cwa in Köppen climate classification) with average temperatures ranging from 17.1 °C to 24.1 °C along the year; the rainy period is generally from October to March, and the dry period is from April to September (data from Centre of Meteorological and Climate Research Applied to Agriculture- CEPAGRI).

Angatuba is in a transition zone between the semi-deciduous Atlantic Forest and Cerrado. The native vegetation was replaced by cotton and coffee plantations between 1870 and 1930. At the time of the economic crisis of 1929, agriculture collapsed and native vegetation began to recover. In the 1970's intensive forest clearing occurred which was to be replaced by pasture lands based on exotic grasses (*Urochloa* spp., Syn. *Brachiaria*) (Lisboa, 2008). Between August 2006 and November 2007, 2224 ha of the exotic pasture in Fazenda Três Lagoas was converted into *Eucalyptus* production forests, and the remaining area was allocated for natural revegetation (896 ha) in order to attend the Brazilian Forest Code (Martin et al., 2012; Athayde et al., 2015; Rosalino et al., 2014).

## 2.3 Methodology

### 2.3.1 Sampling methodology

Small mammal surveys were conducted in native vegetation patches, abandoned pastures and *Eucalyptus* production forests (Figure 2). Fifteen sampling units were defined, five in each environment from the original grid design, where sampling units are located at 1km from each other. In the first cycle, 30 sampling units were defined: 18 in *Eucalyptus*

plantation, seven in native vegetation and five in abandoned pasture, with 23 monthly sampling campaigns. This is an adaptation of the Biodiversity Research Program methodology (Magnusson et al., 2005). The patches of native vegetation are composed by second growth fragments of Cerrado sensu stricto (dominated by *Anadenanthera falcata* (Benth.) Speg., *Caryocar brasiliense* Cambess., *Dimorphandra mollis* Benth., *Stryphnodendron adstringens* (Mart.) Coville and *Roupala montana* var. *paraensis* (Sleumer) K.S. Edwards), “cerradão” (forest type Cerrado dominated by *Xylopia brasiliensis* Spreng., *Miconia chartacea* Triana, *Tapirira guianensis* Aubl., *Amaioua guianensis* Aubl., *Siparuna guianensis* Aubl., *Persea pyrifolia* (D. Don) Spreng., *Copaifera langsdorffii* Desf., *Picea obovata* Ledeb. and *Machaerium villosum* Vogel) and riparian forest (dominated by *Calophyllum brasiliense* Cambess., *Nectandra megapotamica* (Spreng.) Mez, *Sorocea bonplandii* (Baill.) W.C. Burger, Lanj. & Wess. Boer, *Gymnanthes concolor* (Spreng.) Müll. Arg., *Bauhinia* sp. L., *Croton floribundus* Spreng. and *Piptadenia gonoacantha* (Mart.) J.F. Macbr.) (Athayde, 2013). Exotic annual and perennial herbaceous species of the Poaceae family dominate the patches of abandoned pastures, with the presence of woody individuals of low stature, mainly of the families Fabaceae, Myrtaceae and Caryocaraceae. The production forests are composed mostly by *Eucalyptus grandis* W. Hill, *E. urophylla* S.T. Blake and their hybrid *E. grandis*, with practically no understory vegetation, but with some native trees (*Copaifera langsdorffii* Desf., *Pera obovata* (Klotzsch) Baill., *Copaifera langsdorffii* Desf., *Pterogyne nitens* Tul., *Tabebuia alba* (Cham.) Sandwith) (Martin et al., 2012).

During the early second cycle of *Eucalyptus* plantation (first three years of implantation of second harvest cycle in Angatuba), between May 2015 and March 2016, nine monthly sampling campaigns (one week/month) were carried out to monitor all grid nodes within the study area (no data was collected in June and August 2015 due to logistical impediments). Animals were captured in pitfall traps with drift fences (Cechin & Martins, 2000; Lyra-Jorge & Pivello, 2001), which have proved to be an effective method in small-mammals diversity assessments (Umetsu et al., 2006; Dizney et al., 2008, Bovendorp et al., 2017).

Each sampling unit consisted of a Y-shape structure containing four pitfall traps with drift fences (Mengak & Guynn, 1987; Lyra-Jorge & Pivello, 2001; Umetsu et al., 2006). The pitfall traps (100 L buckets) were located at the Y extremes and center, at a distance of 15 m from each other, connected by a plastic net with 80 cm high (buried 10 cm). The buckets had

small holes drilled into the bottom to allow for drainage. A water container and a piece of styrofoam were placed inside each bucket during sampling to prevent animals' dehydration and drowning, respectively. In the monthly sampling campaigns, pitfalls were active for four consecutive nights and monitored every morning, in order to logistically cover all sampling units simultaneously. Individuals were sexed, measured and marked with subcutaneous microchips (Animalltag®) and external ear marks (Ear-punching) and released at the capture site (Martin et al., 2012).

### 2.3.2 Analytical methodology

Estimates 9.1 Windows (Colwell & Elsensohn, 2014) was used to apply a Bootstrap technique in species incidence curves, with campaigns as a sampling unit and 100 random assignments per calculation, for error estimates. The asymptote time series sigmoid model was considered as the estimated number of species per landscape unit, calculated using Minitab 16 software (Minitab Inc., State College, PA, USA).

Sampling effort (*SEf*) was calculated according to the following formula: (proposed by Martin et al., 2012):

$$SEf = nC \times nSD \times nSU \times nPF$$

where *nC* is the number of sampling campaigns, *nSD* the number of sampling days, *nSU* the number of sampling units and *nPF* the number of buckets. The sampling effort was also used to calculate the capture success (*CS*) per species and landscape unit, according with the formula:

$$CS = \frac{TC}{SEf} \times 100$$

where *TC* is the total number of individuals captured (overall and by species) and *SEf* is the sampling effort. The number of captured individuals (overall and by species) (*TC*), together with the sampling effort were also used to calculate an abundance index estimate (*AbI*), as follows:

$$AbI = \frac{TC}{SEf}$$

Thus, the total a priori sampling effort was 2160 trap-night as the product of the total sampling campaigns ( $n = 9$ ) by the number of sampling days ( $n = 4$  per campaign), by the number of sampling units (Y-shape;  $n = 15$  per sampling day per sampling campaign), and by the total number of buckets ( $n = 4$  per sampling unit). The analysis of the spatial–temporal variation of these abundance index estimates for each species within the study area and for the three landscape units was performed in software R (Venables et al., 2009). data distributions were tested with Kolmogorov-Smirnov tests and homoscedasticity was tested using Bartlett's tests. To test for differences in species richness and abundance between the three landscape units considered (native vegetation, abandoned pasture and *Eucalyptus* plantations), one-way analysis of variance (ANOVA) was used (Zar, 2010), together with analysis of means (ANOM – Ott, 1983). The relationship between the types of landscape units and the species composition and relative abundance was evaluated using correspondence analysis (Manly, 1994). The relationship between species richness/number of captured individuals and distance from the border and distance of the water in the native vegetation of matrix was evaluated, applying regression analysis. All of these analyzes were performed using Minitab 16 (Minitab Inc., State College, PA, USA).

The number of individuals detected by the sampling/detectability method (Mackenzie et al., 2002; MacKenzie et al., 2005) was considered as an abundance index. The number of small mammal families detected in the study area was considered as a surrogate of phylogenetic diversity (adapted from Faith & Pollock, 2014). Last but not least, the number of trophic categories of small mammals was used as a proxy of functional diversity (adapted from Dotta & Verdade, 2007, 2009, 2011).

## 2.4 Results

Fifteen small mammal species were detected, nine placental (Order Rodentia) and six marsupials (Order Didelphimorphia), totaling 672 captured individuals (overall capture success: 31.11%), including 92 recaptures (Table 1). The species incidence curves indicate that the sampling effort was sufficient to characterize the small mammals' landscape alpha diversity, between 89% and 95% approximately of the estimated species richness per environment and in the total study area. The non-parametric bootstrap estimator for the species incidence curves per environment estimated an asymptote species richness value for *Eucalyptus* plantations, native vegetation and abandoned pasture of 7.42, 14.38 and 12.36, respectively (Figure 3), which are similar to those actually detected: 7 in *Eucalyptus*; 13 in

native vegetation; and 11 in abandoned pasture (Table 1, Figure 3). The species richness in the whole study area, estimated by the bootstrap procedure was 15.85 (15; 94.6% of the estimated species richness) (Table 2).

During the first cycle of *Eucalyptus* plantation (Table 3), Martin et al. (2012) detected fourteen small mammal species (95% sampling efficiency), ten placental mammals (Order Rodentia) and four marsupials (Order Didelphimorphia), totaling 1640 captured (overall capture success: 32.95%) animals and 155 of which were recapture. Furthermore, the non-parametric bootstrap estimator for the species incidence curves per type environment estimated an asymptote species richness value for *Eucalyptus* plantations, native vegetation and abandoned pasture of 12.82, 12.98 and 11.72, respectively. For each environment, they detected 13 species in *Eucalyptus* plantation; 13 species in native vegetation; and 11 species in abandoned pasture. In this study of the early second cycle of *Eucalyptus* plantation, five new species were detected in study area compared to first cycle of *Eucalyptus* plantation: *Nectomys squamipes*, *Holochilus brasiliensis*, *Marmosa paraguayana*, *Monodelphis* sp. (identified to genus level) and *Oxymycterus delator*. In addition, three species present in the first cycle were not detected on the second: *Juliomys pictipes*, *Cavia aperea* and *Rattus rattus* (exotic species).

All the captured species are classified as of Least Concern by the IUCN Red List (IUCN, 2016) with the exception of *Cryptonanus agricolai*, which is Data Deficient. According to the Decree N° 56.031/2010 of São Paulo state in Brazil also all species are classified as Least Concern, except for *Holochilus brasiliensis*, which is Data Deficient. No endangered species were detected in the present study. The small mammal assemblage of this study is dominated by *Oligoryzomys nigripes* (374 individuals) in all three habitat types (93 in *Eucalyptus* plantation; 159 in native vegetation; and 122 in abandoned pasture) (Figure 4). In the first cycle, *Oligoryzomys flavescens* dominated with 653 individuals.

The species assemblage did not vary in terms of richness ( $F = 3.70$ ;  $df = 14$ ;  $p = 0.056$ ), number of families ( $F = 2.16$ ;  $df = 14$ ;  $p = 0.158$ ) and number of functional groups (trophic categories) ( $F = 1.40$ ;  $df = 14$ ;  $p = 0.284$ ). However, there was a significant difference between environments, in terms of number of individuals captured ( $F = 7.63$ ;  $df = 14$ ;  $p = 0.007$ ), with highest number of individuals captured on the abandoned pasture (Figure 5). Furthermore, there appear to be some species/environment relationships (Venn diagram), *Oxymycterus delator* and *Holochilus brasiliensis* appear to be predominantly associated with anthropic environments (i.e. abandoned pastures), whereas *Cerradomys subflavus*, *Didelphis*

*aurita* and *Monodelphis* sp., appear to be more related with native vegetation (Figure 6). The correspondence analysis first dimension appears to separate open (i.e. pastures) from forest environments (*Eucalyptus* and native vegetation), whereas the second dimension appears to separate the landscape matrix (*Eucalyptus* plantations) from the conservation area (native vegetation) (Figure 7).

The regression analyses suggest that there is no relationship between species richness and number of individual captured and distance from the border of the *Eucalyptus* plantations ( $p=0.490$ ,  $r^2_{aj}=0.375$ ,  $df = 4$ ) ( $p = 0.164$ ,  $r^2_{aj}=0.372$ ,  $df = 4$ ) and the nearest water course ( $p=0.375$ ,  $r^2_{aj}=0.190$ ,  $df = 4$ ) ( $p = 0.489$ ,  $r^2_{aj}< 0.001$ ,  $df = 4$ ) between species and environment (Figure 8-9). The present results also indicate a possible temporal variation within each landscape unit, with vegetation structure changes. For example, some species increase in anthropic environments (e.g. *N. lasiurus* in the *Eucalyptus* plantations and abandoned pasture), but decline in native vegetation (Figure 10).

## 2.5 Discussion

In this study, according to the sampling effort, the total number of estimated species for the study area was similar to the total observed. This result suggests that the diversity was estimated properly given the limitations of the sampling method (Sutherland, 2006). The new species detected in our study area, enhances diversity of the landscape; therefore our first working hypothesis was validated. Likewise, the new small rodents detected are semiaquatic: *Nectomys squamipes* (primary forest vegetation near streams), *Oxymycterus delator* (the wet grasslands known locally as “veredas” and “campos”) and *Holochilus brasiliensis* (riparian and swampy habitats) (Patton et al., 2015). The new marsupials (*Marmosa paraguayana* and *Monodelphis* sp.) are associated with Cerrado biome and forest (Gardner, 2007; Alho, 2005). On the other hand, *Juliomys pictipes* and *Cavia aperea*, inhabit the Atlantic Forest and their distribution includes the state of São Paulo (Patton et al., 2005) and in the first cycle of *Eucalyptus* plantation only 1-3 individuals were collected. Therefore, non-detection is more likely related to methodological constraints (e.g., trap avoidance by the species in question) than to a small population size. For example, *Juliomys pictipes* is a primarily arboreal rodent and species of *Juliomys*, are rarely collected in live traps (Patton et al., 2005). *Cavia aperea*, is primarily associated with grasslands (Patton et al., 2005); however, changes in habitat structure (e.g. conversion of pasture to an arboreal) create spatial and temporal heterogeneity in habitat quality, differentially affecting species with distinct natural histories (Pinotti et al.,

2015).

In the first cycle, the sampling effort was high and their study suggests that agro-silvicultural landscape matrix can have some conservation value in the first years of implementation of *Eucalyptus* plantation, by adding species to the system. Specifically, *Eucalyptus* plantations and abandoned pastures can be considered as habitats which should be considered when managing the area (15% of the richness has only been detected within these habitats). Also, the specific composition of the small mammals' assemblage varied in terms of richness and relative abundance and is not temporally static, changing temporally as the vegetation structure changes (Martin et al., 2012). The sampling efficiency can be considered satisfactory at the present study (second cycle) as new species were detected in the native vegetation and abandoned pasture environments even with a significantly smaller sampling effort both in space and time. Therefore, the maintenance in the long term of an understory within the *Eucalyptus* plantation, may help support small mammal communities, because these patches can increase available niches which enhance carrying capacity of the silvicultural landscape as a whole for the present species (Carrilho et al., 2017).

The species richness observed in the study area (15 species) is similar to that detected in other studies of anthropogenic habitats of São Paulo State (Umetsu & Pardini, 2007a; Martin et al., 2012; Rosalino et al., 2014a; Magioli et al., 2016; Gheler-Costa et al., 2012b). Approximately half of the total species detected (seven species) are characteristic of the Cerrado biome (Mares et al., 1986; Alho, 2005; Gardner, 2007; Carmignotto et al., 2014; Patton et al., 2015). However, the Cerrado biome in its most pristine stage may support 28 genera of terrestrial non-volant small mammals (Vieira & Palma, 2005). Land use change (native vegetation replaced by agro-silvicultural fields) as well as changes in agricultural practices may affect the species diversity, as they have different capacity to adapt to such anthropogenic selective pressures (Verdade et al., 2011). Studies in the Cerrado have suggested a patchy distribution for the nonvolant small mammals which are associated with the distinct habitats in the region (e.g., Mares et al., 1986; Lacher & Alho, 2001; Santos-Filho et al., 2012) with distinct species assemblages found in different areas (Carmignotto et al., 2012). Also, the relative abundance of species varies among localities, and some species can be found in high numbers at a given site, but may be rare or even absent in others (i. e. Marinho-Filho et al., 1994). Usually, most species tend to be locally rare and few are very abundant within all or most assemblages (Vieira & Palma, 2005).

Species abundance appears to vary between present environments (native vegetation

patches, abandoned pasture and *Eucalyptus* plantations). Olifiers et al. (2005) claimed that “the main differences in species composition between areas resulted from changes in habitat characteristics related to habitat heterogeneity”. In some areas of the world, the implementation of agro-ecosystems have increased habitat spatial heterogeneity with the maintenance of both agriculture and native patches in the landscape, which have been beneficial for many mammals, including some generalist species, as well as several opportunistic species (Mills et al., 1991; MacDonald et al., 2007), like *O. nigripes*, *O. flavescens*, *C. tener* and *N. lasiurus*. In all three environments, *O. nigripes* was always one of the first species detected and of greater abundance. This rodent is the most habitat-generalist of all Brazilian *Oligoryzomys* species, occurring in primary and secondary vegetation in Atlantic Forest and Cerrado (Bonvicino & Weksler, 1998) and frequently show high abundances at the edge of small forest fragments, grasslands, and in abandoned pastures (Olifiers et al., 2005). Also, *O. nigripes* is highly mobile, which helps to reduce the chance of predation, and is efficient in searching for resources in habitats with low vegetation cover (Pedó et al., 2010; Taraborelli et al., 2003). In the first cycle, *O. flavescens* was the most dominant and found in both, the Atlantic Forest and gallery forest in Cerrado (Patton et al., 2015). Furthermore, in agroecosystems, *O. flavescens* was associated with high vegetation cover and graminoid richness (Gorosito et al., 2018). Thus, the agro-silvicultural landscape (first and second cycle) is dominated by generalistic and opportunistic rodent species (*O. nigripes*, *O. flavescens*, *C. tener* and *N. lasiurus*). In relation to marsupials, *C. agricolai* and *G. microtarsus* were present in the all environments of the study area, which may indicate a certain improvement of the areas carrying capacity due to the land use changes from pasture (where those species were previously absent (Gheler-Costa et al., 2012) to *Eucalyptus* (Martin et al., 2012)).

In this study, abandoned pastures had the highest number of individuals captured. This result suggests that this habitat which resembles a shrubland, has a high availability of food and shelter small mammals. Occurring in a wide range of habitats (e.g. Khidas et al., 2002; Fischer et al., 2011; Scott et al., 2008), their presence and abundance are strongly influenced by environmental factors such as food, shelter, vegetation structure, habitat type, landscape composition and connectivity, which affect their behavioral ecology (Hansson, 1979, 1982 ; Angelstam et al., 1987; Jensen et al., 2003) and demography (Ecke et al., 2001, 2002 ; Wijnhoven et al., 2005). In agriculture landscapes the heterogeneity of the landscape matrix and surrounding habitats may determine species presence and persistence (Scott et al., 2008;

Sponchiado et al., 2012).

For both the first and the second cycle of *Eucalyptus* plantation had the smaller species richness and relative abundance when compared to the native vegetation and abandoned pasture (see Martin et al., 2012 for the first cycle). However, production forests can provide complementary conservation services (e.g., buffer sensitive areas or protective cover for vertebrates (Barlow et al., 2007; Lindenmayer & Franklin, 2002); and may also enhance connectivity if permeable (Marques et al., 2015); especially if the landscape is also composed by non-forested environments, with intensive human/cattle use (e.g., livestock pastures) (Rosalino et al., 2014). According to Stallings (1990), a higher number of small mammal species is found on non-managed tree plantations (e.g. *Eucalyptus* plantations) with a well-developed native understory. As suggested by Lindenmayer & Hobbs (2004), the maintenance of native understory seems to be an important management technique to increase permeability of homogeneous tree plantations and the *Eucalyptus* plantations can be used as corridors between native habitats. Thus, this may be a crucial management strategy that promotes small mammal abundance (Carrilho et al., 2017). However, in this study area, quite likely because the *Eucalyptus* plantations replaced a formed matrix of exotic pastures, its understory vegetation is still predominantly formed by grass (i.e., *Urochloa* spp., Syn. *Brachiaria*). Also, scattered trees maintained within the plantations due to certification procedures (e.g., Forest Stewardship Council), might be more relevant to biodiversity than the understory vegetation per se (see Athayde et al. 2015 for diversity of trees and Millan et al. 2015 for the diversity of birds in *Eucalyptus* plantations in this study area).

Specifically, *N. lasiurus* and *C. tener* were more abundant in pasture, but there were captures inside forest fragments, demonstrating adaptability in habitat use (Santos-Filho, 2005). *D. aurita* has a preference for forest interiors (Ribeiro et al., 2016), however, this species can also be found at the edge of wetlands and mangroves, as well as in urbanized areas (Graipel & Santos-Filho, 2006). *C. subflavus* is mainly associated to forest formations that occur within the Cerrado (Bonvicino et al., 2014), however together with *C. tener* and *N. lasiurus* favor open areas (Percequillo et al., 2008; Vivo & Carmignotto, 2015). In this study, *C. agricolai* was more abundant in *Eucalyptus* stands, showing that this marsupial can occupy different vegetation strata and cross different types of habitat between fragments of forest and that monoculture *Eucalyptus* are permeable to some species of marsupials (Passamani & Fernandez, 2011). The species *H. brasiliensis* and *O. delator* were only detected in abandoned pasture, possibly due to the proximity of the water, as these species are associated

with riparian habitats (Gardner, 2007). The absence of these species in the first cycle may be related to the vegetation succession (vegetation changes between first and second cycle) and increased complexity, which produce more niches and a wider range of resources. Consequently this results in greater faunal richness and diversity (Gentile & Fernandez, 1999) and the variable patterns of relative abundance found among local species (Martin et al., 2012).

Our results did not detect a relationship between species richness and distance from the border and water in *Eucalyptus* plantations. Thus, in regards to the second hypothesis, no border effect was found within the matrix in relation to small mammal richness at this scale (up to 1km). This result corroborates previous studies in the area (Rosalino et al., 2014), but contradicts other studies focused on diversity in heterogeneous environments (e.g., Barnett et al., 1977; Friend, 1982). In agricultural landscapes, riparian habitats usually have higher availability of resources when compared to open areas, mainly associated with water availability and habitat complexity (Rosalino et al., 2014) and furthermore several other studies that have reported the importance of natural wetland habitats for small mammals (Marques et al., 2015; Michelat & Giraudoux, 2006; Scott et al., 2008). Therefore, the species richness and abundance of rodents near these patches is enhanced (Rosalino et al., 2014). For example, our study in the last campaigns (months with the greatest precipitation), rodent species with semiaquatic mode of life were detected. In the case of *N. squamipes*, the highest number of individual captures was in native vegetation. As this species is often found in flooded grasslands, parts of the matrix may provide suitable habitat (Pires et al., 2005). However, the species that use the matrix as habitat do so apparently homogeneously even up to 1km far from the water course and the riparian vegetation. Of course, those are generalist species.

The specific composition of the small mammals' assemblage is not temporally static. Their abundance (or capturability) vary along the year and along the *Eucalyptus* growth (Martin et al., 2002) and changes in vegetation structure (Penman et al., 2011). Overall, cumulative precipitation usually favoured the abundance of most species, determining small mammal seasonal fluctuations (Marques et al., 2015), by modifying food and refuge availability (Ernest et al., 2000; Milstead et al., 2007). In addition, communities may experience a change in species dominance during succession (Dunn, 2004; Bowen et al., 2007), for example, generalists' species of small mammals occupy a wide range of habitat types. Thus, they are more adaptable to disturbance, whereas specialists' species tend to be

more sensitive because of their habitat requirements (Stephens et al., 2012). In the second cycle of *Eucalyptus* plantations, the abundance and richness of small mammals fluctuated within each landscape unit. Species responses appear to be related to their life-history (Kelly et al., 2013). In comparison with the temporal variation of the first cycle, was similar for some species for each environment (third hypothesis). The first species detected for the two cycles were: *O. flavescens*, *N. lasiurus*, *C. tener* and *A. montensis* in native vegetation; *O. flavescens* and *C. tener* in abandoned pasture; and *O. flavescens*, *C. tener* and *C. agricolai* in *Eucalyptus* plantation; and the last detected species were: *D. albiventris* and *G. microtarsus* in native vegetation; *A. montensis* and *G. microtarsus* in abandoned pasture; *D. albiventris* in *Eucalyptus* plantation. On the second cycle, *O. nigripes* was the most abundant rodent for all months. Thus, generalist characteristics such as the ability to use low-quality environments, often by utilizing different resources based on their availability (Rosalino et al., 2014) means that some species are able to make use of matrix habitats, including the *Eucalyptus* plantations (especially in this first growing phase: 0–3 years). The population of *N. lasiurus* increased in the last two campaigns in both abandoned pasture and *Eucalyptus* plantations, which may be related to the spermatogenic activity significantly increased at the rainy season (January-March) in southeastern Brazil as suggested by Parreira & Cardoso (1993). Likewise, the reproductive pattern of female *N. squamipes* is closely related to availability of fruits and rainfall (Bergallo & Magnusson, 1999) and the highest number of individual captures was in the month of February. Population fluctuations of small mammals in tropics usually related to temporal and environmental variations in resource availability (Bergallo & Magnusson, 1999). However, local factors such as competition with morphologically similar species, habitat heterogeneity and resource availability may play important roles in the variation of abundance of small mammals (Hannibal et al., 2016). Seasonal feedback structures dominated by intra- and inter-specific competitive interactions may be at the basis of the population dynamics of small mammals (Merritt et al., 2001).

## 2.6 Conclusions

- The sampling efficiency can be considered satisfactory in the present study as five new species were detected in the native vegetation and abandoned pasture environments even with a significantly smaller sampling effort both in space and time.
- Species abundance appears to vary between present environments (native vegetation patches, abandoned pasture and *Eucalyptus* plantations).

- Abandoned pastures had the highest number of individuals captured. This habitat which resembles a shrubland, has a high availability of food and shelter small mammals.
- For both the first and the second cycle of *Eucalyptus* plantation had the smaller species richness and relative abundance than the native vegetation and abandoned pasture. However, production forests can provide complementary conservation services and may also enhance connectivity.
- The maintenance of native understory seems to be an important management technique to increase permeability of homogeneous tree plantations and the *Eucalyptus* plantations can be used as corridors between native habitats.
- The relationship between species richness and border/water distance in *Eucalyptus* plantations was not detected, however, riparian habitats, given their resource availability, have a positive effect on species composition.
- The specific composition of small mammal assemblages is not temporally static and in comparison, with the temporal variation of the first cycle, was similar for some species for each environment. However, it is necessary to study longer sampling periods in the dry and rainy season and to consider other aspects such as competition, habitat heterogeneity and resource availability that can also influence in the variation of abundance of small mammals.
- The presence of native vegetation patches associated with riparian areas and abandoned pastures in the *Eucalyptus* plantation matrix and the role of small mammals as a food resource for predators on a trophic structure, gives conservation value to silvicultural landscapes in southeastern Brazil.
- It is necessary to stress that the present results apply only to young (0–3 year old) *Eucalyptus* plantations at the first productive cycle, which lasts 6–7 years from implantation to harvest. In this way, long-term ecological monitoring is required to assess evolutionary and ecological patterns, including spatio-temporal dimensions, of anthropogenic environments.

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## Tables and figures

**Table 1.** Small mammals in silvicultural landscape in the early second *Eucalyptus* plantation cycle.

| Order/Family                        | Species   | Common name                 | Trophic category <sup>1</sup> | Number of individuals captured in pitfall traps |                 |                 |                        |
|-------------------------------------|---|-----------------------------|-------------------------------|---|-----------------|-----------------|------------------------|
|                                     |   |                             |                               | NV <sup>2</sup>                                 | AP <sup>3</sup> | EU <sup>4</sup> | Total (r) <sup>5</sup> |
| Didelphimorphia/<br>Didelphidae     | <i>Cryptonanus agricolai</i> (Moojen, 1943)         | Agricola's Opossum          | Insectivorous / Omnivorous    | 2   | 1               | 9               | 12                     |
|                                     | <i>Didelphis albiventris</i> (Lund, 1840)           | White-eared Opossum         | Frugivorous / Omnivorous      | 2   | 0               | 1               | 3(1)                   |
|                                     | <i>Didelphis aurita</i> (Wied-Neuwied, 1826)        | Big-eared Opossum           | Frugivorous / Omnivorous      | 11  | 0               | 0               | 11(1)                  |
|                                     | <i>Gracilinanus microtarsus</i> (J.A. Wagner, 1842) | Brazilian Gracile Opossum   | Insectivorous / Omnivorous    | 3   | 2               | 4               | 9                      |
|                                     | <i>Marmosa paraguayana</i> (Tate, 1931)             | Tate's Woolly Mouse Opossum | Insectivorous / Omnivorous    | 1   | 2               | 0               | 3                      |
|                                     | <i>Monodelphis sp</i> (Burnett, 1830)               | Short-tailed Opossum        | Insectivorous / Omnivorous    | 1   | 0               | 0               | 1                      |
| Rodentia/<br>Cricetidae             | <i>Akodon montensis</i> (Thomas, 1913)              | Montane Grass Mouse         | Insectivorous / Omnivorous    | 18  | 4               | 0               | 22                     |
|                                     | <i>Calomys tener</i> (Winge, 1887)                  | Delicate Vesper Mouse       | Frugivorous / Granivorous     | 5   | 59              | 10              | 74(12)                 |
|                                     | <i>Cerradomys subflavus</i> (Wagner, 1842)          | Flavescent Cerradomys       | Frugivorous / Granivorous     | 2   | 0               | 0               | 2                      |
|                                     | <i>Holochilus brasiliensis</i> (Desmarest, 1819)    | Brazilian Marsh Rat         | Frugivorous / Herbivore       | 0   | 1               | 0               | 1                      |
|                                     | <i>Necomys lasiurus</i> (Lund, 1840)                | Hairy-tailed Akodont        | Frugivorous / Omnivorous      | 20  | 18              | 5               | 43(3)                  |
|                                     | <i>Nectomys squamipes</i> (Brants, 1827)            | Atlantic Water Rat          | Frugivorous / Omnivorous      | 6   | 1               | 0               | 7                      |
|                                     | <i>Oligoryzomys flavescens</i> (Waterhouse, 1837)   | Flavescent Colilargo        | Frugivorous / Granivorous     | 8   | 83              | 15              | 106(12)                |
|                                     | <i>Oligoryzomys nigripes</i> (Olfers, 1818)         | Black-footed Colilargo      | Frugivorous / Granivorous     | 159   | 122             | 93              | 374(63)                |
|                                     | <i>Oxymycterus delator</i> (Thomas, 1903)           | Spy Hociudo                 | Insectivorous / Omnivorous    | 0   | 4               | 0               | 4                      |
| <b>Total(r)</b>                     |   |                             |                               | 238 (31)  | 297 (36)        | 137 (25)        | 672(92)                |
| <b>Sampling effort (trap-night)</b> |   |                             |                               | 720   | 720             | 720             | 2160                   |

<sup>1</sup> Source: (Paglia et al., 2012)

<sup>2</sup>: NV: Native vegetation

<sup>3</sup>: AP: Abandoned pasture

<sup>4</sup>: EU: *Eucalyptus* plantation

<sup>5</sup>: (r): recaptures

**Table 2.** Sampling efficiency of small mammals in silvicultural landscape.

| Environment                  | r <sub>det</sub> | r <sub>est</sub> | (r <sub>det</sub> /r <sub>st</sub> )% |
|------------------------------|------------------|------------------|---------------------------------------|
| Landscape                    | 15               | 15.8538          | 94.6                                  |
| Native vegetation            | 13               | 14.3838          | 90.4                                  |
| Abandoned pasture            | 11               | 12.3606          | 89.0                                  |
| <i>Eucalyptus</i> plantation | 7                | 7.4236           | 94,3                                  |

**Table 3.** Small mammals in silvicultural landscape in the first second *Eucalyptus* plantation cycle (Martin et al., 2012).

| Order/Family                        | Species   | Common name                  | Trophic category <sup>2</sup> | Number of individuals captured in pitfall traps |                 |                 |                        |
|-------------------------------------|---|------------------------------|-------------------------------|---|-----------------|-----------------|------------------------|
|                                     |   |                              |                               | NV <sup>3</sup>                                 | AP <sup>4</sup> | EU <sup>5</sup> | Total (r) <sup>6</sup> |
| Didelphimorphia/<br>Didelphidae     | <i>Cryptonanus agricolai</i> (Moojen, 1943)         | Agricola's Opossum           | Insectivorous / Omnivorous    | 1   | 14              | 34              | 49                     |
|                                     | <i>Didelphis albiventris</i> (Lund, 1840)           | White-eared Opossum          | Frugivorous / Omnivorous      | 4   | 0               | 5               | 9(2)                   |
|                                     | <i>Didelphis aurita</i> (Wied-Neuwied, 1826)        | Big-eared Opossum            | Frugivorous / Omnivorous      | 6   | 0               | 0               | 6(2)                   |
|                                     | <i>Gracilinanus microtarsus</i> (J.A. Wagner, 1842) | Brazilian Gracile Opossum    | Insectivorous / Omnivorous    | 3   | 1               | 8               | 12(2)                  |
| Rodentia/<br>Cricetidae             | <i>Akodon montensis</i> (Thomas, 1913)              | Montane Grass Mouse          | Insectivorous / Omnivorous    | 66  | 20              | 15              | 101(17)                |
|                                     | <i>Calomys tener</i> (Winge, 1887)                  | Delicate Vesper Mouse        | Frugivorous / Granivorous     | 42  | 145             | 219             | 406(66)                |
|                                     | <i>Cerradomys subflavus</i> (Wagner, 1842)          | Flavescent Cerradomys        | Frugivorous / Granivorous     | 0   | 1               | 1               | 2                      |
|                                     | <i>Juliomys pictipes</i> (Osgood, 1933)             | Small Red-nosed Tree Mouse   | Frugivorous / Omnivorous      | 2   | 0               | 1               | 3                      |
|                                     | <i>Necomys lasiurus</i> (Lund, 1840)                | Hairy-tailed Akodont         | Frugivorous / Omnivorous      | 23  | 36              | 38              | 97(2)                  |
|                                     | <i>Oligoryzomys flavescens</i> (Waterhouse, 1837)   | Flavescent Colilargo         | Frugivorous / Granivorous     | 222   | 204             | 227             | 653(23)                |
|                                     | <i>Oligoryzomys nigripes</i> (Olfers, 1818)         | Black-footed Colilargo       | Frugivorous / Granivorous     | 122   | 42              | 130             | 294(33)                |
|                                     | <i>Oxymycterus</i> sp. (Waterhouse, 1837)           | Spy Hociudo                  | Insectivorous / Omnivorous    | 2   | 3               | 1               | 6                      |
| Caviidae                            | <i>Cavia aperea</i> (Erxleben, 1777)                | Brazilian Guinea Pig         | Herbivore grazer              | 0   | 0               | 1               | 1                      |
| Muridae                             | <i>Rattus rattus</i> <sup>1</sup> (Linnaeus, 1758)  | Rat noir/House Rat/Black Rat | Omnivorous                    | 2   | 0               | 0               | 2                      |
| <b>Total(r)</b>                     |   |                              |                               | 496 (41)  | 473(47)         | 684 (59)        | 1640(147)              |
| <b>Sampling effort (trap-night)</b> |   |                              |                               | 1030  | 893             | 3094            | 4977                   |

<sup>1</sup>: Exotic species

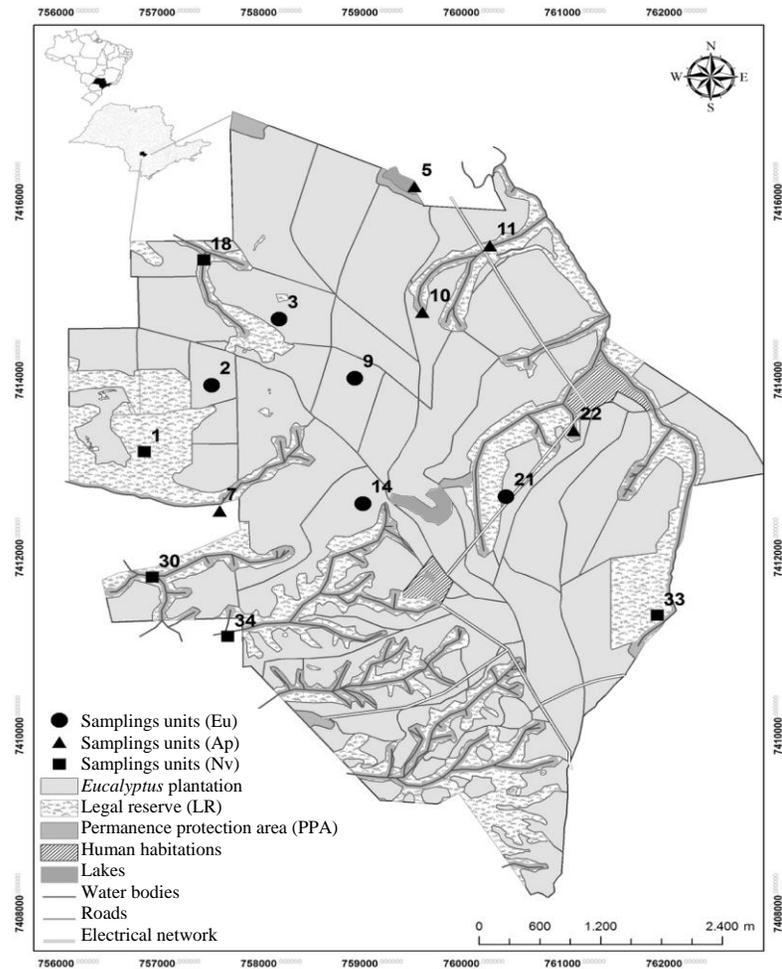
<sup>2</sup>: Source: (Paglia et al., 2012)

<sup>3</sup>: NV: Native vegetation

<sup>4</sup>: AP: Abandoned pasture

<sup>5</sup>: EU: *Eucalyptus* plantation

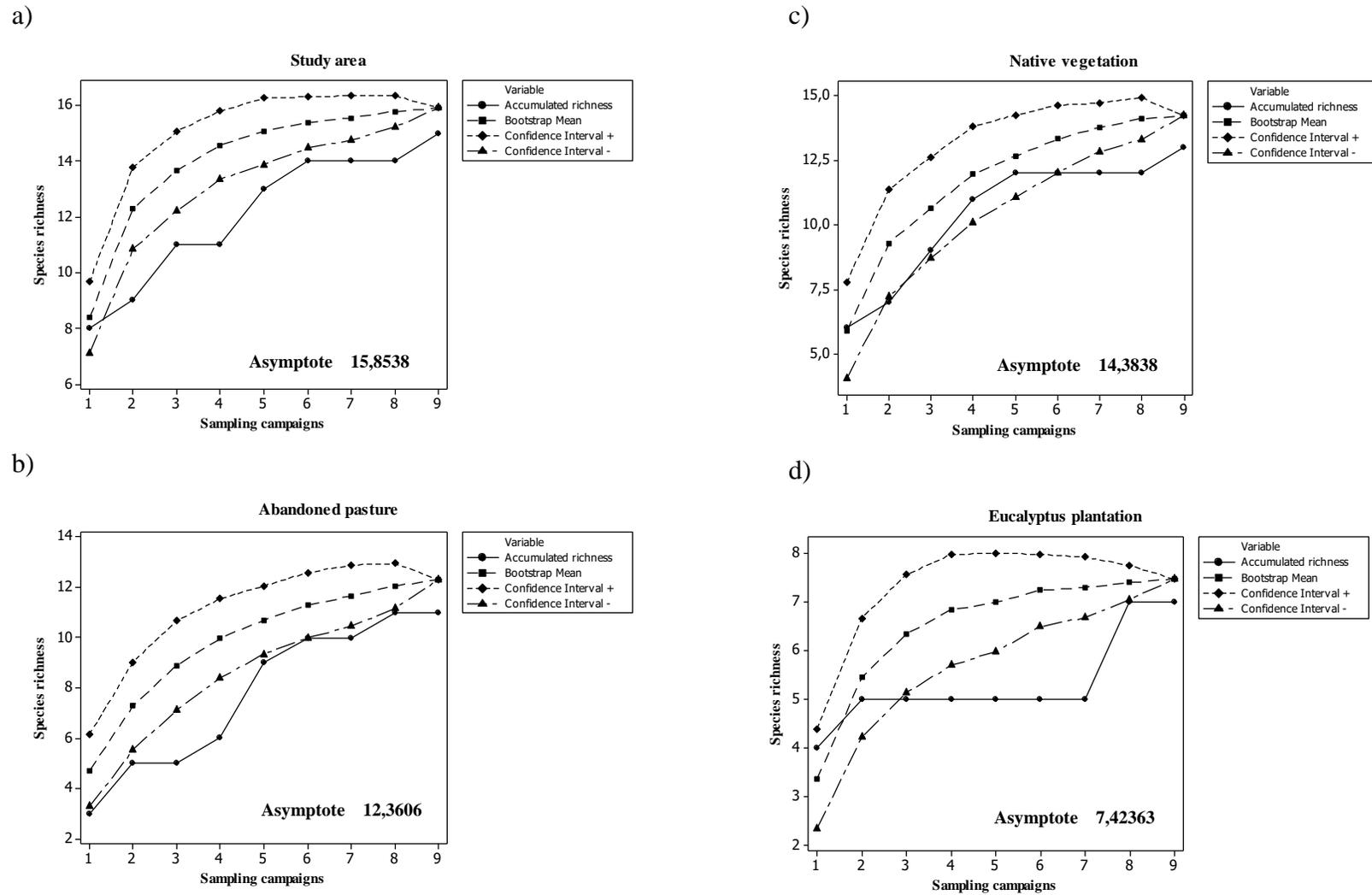
<sup>6</sup>: (r): recaptures



**Figure 1.** Location of Fazenda Três Lagoas, in Angatuba municipality, São Paulo State, Southeastern Brazil. Black bold dots represent sampling units (*Eucalyptus* plantation (Eu), Abandoned pasture (Ap), Native vegetation (Nv)).

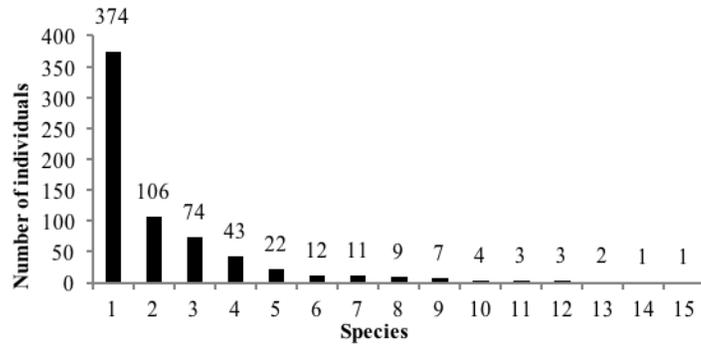


**Figure 2.** Environments of study area: a) Native vegetation, b) Abandoned pasture, c) *Eucalyptus* plantation.



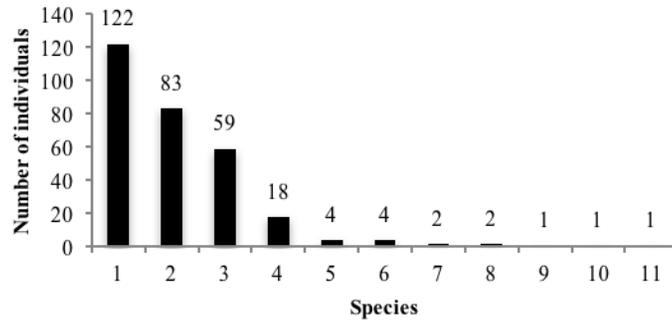
**Figure 3.** Species incidence curves, for each landscape unit and for the system (a: Study area; b: Abandoned pasture; c: Native vegetation; d: *Eucalyptus* plantation).

a)



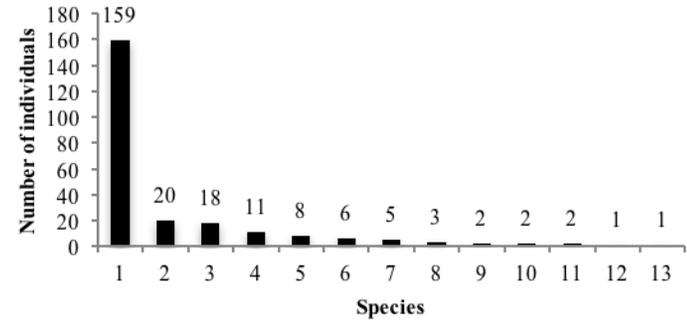
Species: (1) *O. nigripes*; (2) *O. flavescens*; (3) *C. tener*; (4) *N. lasiurus*; (5) *A. montensis*; (6) *C. agricolai*; (7) *D. aurita*; (8) *G. microtarsus*; (9) *N. squamipes*; (10) *O. delator*; (11) *D. albiventris*; (12) *M. paraguayana*; (13) *C. subflavus*; (14) *H. brasiliensis*; (15) *Monodelphis* sp.

b)



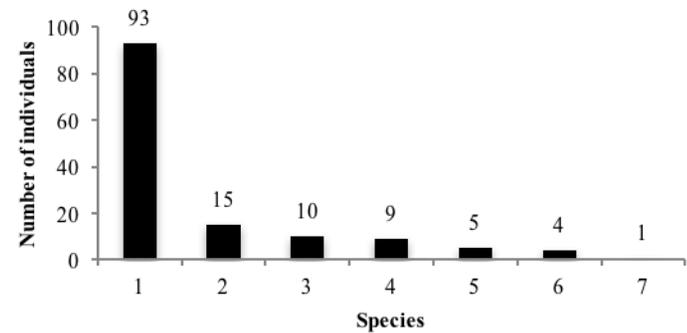
Species: (1) *O. nigripes*; (2) *O. flavescens*; (3) *C. tener*; (4) *N. lasiurus*; (5) *A. montensis*; (6) *O. delator*; (7) *G. microtarsus*; (8) *M. paraguayana*; (9) *C. agricolai*; (10) *N. squamipes*; (11) *H. brasiliensis*.

c)



Species: (1) *O. nigripes*; (2) *N. lasiurus*; (3) *A. montensis*; (4) *D. aurita*; (5) *O. flavescens*; (6) *N. squamipes*; (7) *C. tener*; (8) *G. microtarsus*; (9) *C. agricolai*; (10) *D. albiventris*; (11) *C. subflavus*; (12) *M. paraguayana*; (13) *Monodelphis* sp.

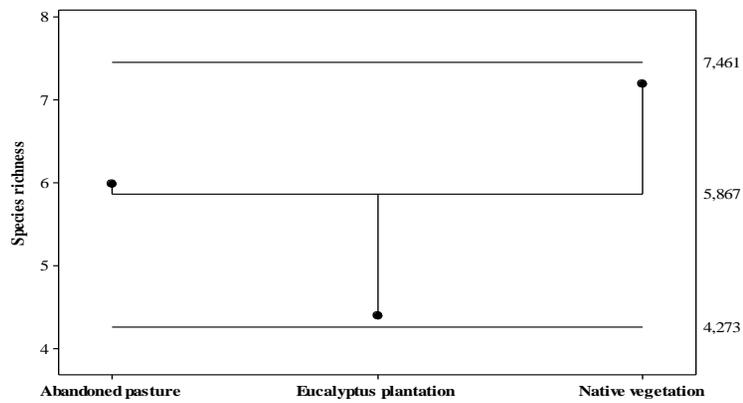
d)



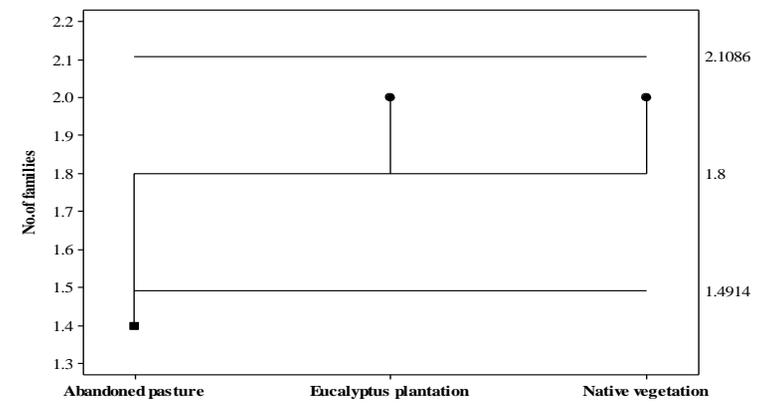
Species: (1) *O. nigripes*; (2) *O. flavescens*; (3) *C. tener*; (4) *C. agricolai*; (5) *N. lasiurus*; (6) *G. microtarsus*; (7) *D. albiventris*.

**Figure 4.** Species accumulation curves, for each landscape unit and for the entire system (a: Study area; b: Abandoned pasture; c: Native vegetation; d: *Eucalyptus* plantation).

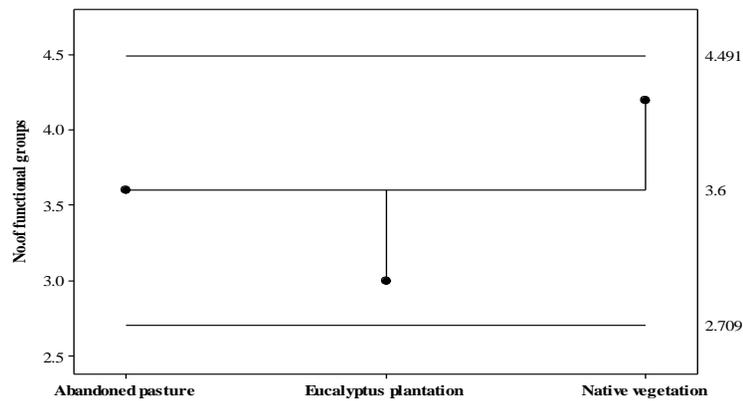
a)



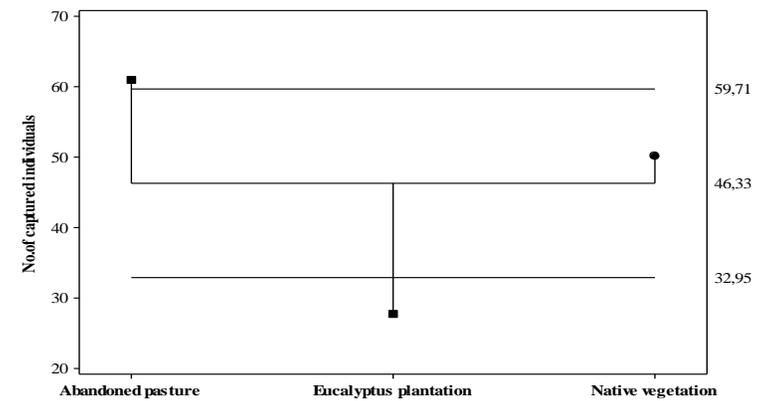
c)



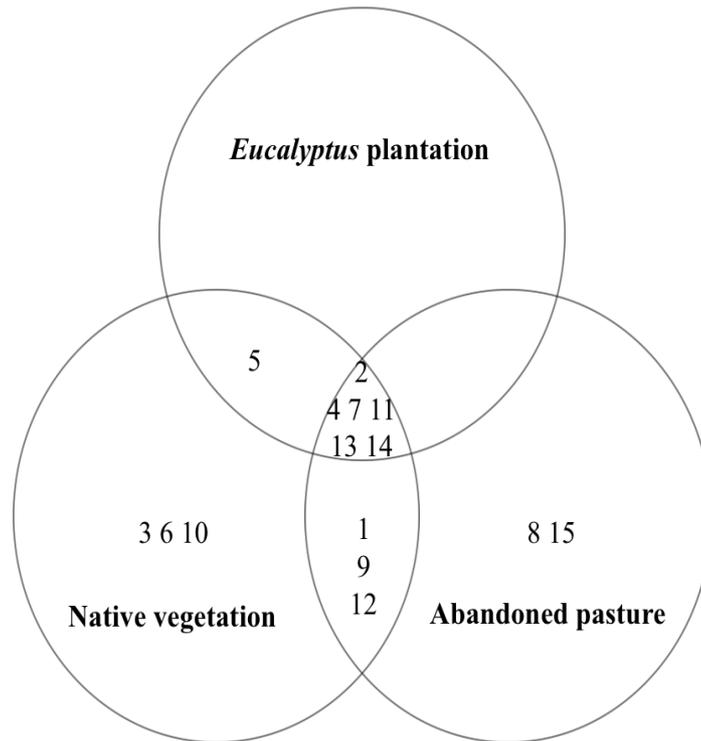
b)



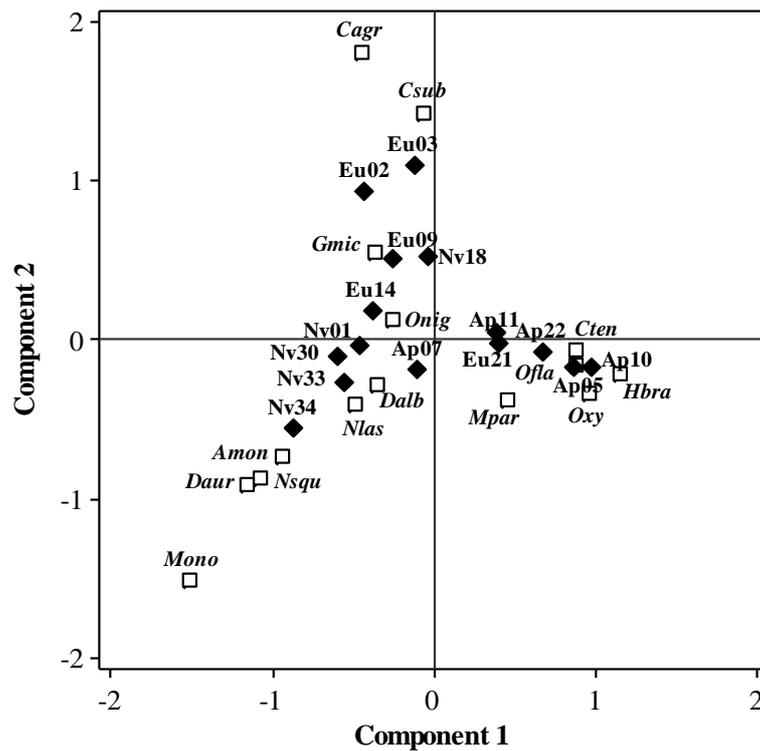
d)



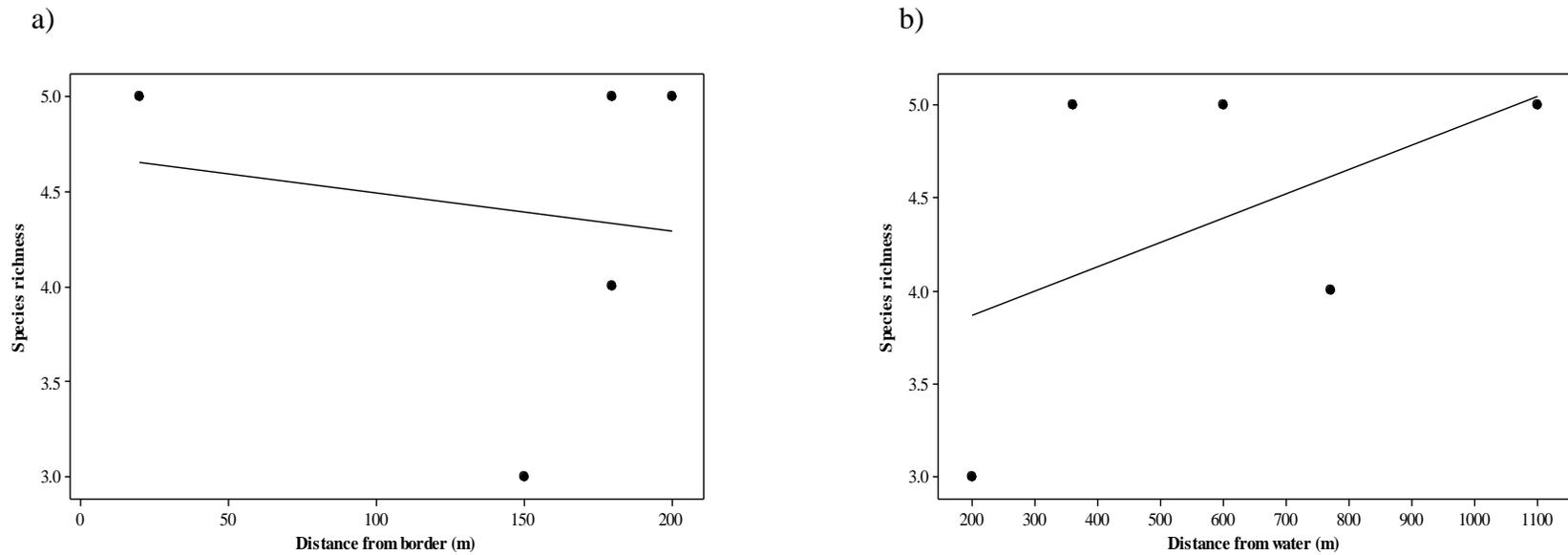
**Figure 5.** Relationship between diversity and abundance of small mammals and present environments in silvicultural landscape dominated by *Eucalyptus* plantations. a) Species richness; b) No. of families; c) No. of functional groups; d) Number of individuals captured. Analysis of means (ANOM):  $p < 0.05$ .



**Figure 6.** Venn diagram: relationship between small mammals and environments components of a landscape dominated by *Eucalyptus* plantations. Species: (1) *Akodon montensis*; (2) *Calomys tener*; (3) *Cerradomys subflavus*; (4) *Cryptonanus agricolai*; (5) *Didelphis albiventris*; (6) *Didelphis aurita*; (7) *Gracilinanus microtarsus*; (8) *Holochilus brasiliensis*; (9) *Marmosa paraguayana*; (10) *Monodelphis* sp.; (11) *Necomys lasiurus*; (12) *Nectomys squamipes*; (13) *Oligoryzomys flavescens*; (14) *Oligoryzomys nigripes*; (15) *Oxymycterus delator*.

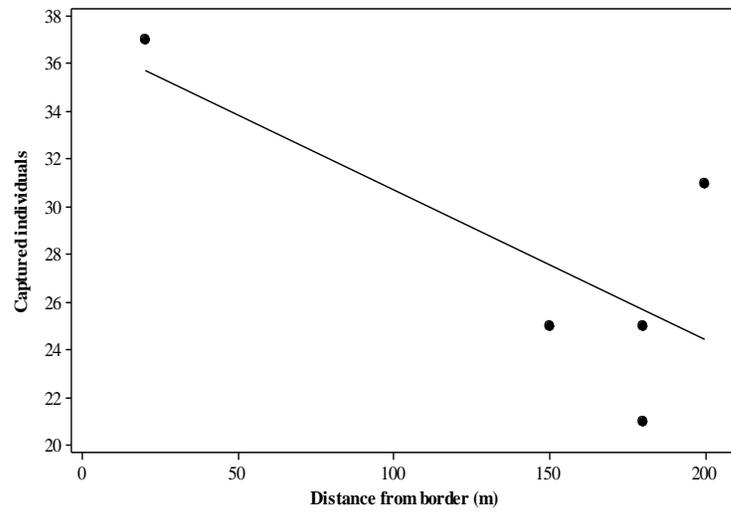


**Figure 7.** Correspondence Analysis plot: small mammals ( $\square$ ) distribution pattern in silvicultural landscape (*Amon* – *Akodon montensis*, *Cten* – *Calomys tener*, *Csub* – *Cerradomys subflavus*, *Cagr* – *Cryptonanus agricolai*, *Dalb* – *Didelphis albiventris*, *Daur* – *Didelphis aurita*, *Gmic* – *Gracilinanus microtarsus*, *Hbra* – *Holochilus brasiliensis*, *Mpar* – *Marmosa paraguayana*, *Mono* – *Monodelphis sp.*, *Nlas* – *Necomys lasiurus*, *Nsqu* – *Nectomys squamipes*, *Ofla* – *Oligoryzomys flavescens*, *Onig* – *Oligoryzomys nigripes*, *Oxy* – *Oxymycterus delator*). Environments ( $\blacklozenge$ ): Native vegetation (Nv); Abandoned pasture (Ap); *Eucalyptus* plantation (Eu).

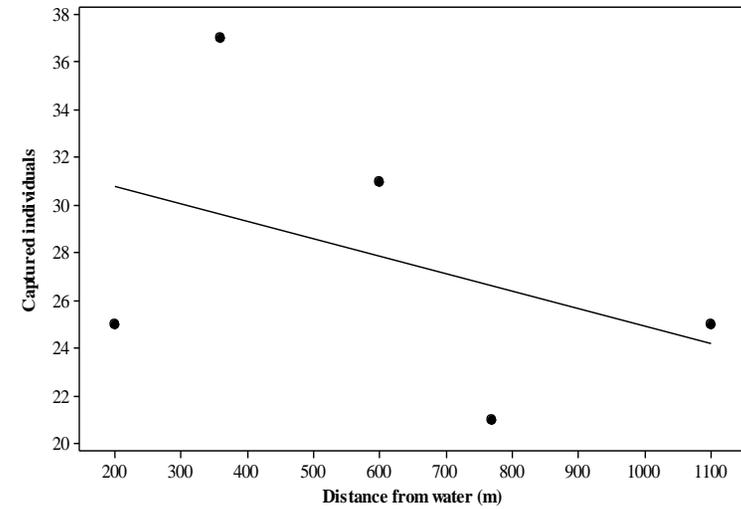


**Figure 8.** Relationship between species richness and distance from the border (a) and distance of the water (b) in *Eucalyptus* plantations.

a)

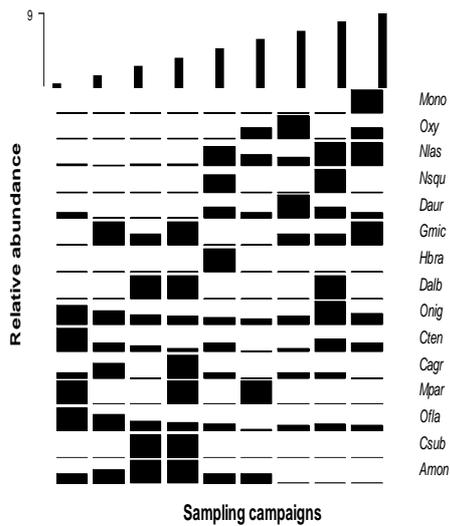


b)

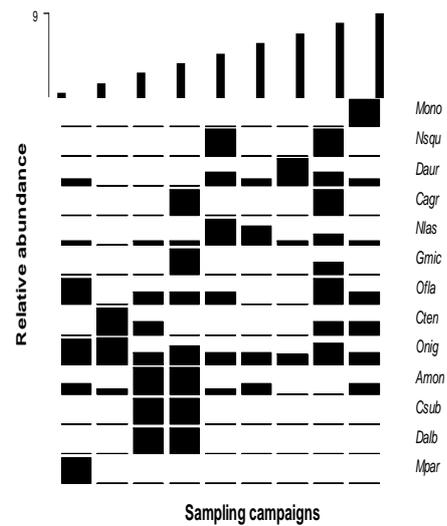


**Figure 9.** Relationship between number of captured individuals and distance from the border (a) and distance of the water (b) in *Eucalyptus* plantations.

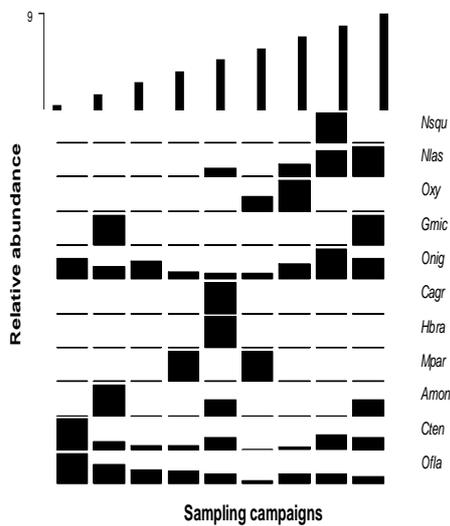
### Study area



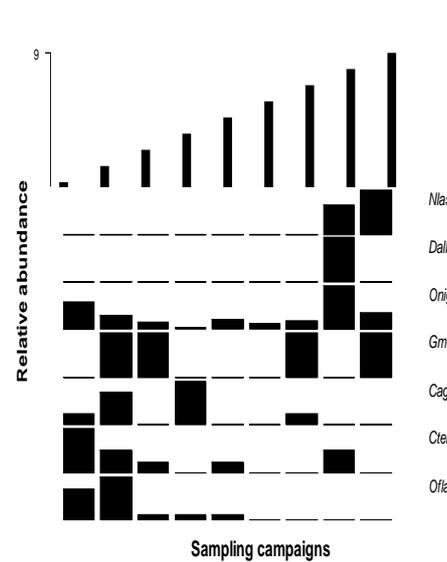
### Native vegetation



### Abandoned pasture



### Eucalyptus plantation



**Figure 10.** Temporal variation in the relative abundance of the different small mammals species detected in the study area (*Mono* - *Monodelphis sp.*, *Oxy* - *Oxymycterus delator*, *Nlas* - *Necomys lasiurus*, *Nsqu* - *Nectomys squamipes*, *Daur* - *Didelphis aurita*, *Gmic* - *Gracilinanus microtarsus*, *Hbra* - *Holochilus brasiliensis*, *Dalb* - *Didelphis albiventris*, *Onig* - *Oligoryzomys nigripes*, *Cten* - *Calomys tener*, *Cagr* - *Crytonanus agricolai*, *Mpar* - *Marmosa paraguayana*, *Ofla* - *Oligoryzomys flavescens*, *Csub* - *Cerradomys subflavus*, *Amon* - *Akodon montensis*).

Top graph in each environment represent the cumulative number of captures per sampling months.

### 3. CHAPTER 2: RELATIONSHIP BETWEEN LANDSCAPE METRICS AND PATTERNS OF DIVERSITY, DISTRIBUTION AND ABUNDANCE OF SMALL MAMMALS IN A SILVICULTURAL LANDSCAPE

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#### **Abstract.**

Small mammals have been considered ecological indicators for having a relatively high abundance and varying responses to spatial and temporal dynamics even inside the agricultural landscapes of southeastern Brazil. However, there is still little information on the possible causes of such abundance. The main goal of this study was to evaluate the relationships between landscape metrics and patterns in diversity, distribution and abundance of small mammals in a silvicultural landscape. From May 2015 to March 2016 monthly sampling campaigns were carried out over a grid of 15 sampling units of pitfall traps, five in *Eucalyptus* plantations, five in native vegetation and five in abandoned pastures. The species richness and family diversity of small mammals was predominantly determined by the percentage of native vegetation and the phylogenetic diversity of small mammals also has been affected by the landscape shape index, both 2D landscape metrics as they are basically related with area. However, the abundance of small mammals can be determined by an indirect estimate of the native vegetation biomass (i.e., NDVI), which can be considered as a 3D landscape metric as it is related to volume. Such patterns suggest native vegetation recovery as one of best strategies to increase conservation value of agricultural landscapes. In addition, the present results support the use of native vegetation biomass as a proxy of small mammals' abundance in agricultural landscapes.

**Keywords:** Biomass. Marsupials. Monitoring of biodiversity. Remote sensing. Rodents. Silvicultural landscapes.

#### **3.1 Introduction**

Landscape ecology uses landscape metrics defined as measurable biotic and abiotic characteristics of the environment to obtain quantitative data concerning ecological resources and landscape functioning (McAlpine & Eyre, 2002). Landscape metrics are often used for the quantification of landscape patterns (Gustafson, 1998) and indicators for landscape functions (Uuemaa et al., 2009). Landscape metrics are common tools of landscape ecologists

and can contribute to the understanding of the relationship between patterns and processes. However, they must perform well in highly fragmented landscapes, where habitat alteration and biodiversity loss have been more dramatic (Corry, 2005). Furthermore, landscape metrics are usually based on remote sensing data, which can provide temporal information on land use (Chmielewski et al., 2014).

Remote sensing can deliver data on habitat quantity (e.g. amount, configuration) and quality (e.g., structure, distribution of species, habitat types and/or communities (He et al., 2011) at differing spatial scales and temporal frequencies (Wulder et al., 2004). Hence, these data are increasingly required in conservation management (Mairota et al., 2015). Additionally, a wide range of remote sensing data sources (e.g., hyperspatial, hyperspectral) and products (e.g., vegetation indices such as the Normalized Difference Vegetation Index (NDVI)) are beginning to be used for ecological monitoring and can play a key role, particularly when coupled with field data (Nagendra, 2001). Such approaches hold great promise for adaptive conservation management, where the integration of remote sensing analyses with field datasets generates impacts on land cover and habitat change (Nagendra & Rocchini, 2008) or fragmentation (Mairota et al., 2013). Likewise, monitoring for biodiversity conservation should include four critical areas of assessment: changes in habitat extent and landscape structure, habitat degradation, alterations in biodiversity, and tracking of pressures and threats within and outside protected areas (Mairota et al., 2013).

Fragmented and human modified landscapes have different types of matrices (Biz et al., 2017), defined by Fahrig (2003) as extensive non-habitat areas surrounding remaining habitat fragments with the matrix being an important element with the landscape mosaic because it affects wildlife habitat. Therefore, to quantify and manage habitat quality for wildlife in modified landscapes, it is necessary to consider the characteristics of both patch and matrix elements of the whole landscape mosaic (Brady et al., 2009). Landscape matrices are increasingly recognised as being important to biodiversity conservation in modified landscapes (Franklin & Lindenmayer, 2009; Kupfer et al., 2006). Nevertheless, most studies that have investigated the influence of landscape structure on species distribution have not considered the heterogeneity of altered habitats of the matrix, which is usually high in human dominated landscapes (Umetsu et al., 2008). The understanding of processes and patterns in fragmented landscapes should take into account the suitability of altered habitats around remnants (i.e., the matrix habitats) for the occurrence of wildlife dispersal (Umetsu et al., 2008). Habitat heterogeneity is an important feature in promoting animal species diversity and

richness, with a large number of species showing positive correlations with vegetation spatial diversity (Tews et al., 2004).

Agricultural landscapes are formed by a matrix of agricultural fields which are agricultural ecosystems (i.e., an agroecosystem), with distinct nutrient cycles and species composition (both usually artificially maintained). Their conservation value is more related to the landscape  $\beta$ -diversity than to the matrix  $\alpha$ -diversity (Verdade et al., 2014a). Also, animals can perceive levels of matrix quality and modify their movement behavior in order to minimize risks and maximize benefits according to each environment (Zollner & Lima, 2005; Cornelius et al., 2017). For example, Millan et al (2015) suggest that site occupancy by birds is positively associated with increasing spatial complexity within *Eucalyptus* stands, with species responding to the retention of native scattered trees and the presence of understory. Other authors suggest that the matrices can have different degrees of permeability depending on their vegetation structure, acting as either a complete or a semipermeable barrier (Gascon et al., 1999; Castellón & Sieving, 2006; Driscoll et al., 2013;). For example, Biz et al (2017) propose for the birds that the *Eucalyptus* plantation is the highest quality matrix; that is, with lower risk (lower density of predators and vegetation cover), with higher permeability and more benefits because of food availability.

Mammals have been considered ecological landscapers (Sinclair, 2003) and small mammals are well known for their variable responses to spatial and temporal dynamics (Whitford, 1976; Brown & Kurzius, 1987; Brown & Zeng, 1989), even inside the matrix (e.g., Martin et al., 2012). Furthermore, small rodents and marsupials are the most diverse ecological group of Neotropical mammals (Fonseca et al., 1996; Costa et al., 2005), thus considered as good indicators of habitat disturbance (Pardini, 2004; Wijesinghe & Brooke, 2005; Lambert et al., 2006; Umetsu & Pardini, 2007; Gheler-Costa et al., 2012; Martin et al., 2012; Rosalino et al., 2014) and fragmentation (Viveiros De Castro & Fernandez, 2004; Pardini et al., 2005), also playing an important role in forest regeneration (Brewer & Rejmánek, 1999). Also, small mammals are a potential group for studying and modeling the effects of human activities on biodiversity in tropical forest landscapes, because of their short life cycles, easy capture, relatively well-known taxonomy (Umetsu et al., 2008) and their capacity to respond to landscape disturbance on a small scale (Corry, 2005; Rosalino et al., 2013).

Mammalian species richness is usually considered as an effective indicator for prioritizing biodiversity conservation in environmental decision-making (Ramesh et al., 2016). However, species richness may be biased by a recent evolutionary history, whereas

phylogenetic and functional diversity can be, respectively, related to the long-term evolutionary process and to ecological processes (Faith & Pollock, 2014). The relationships between species richness and relative abundance provide a momentary pattern in biological diversity (Magnusson, 2002b; Bonar et al., 2010), which varies along the time in response to evolutionary and ecological processes, especially in terms of trophic structure (Verdade et al., 2014b).

Conservation priorities based on maximizing species richness may ensure the conservation of phylogenetic diversity (e.g. Rodrigues & Gaston (2002)) and their measure provides a way to quantify biodiversity values (Faith & Pollock, 2014). Additionally, alterations in food resources availability and spatial-temporal heterogeneity tend to act as selection forces towards individuals. On a single generation time scale, individuals tend to respond to such alterations by behavioral change (or acclimation) in relation to two basic behavioural-ecological processes: feeding ecology (food resources availability) and use of space (the land use change in spatial terms (Tuytens & MacDonald, 2000; Dotta & Verdade, 2007; Verdade et al., 2011)).

Additionally, landscape metrics can be used to evaluate species richness of mammals (Ramesh et al., 2016) in two and three dimensions. However, studies that quantify the complexity of the 2D landscape do not clearly link the patterns to the processes (Li & Wu, 2004; Cushman et al., 2008). One way to interpret this link is to examine what aspect of 3D vegetation is being captured by landscape metrics (Monmany et al., 2015). For example, surface metrics represent quantitative measurements that vary continuously across the landscape and the data can be conceptualized as representing a three-dimensional surface (e.g., biomass) (McGarigal, 2015). However, estimates of biomass in complex environments, such as forests, are still relatively imprecise (Lillesand et al., 2004) and their relation to the richness and abundance of individuals of wild fauna and flora species is practically unknown (Green et al., 2005). Moreover, there is little information about the effect of landscape metrics on ecological functions and species functional traits (Magioli et al., 2016).

In this context, the main objective in this study was to evaluate the relationship between landscape metrics and patterns of diversity, distribution and abundance of small mammals in a silvicultural landscape. The working hypotheses is that the diversity and abundance of small mammals can be estimated from 2D and 3D landscape metrics.

### **3.2 Study area**

This study was carried out in Angatuba municipality, São Paulo State in Southeastern

Brazil, comprising Fazenda Três Lagoas (23°22'0''–23°20'41''S/48°28'0''–48°27'57''W), located in the Alto Paranapanema water basin and encompassing 3242 ha (Figure 1). The local climate is subtropical (Cwa in Köppen climate classification) with average temperatures ranging from 17.1 °C to 24.1 °C along the year; the rainy period is generally from October to March, and the dry period is from April to September (data from Centre of Meteorological and Climate Research Applied to Agriculture- CEPAGRI).

Angatuba is in a transition zone between the semi-deciduous Atlantic Forest and Cerrado. The native vegetation was replaced by cotton and coffee plantations between 1870 and 1930. At the time of the economic crisis of 1929, agriculture collapsed and native vegetation began to recover. In the 1970's intensive forest clearing occurred which was to be replaced by pasture lands based on exotic grasses (*Urochloa* spp., Syn. *Brachiaria*) (Lisboa, 2008). Between August 2006 and November 2007, 2224 ha of the exotic pasture in Fazenda Três Lagoas was converted into *Eucalyptus* production forests, and the remaining area was allocated for natural revegetation (896 ha) in order to attend the Brazilian Forest Code (Martin et al., 2012; Athayde et al., 2015; Rosalino et al., 2014).

### 3.3 Methodology

#### 3.3.1 Sampling methodology

Small mammal surveys were conducted in native vegetation patches, abandoned pastures and *Eucalyptus* production forests. Fifteen sampling units were defined, five in each environment from the original grid design, where sampling units are located at 1km from each other. This is an adaptation of the Biodiversity Research Program methodology (Magnusson et al., 2005). The patches of native vegetation are composed by second growth fragments of Cerrado sensu stricto (dominated by *Anadenanthera falcata* (Benth.) Speg., *Caryocar brasiliense* Cambess., *Dimorphandra mollis* Benth., *Stryphnodendron adstringens* (Mart.) Coville and *Roupala montana* var. *paraensis* (Sleumer) K.S. Edwards), “cerradão” (forest type Cerrado dominated by *Xylopia brasiliensis* Spreng., *Miconia chartacea* Triana, *Tapirira guianensis* Aubl., *Amaioua guianensis* Aubl., *Siparuna guianensis* Aubl., *Persea pyrifolia* (D. Don) Spreng., *Copaifera langsdorffii* Desf., *Picea obovata* Ledeb. and *Machaerium villosum* Vogel) and riparian forest (dominated by *Calophyllum brasiliense* Cambess., *Nectandra megapotamica* (Spreng.) Mez, *Sorocea bonplandii* (Baill.) W.C. Burger, Lanj. & Wess. Boer, *Gymnanthes concolor* (Spreng.) Müll. Arg., *Bauhinia* sp. L., *Croton floribundus* Spreng. and *Piptadenia gonoacantha* (Mart.) J.F. Macbr.) (Athayde, 2013). Exotic annual and perennial herbaceous species of the Poaceae family dominate the patches of abandoned pastures, with

the presence of woody individuals of low stature, mainly of the families Fabaceae, Myrtaceae and Caryocaraceae. The production forests are composed mostly by *Eucalyptus grandis* W. Hill, *E. urophylla* S.T. Blake and their hybrid *E. grandis*, with practically no understory vegetation, but with some native trees (*Copaifera langsdorffii* Desf., *Pera obovata* (Klotzsch) Baill., *Copaifera langsdorffii* Desf., *Pterogyne nitens* Tul., *Tabebuia alba* (Cham.) Sandwith) (Martin et al., 2012).

During the early second cycle of *Eucalyptus* plantation (first three years of implantation of second harvest cycle in Angatuba), between May 2015 and March 2016, nine monthly sampling campaigns (one week/month) were carried out to monitor all grid nodes within the study area (no data was collected in June and August 2015 due to logistical impediments). Animals were captured in pitfall traps with drift fences (Cechin & Martins, 2000; Lyra-Jorge & Pivello, 2001), which have proved to be an effective method in small-mammals diversity assessments (Umetsu et al., 2006; Dizney et al., 2008, Bovendorp et al., 2017).

Each sampling unit consisted of a Y-shape structure containing four pitfall traps with drift fences (Mengak & Guynn, 1987; Lyra-Jorge & Pivello, 2001; Umetsu et al., 2006). The pitfall traps (100 L buckets) were located at the Y extremes and center, at a distance of 15 m from each other, connected by a plastic net with 80 cm high (buried 10 cm). The buckets had small holes drilled into the bottom to allow for drainage. A water container and a piece of styrofoam were placed inside each bucket during sampling to prevent animals' dehydration and drowning, respectively. In the monthly sampling campaigns, pitfalls were active for four consecutive nights and monitored every morning, in order to logistically cover all sampling units simultaneously. Individuals were sexed, measured and marked with subcutaneous microchips (Animalltag®) and external ear marks (Ear-punching) and released at the capture site (Martin et al., 2012).

To obtain the plant biomass data, each sampling unit consisted of plots with dimensions of 10 x 30 m, sub-divided into 3 subplots of 10 x 10 m were installed. Diameter measurements were taken at 1.3 m height of all arboreal individuals with Circumference at Breast Height (CBH) equal to or greater than 15 cm, using a tape measure. Individuals were marked with nameplates. The landscape metrics, equations, units, range and descriptions are presented in Table 1. Among them, two-dimensional (2D) (e.g. fractal dimension index, effective meshsize and shape index and percentage native vegetation patches) and three-dimensional (3D) (e.g. NDVI and biomass of native vegetation patches) were used. The 2D metrics are related to patterns of patch shape and are based on perimeter-area relationships.

The 3D metrics are related to the volume (i.e., biomass) of the native vegetation (McGarigal, 2015). In addition, different buffer sizes were used to test a possible effect of spatial scale between the landscape metrics and patterns of small mammals' diversity.

### **3.3.2 Analytical methodology**

Ninety-six regressions were tested between 24 independent variables related to landscape metrics and four dependent variables related to the diversity of small mammals using Minitab 17 software (Minitab Inc., State College, PA, USA). The landscape-independent variables are 2D and 3D, respectively related to area land and biomass of the native vegetation (Table 1). Dependent variables refer to measures of diversity and abundance of small mammals (Table 2). The relationship between the patterns of diversity and abundance of small mammals was tested by correlation analysis (Pearson).

The number of individuals detected by the sampling / detectability method (Mackenzie et al., 2002; MacKenzie et al., 2005) was considered as an abundance index. The number of small mammal families and tribes detected in the study area was considered as a surrogate of phylogenetic diversity (adapted from Faith & Pollock, 2014). Last but not least, the number of trophic categories of small mammals (adapted from Dotta & Verdade, 2007, 2009, 2011), was used as a proxy of functional diversity.

## **3.4 Results**

The sampling effort of 2160 trap-nights yielded a total of 15 species of nine placental (Order Rodentia) and six marsupials (Order Didelphimorphia), totaling 672 captured individuals, including 92 recaptures (Table 3). Of the 96 regressions tested, eight (9%) were considered significant ( $p < 0.05$ ;  $0.130 \leq \text{radj}^2 \leq 0.675$ ) (Table 4). In general, 2D metrics prevailed as predictors of small mammal diversity whereas metrics related to their abundance (Tables 4-5, Figures 2-10).

In addition, there was a significant correlation between biomass estimates of native vegetation in the field and NDVI (Table 6). There are also significant correlation between the taxonomic diversity and functional diversity of the small mammals (Table 6). Thus, our hypothesis was validated. Taxonomic and phylogenetic diversity of small mammals can be estimated based on 2D metrics (e.g., percentage of native vegetation and shape index) and abundance of small mammals can be estimated based in 3D metrics (e.g., NDVI).

### 3.5 Discussion

The 2D landscapes metrics results revealed that the relationships between species richness and percentage of native vegetation was significant when working on a spatial scale up to a buffer of 250–500 m. Relationships between the diversity of small mammal families with the percentage of native vegetation in a buffer of 50 and 100 m and relationship between the diversity of small mammal tribes with the percentage of native vegetation in a buffer of 500 m were also identified. This corroborates what several authors have proposed, in which demographic variability in small mammal populations occurs over relatively short distances (100 m) (Krohne & Burgin, 1990; Bowman et al., 2000; Bowman et al., 2001). However, a buffer of 250–500 m produced a contrasting result because long-distance movements in small mammals (longer than 100 m) are rare and were not significantly associated with their abundance (Krohne & Burgin, 1990; Gentile & Cerqueira, 1995; Bowman et al., 2000, 2001; Pires et al., 2002; Umetsu et al., 2008). In this way, movement patterns of animals closely follow the structure of the environment and with a broad distribution of long movements alternating with a concentration of shorter moves in selected patches might be most suitable for movement in heterogeneous forests (Wells et al., 2006). The present results stress the importance of patches of native vegetation in the matrix, for the conservation of the biodiversity of small mammals and therefore, to increase conservation value of agricultural landscapes.

Furthermore, relationship between diversity of small mammals' families and shape index in a buffer 50, 100 and 250 m was also significant. Shape index measures the complexity of patch (McGarigal, 2015), thus, the interaction of patch shape and size may influence several important ecological processes; for example in the dispersal of small mammals between patches (Buechner, 1989). Also, shape is one example of the state-space measures of landscape features and represent spatial characteristics based on fragmentation pattern, rather than providing immediate insights on the fragmentation process (Trzcinski et al., 1999; Lee et al., 2002; Fahrig, 2003; Timo et al., 2016). Additionally, phylogenetic diversity was represented by the diversity of families and tribes and is now recognized as a basis for setting conservation priorities among species or areas (Faith, 1992; Mace, 2003; Forest et al., 2007). Also, Faith & Pollock (2014) claimed that: “the PD measure reflects expected patterns of feature diversity among species and so provides a way to quantify biodiversity option values” (p.48).

Additionally, the increase in *Eucalyptus* stands shape complexity may well reflect the increase of natural vegetation within the landscape. Also, more complex shapes of *Eucalyptus*

strands may represent higher length and complexity of contacts with native vegetation (Timo et al., 2016). This is likely to favor directly the occurrences of large herbivores and indirectly foster the subsistence of omnivorous and insectivorous species (e.g., small mammals) (Fletcher, 2005; Fleury & Galetti, 2006; Fischer & Lindenmayer, 2007; Taylor et al., 2008; Pawson et al., 2009). According to Biz et al (2017), quantifying the effects of the matrix type provides information on the behavior of the movement and on the persistence of species in fragmented landscapes, for example, in areas with greater permeability, *Eucalyptus* plantations around remnants of isolated native vegetation. In this way, relatively simple indices can improve our understanding of species distribution, and could be applied in modeling, monitoring and managing complex tropical landscapes (Umetsu et al., 2008). Also, the advantage of using two-dimensional data is that the location of an ecotone can be detected along with complementary information about the variation of its width and shape (Fortin, 1994)

With respect to 3D landscape metrics, there was a significant relationship between abundance mammals and the NDVI in a buffer of 250 m. These results support the use of native vegetation biomass as a proxy of small mammal abundance in agricultural landscapes. Therefore, wildlife species or groups, such as small mammal species, have the potential to tell us about the functional effects of changes in forest structure and they have the potential to function as ecological indicators (Pearce & Venier, 2005). Likewise, changes in NDVI (e.g., seasonal) can be used to estimate the increase in vegetation “greenness” that may elicit a response from primary consumers like small mammals (Reed et al., 1994; Smith et al., 2017). Verschuyt et al (2011) suggests the intensive production of biomass in forests, which supports a large proportion of biodiversity, can change the composition of species, the nutrient cycle and, later, the biodiversity of the habitat. Thus, small mammals can be good indicators of sustainable forest management, because they can be used to provide information on the structure and dynamics of biodiversity (Teder et al., 2007; Trivellone et al., 2014) and can assist public policy, local managers and stakeholders in decision-making processes (Balmford, 2005; Rüdissler et al., 2012); for example, management agricultural areas in the “Brazilian Forest Code”. Likewise, such results may be important for public health, because of the transmission of several zoonoses from wildlife to humans, where small mammals may act as wild reservoirs of hantavirus disease, hemorrhagic fever, trypanosomiasis, leishmaniasis, among others (Bonecker et al., 2009). For example, *N. squamipes* was reported as an important wild reservoir of Schistosomiasis (Bonecker et al., 2009), the Sigmondontinae rodents (e.g., tribes: Oryzomyini, Phyllotini, Akodontini) have been described as important

host of hantaviruses (Mills & Childs, 1998) and species of genus *Oligoryzomys* sp., *Akodon* sp. and *Necomys* sp. are considered the most important reservoirs of this zoonoses (Lemos & Silva, 2005; Suzuki et al., 2004).

The present results show that there is a significant correlation between biomass estimates of native vegetation in the field and NDVI. Such a relationship should be investigated in future studies in order to allow the extensive use of remote sensing in monitoring biodiversity. Nagendra et al (2013) suggest the use remote sensing in conjunction with field datasets on biodiversity distributions in different management zones for effective adaptive management and monitoring. Additionally, there are other studies that suggest other landscape metrics for the management of heterogeneous habitats. Gonçalves et al (2012) suggest that variables measuring complexity of land uses (e.g., Mean Patch Edge and Mean Shape Index) exerted a positive influence on small mammal richness. Also, they suggest that for the overall mammal community, the positive influence of habitat diversity is displayed at the shrub cover level, being most relevant when interacting with unfavorable habitats such as pine stands (Gonçalves et al., 2012).

Also, these results suggest significant correlation between the taxonomic diversity and functional diversity of the small mammals. Such correlations may be related to ecological and evolutionary causal relationships, and should be prioritized in future studies on the subject. However, in order to be sustainable, agriculture depends on wild lineages of agricultural crops for genetic improvement (resistance to pathogens to different soil fertilities, climate change (Tanksley & McCouch, 1997). These wild genes depend on the maintenance of the evolutionary process of populations, which is only possible *in situ*. For this reason, agricultural landscapes should incorporate a second but also crucial mission: the conservation of wild species (Verdade et al., 2014a).

### **3.6 Conclusions**

- The taxonomic and phylogenetic diversity of small mammals have been predominantly correlated to the percentage of native vegetation.
- The phylogenetic diversity there represent by the diversity of families of small mammals has been affected by the landscape shape index.
- The abundance of small mammals has been determined by an indirect estimate of the native vegetation biomass (i.e., NDVI), which can be considered a 3D landscape metric as it is related to volume.

- The present results support the use of native vegetation biomass as a proxy of small mammal abundance in agricultural landscapes and the native vegetation recovery as one of the best strategies to increase conservation value of agricultural landscapes.
- Small mammal species have the potential to function as ecological indicators and the landscape metrics can be a useful tool for multidisciplinary frameworks when it comes to integrating ecological approaches into management of agricultural landscapes.
- It is necessary to stress that the present results apply only to the transition area between Atlantic Forest and Cerrado in the state of São Paulo, Brazil. Similar studies should be prioritized in other areas in order to enhance its applicability as the patterns here detected tend to be context-specific.
- Long-term ecological monitoring will allow to evaluate evolutionary and ecological patterns, including the spatial-temporal dimensions, of the anthropic environments. The present methodology might be helpful in such circumstance.

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## Tables and figures

**Table 1.** 2D and 3D landscape metrics.

| Landscape metrics                                   | Unit      | Equation | Range   | Description  |   |
|---|-----------|----------|---|--|---|
| <b>2D</b>   |           |          |   |  |   |
| Fractal Index <sup>1</sup>                          | Dimension | None     | $FRAC = \frac{2 \ln(.25 p_{ij})}{\ln a_{ij}}$ <p><math>p_{ij}</math> = perimeter (m) of patch ij.<br/> <math>a_{ij}</math> = area (m<sup>2</sup>) of patch ij.</p>                                  | $1 \leq FRAC \leq 2$<br><br>1 for simple shapes and 2 for complex shapes.  | FRAC reflects shape complexity across a range of spatial scales (patch sizes).  |
| Effective meshsize <sup>1</sup>                     | Ha        | None     | $MESH = \frac{\sum_{j=1}^n a_{ij}^2}{A} \left( \frac{1}{10.000} \right)$ <p><math>a_{ij}</math> = area (m<sup>2</sup>) of patch ij.<br/> <math>A</math> = total landscape area (m<sup>2</sup>).</p> | Ratio of cell size to landscape area<br>$\leq MESH \leq$ total landscape (A)<br><br>Lower limit: consist of a single one pixel patch and is maximum: the landscape consists of a single patch. | MESH gives the area- weighted mean patch size of patches of the corresponding patch size. The proportional area of each patch is based on the total landscape area.   |
| Shape Index <sup>1</sup>                            | None      | None     | $SHAPE = \frac{.25 p_{ij}}{\sqrt{a_{ij}}}$ <p><math>p_{ij}</math> = perimeter (m) of patch ij.<br/> <math>a_{ij}</math> = area (m<sup>2</sup>) of patch ij.</p>                                     | $SHAPE \geq 1$ , without limit.<br><br>$SHAPE = 1$ , when the patch is square and increases without limit as patch shape becomes more irregular.   | Shape index corrects for the size problem of the perimeter-area ratio index by adjusting for a square standard and, as a result, is the simplest and perhaps most straightforward measure of shape complexity.  |
| <b>3D</b>   |           |          |   |  |   |
| Normalized Difference Vegetation Index <sup>2</sup> | None      | None     | $NDVI = \frac{(\rho_{NIR} - \rho_{red})}{(\rho_{NIR} + \rho_{red})}$ <p><math>\rho_{NIR}</math>: near infrared reflectance.<br/> <math>\rho_{red}</math>: red bands reflectance.</p>                | Number that ranges from minus one (-1) to plus one (+1).<br><br>A zero means no vegetation and close to +1 (0.8 - 0.9) indicates the highest possible density of green leaves.                 | It estimates the biomass and is computed from the near infrared and red parts of the electromagnetic spectrum and provides a measure of absorption of red light by plant chlorophyll as well as the reflection of infrared radiation by water-filled cells. |
| BiomassNV <sup>3</sup>                              | Kg        | None     | $TAGB = \exp(-2.265242 + 2.406563^* \log(DBH))$ <p>TAGB: Total aboveground biomass (kg).<br/>           DBH: Diameter at Breast Height (cm).</p>  |  | For the quantification of biomass in native vegetation patches, the proposed model for the Semideciduous Seasonal Forest was used. The proposed fixed effect model uses only the variable diameter.   |

Source: <sup>1</sup>(McGarigal, 2015). <sup>2</sup>(Huete et al., 2002; Ahamed et al., 2011).<sup>3</sup>(Sotomayor, 2013).

**Table 2.** Dependent (predictor) and independent variables used in the present study.

| <b>Variable type</b> | <b>Initials</b>  | <b>Description</b>  |
|----------------------|--|---|
| Independent          | %NV50  | Percentage of native vegetation in a buffer of 50 m diameter          |
|                      | FDI50  | Fractal dimension index in a buffer of 50 m diameter (Dimensionless)  |
|                      | EM50   | Effective meshsize in a buffer of 50 m diameter (m <sup>2</sup> )     |
|                      | ShapeIndex50   | Shape index in a buffer of 50 m diameter (Dimensionless)              |
|                      | NDVI50   | NDVI in a buffer of 50 m diameter                                     |
|                      | BiomassVN50  | Biomass of native vegetation in a buffer of 50 m diameter             |
|                      | %NV100   | Percentage of native vegetation in a buffer of 100 m diameter         |
|                      | FDI100   | Fractal dimension index in a buffer of 100 m diameter (Dimensionless) |
|                      | EM100  | Effective meshsize in a buffer of 100 m diameter (m <sup>2</sup> )    |
|                      | ShapeIndex100  | Shape index in a buffer of 100 m diameter (Dimensionless)             |
|                      | NDVI100  | NDVI in a buffer of 100 m diameter                                    |
|                      | Biomass NV100  | Biomass of native vegetation in a buffer of 100 m diameter            |
|                      | %NV250   | Percentage of native vegetation in a buffer of 250 m diameter         |
|                      | FDI250   | Fractal dimension index in a buffer of 250 m diameter (Dimensionless) |
|                      | EM250  | Effective meshsize in a buffer of 250 m diameter (m <sup>2</sup> )    |
|                      | ShapeIndex250  | Shape index in a buffer of 50 m diameter (Dimensionless)              |
|                      | NDVI250  | NDVI in a buffer of 250 m diameter                                    |
|                      | Biomass NV250  | Biomass of native vegetation in a buffer of 250 m diameter            |
|                      | %NV500   | Percentage of native vegetation in a buffer of 500 m diameter         |
|                      | FDI500   | Fractal dimension index in a buffer of 500 m diameter (Dimensionless) |
| EM500                | Effective meshsize in a buffer of 500 m diameter (m <sup>2</sup> ) |   |
| ShapeIndex500        | Shape index in a buffer of 50 m diameter (Dimensionless)           |   |
| NDVI500              | NDVI in a buffer of 500 m diameter                                 |   |
| Biomass NV500        | Biomass of native vegetation in a buffer of 500 m diameter         |   |
| Dependent            | MP-TD  | Taxonomic diversity of small mammals                                  |
|                      | MP-PD  | Diversity of small mammal families and tribes                         |
|                      | MP-FD  | Functional diversity of small mammals                                 |
|                      | MP-N   | Abundance of small mammals  |

**Table 3.** Small mammals in silvicultural landscape in the early second *Eucalyptus* plantation cycle.

| Order/Family/Tribe                  | Species   | Common name                 | Trophic category <sup>1</sup> | Number of individuals captured in pitfall traps |                 |                 |                        |
|-------------------------------------|---|-----------------------------|-------------------------------|---|-----------------|-----------------|------------------------|
|                                     |   |                             |                               | NV <sup>2</sup>                                 | AP <sup>3</sup> | EU <sup>4</sup> | Total (r) <sup>5</sup> |
| <b>Didelphimorphia</b>              |   |                             |                               |   |                 |                 |                        |
| <b>Didelphidae</b>                  |   |                             |                               |   |                 |                 |                        |
| Thylamyini                          | <i>Cryptonanus agricolai</i> (Moojen, 1943)         | Agricola's Opossum          | Insectivorous / Omnivorous    | 2   | 1               | 9               | 12                     |
|                                     | <i>Gracilinanus microtarsus</i> (J.A. Wagner, 1842) | Brazilian Gracile Opossum   | Insectivorous / Omnivorous    | 3   | 2               | 4               | 9                      |
| Didelphini                          | <i>Didelphis albiventris</i> (Lund, 1840)           | White-eared Opossum         | Frugivorous / Omnivorous      | 2   | 0               | 1               | 3(1)                   |
|                                     | <i>Didelphis aurita</i> (Wied-Neuwied, 1826)        | Big-eared Opossum           | Frugivorous / Omnivorous      | 11  | 0               | 0               | 11(1)                  |
| Marmosini                           | <i>Marmosa paraguayana</i> (Tate, 1931)             | Tate's Woolly Mouse Opossum | Insectivorous / Omnivorous    | 1   | 2               | 0               | 3                      |
|                                     | <i>Monodelphis</i> sp (Burnett, 1830)               | Short-tailed Opossum        | Insectivorous / Omnivorous    | 1   | 0               | 0               | 1                      |
| <b>Rodentia</b>                     |   |                             |                               |   |                 |                 |                        |
| <b>Cricetidae</b>                   |   |                             |                               |   |                 |                 |                        |
| Akodontini                          | <i>Akodon montensis</i> (Thomas, 1913)              | Montane Grass Mouse         | Insectivorous / Omnivorous    | 18  | 4               | 0               | 22                     |
|                                     | <i>Necomys lasiurus</i> (Lund, 1840)                | Hairy-tailed Akodont        | Frugivorous / Omnivorous      | 20  | 18              | 5               | 43(3)                  |
|                                     | <i>Oxymycterus delator</i> (Thomas, 1903)           | Spy Hociudo                 | Insectivorous / Omnivorous    | 0   | 4               | 0               | 4                      |
| Phyllotini                          | <i>Calomys tener</i> (Winge, 1887)                  | Delicate Vesper Mouse       | Frugivorous / Granivorous     | 5   | 59              | 10              | 74(12)                 |
| Oryzomyini                          | <i>Cerradomys subflavus</i> (Wagner, 1842)          | Flavescent Cerradomys       | Frugivorous / Granivorous     | 2   | 0               | 0               | 2                      |
|                                     | <i>Holochilus brasiliensis</i> (Desmarest, 1819)    | Brazilian Marsh Rat         | Frugivorous / Herbivore       | 0   | 1               | 0               | 1                      |
|                                     | <i>Nectomys squamipes</i> (Brants, 1827)            | Atlantic Water Rat          | Frugivorous / Omnivorous      | 6   | 1               | 0               | 7                      |
|                                     | <i>Oligoryzomys flavescens</i> (Waterhouse, 1837)   | Flavescent Colilargo        | Frugivorous / Granivorous     | 8   | 83              | 15              | 106(12)                |
|                                     | <i>Oligoryzomys nigripes</i> (Olfers, 1818)         | Black-footed Colilargo      | Frugivorous / Granivorous     | 159   | 122             | 93              | 374(63)                |
| <b>Total(r)</b>                     |   |                             |                               | 238 (31)  | 297 (36)        | 137 (25)        | 672(92)                |
| <b>Sampling effort (trap-night)</b> |   |                             |                               | 720   | 720             | 720             | 2160                   |

<sup>1</sup> Source: (Paglia et al., 2012)<sup>2</sup>: NV: Native vegetation<sup>3</sup>: AP: Abandoned pasture<sup>4</sup>: EU: *Eucalyptus* plantation<sup>5</sup>: (r): recaptures

**Table 4.** Regression between small mammal diversity<sup>1</sup> and 2D<sup>2</sup> and 3D<sup>3</sup> landscape metrics (p-value).

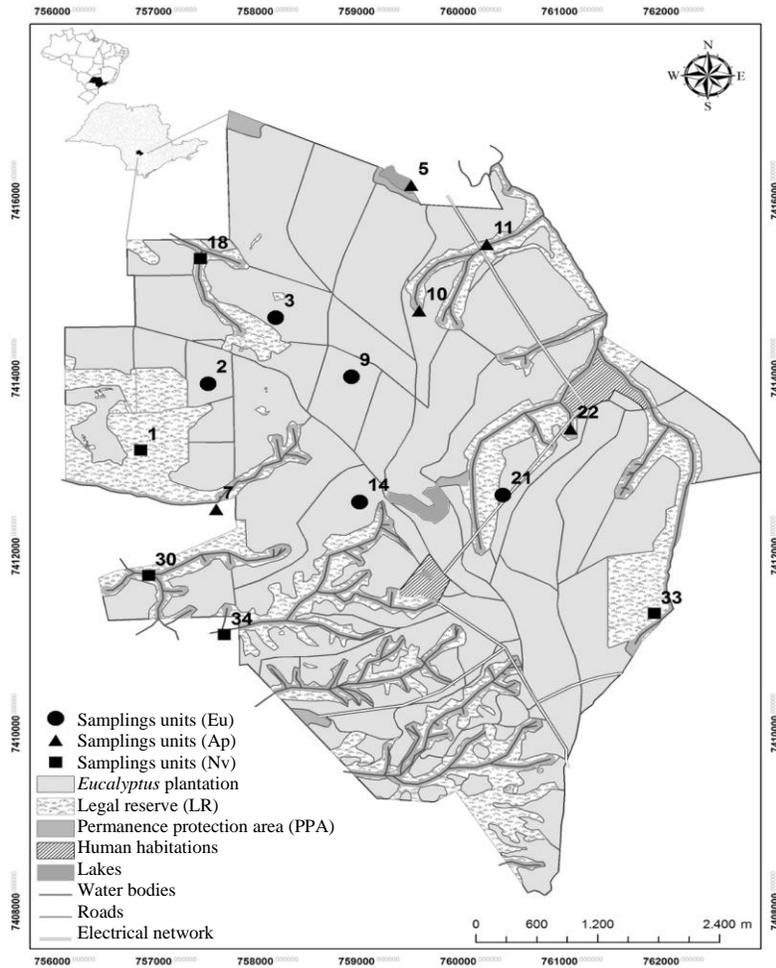
|               | Normality <sup>4</sup> | MP-TD        | MP-PD <sup>5</sup> | MP-PD <sup>6</sup> | MP-FD | MP-N         |
|---------------|------------------------|--------------|--------------------|--------------------|-------|--------------|
| %NV50         | 0,082                  | 0.542        | <b>0.015</b>       | 0.381              | 0.826 | 0.320        |
| FDI50         | <0.01                  | 0.424        | 0.151              | 0.388              | 0.160 | 0.312        |
| EM50          | 0.028                  | 0.187        | 0.180              | 0.246              | 0.138 | 0.555        |
| ShapeIndex50  | <0.01                  | 0.444        | <b>0.030</b>       | 0.436              | 0.300 | 0.911        |
| NDVI50        | >0.15                  | 0.991        | 0.575              | 0.502              | 0.804 | 0.825        |
| BiomassNV50   | >0.15                  | 0.177        | 0.220              | 0.419              | 0.428 | 0.857        |
| %NV100        | >0.15                  | 0.117        | <b>0.033</b>       | 0.215              | 0.726 | 0.863        |
| FDI100        | 0.072                  | 0.337        | 0.130              | 0.218              | 0.896 | 0.765        |
| EM100         | 0.060                  | 0.302        | 0.217              | 0.359              | 0.279 | 0.677        |
| ShapeIndex100 | 0.108                  | 0.427        | <b>0.004</b>       | 0.099              | 0.430 | 0.799        |
| NDVI100       | >0.15                  | 0.378        | 0.898              | 0.904              | 0.316 | 0.858        |
| BiomassNV100  | >0.15                  | 0.177        | 0.220              | 0.419              | 0.428 | 0.857        |
| %NV250        | 0.139                  | <b>0.037</b> | 0.110              | 0.060              | 0.612 | 0.623        |
| FDI250        | >0.15                  | 0.921        | 0.263              | 0.626              | 0.499 | 0.797        |
| EM250         | 0.058                  | 0.398        | 0.528              | 0.905              | 0.550 | 0.395        |
| ShapeIndex250 | >0.15                  | 0.156        | <b>0.003</b>       | 0.123              | 0.243 | 0.747        |
| NDVI250       | 0.088                  | 0.177        | 0.268              | 0.276              | 0.214 | <b>0.030</b> |
| BiomassNV250  | >0.15                  | 0.177        | 0.220              | 0.419              | 0.428 | 0.857        |
| %NV500        | >0.15                  | <b>0.022</b> | 0.209              | <b>0.029</b>       | 0.421 | 0.502        |
| FDI500        | >0.15                  | 0.613        | 0.419              | 0.246              | 0.445 | 0.844        |
| EM500         | >0.15                  | 0.248        | 0.485              | 0.775              | 0.567 | 0.337        |
| ShapeIndex500 | 0.082                  | 0.322        | 0.500              | 0.974              | 0.430 | 0.111        |
| NDVI500       | >0.15                  | 0.642        | 0.215              | 0.513              | 0.547 | 0.365        |
| BiomassNV500  | >0.15                  | 0.177        | 0.220              | 0.419              | 0.428 | 0.857        |

<sup>1</sup> TD, PD, FD e N.<sup>2</sup> %NV50, FD50, EM50 and ShapeIndex50.<sup>3</sup> NDVI50 e BiomassNV50.<sup>4</sup> Kolmogorov-Smirnov Test (p-value).<sup>5</sup> Diversity of families of small mammals.<sup>6</sup> Diversity of tribes of small mammals.**Table 5.** Regression equations between small mammal diversity and 2D and 3D landscape metrics ( $y=a+bx+x^2$ ).

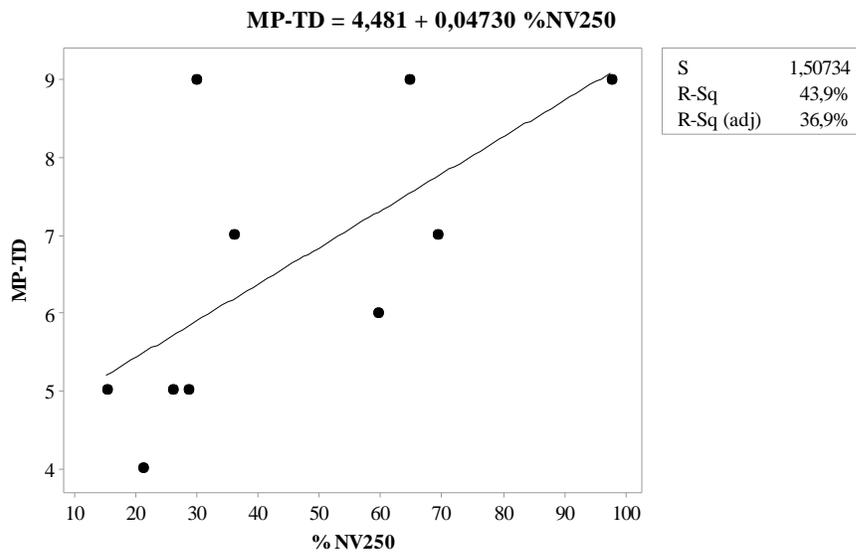
| y                  | x        | a      | b       | p     | $r_{adj}^2$ | df |
|--------------------|----------|--------|---------|-------|-------------|----|
| MP-TD              | %VN250   | 4.481  | 0.0473  | 0.037 | 0.369       | 9  |
| MP-TD              | %VN500   | 4.295  | 0.0658  | 0.022 | 0.437       | 9  |
| MP-PD <sup>1</sup> | %VN50    | 1.058  | 0.01015 | 0.015 | 0.483       | 9  |
| MP-PD <sup>1</sup> | Shape50  | 0.4866 | 1.646   | 0.030 | 0.398       | 9  |
| MP-PD <sup>1</sup> | %VN100   | 1.053  | 0.01024 | 0.033 | 0.383       | 9  |
| MP-PD <sup>1</sup> | Shape100 | 0.0223 | 1.984   | 0.004 | 0.634       | 9  |
| MP-PD <sup>1</sup> | Shape250 | 0.0579 | 2.104   | 0.003 | 0.645       | 9  |
| MP-PD <sup>1</sup> | NDVI250  | 76.84  | 99.29   | 0.030 | 0.397       | 9  |
| MP-PD <sup>2</sup> | %NV500   | 2.731  | 0.03336 | 0.029 | 0.401       | 9  |

<sup>1</sup>: Diversity of families of small mammals.<sup>2</sup>: Diversity of tribes of small mammals.**Table 6.** Correlation between small mammal diversity and 3D landscape metrics.

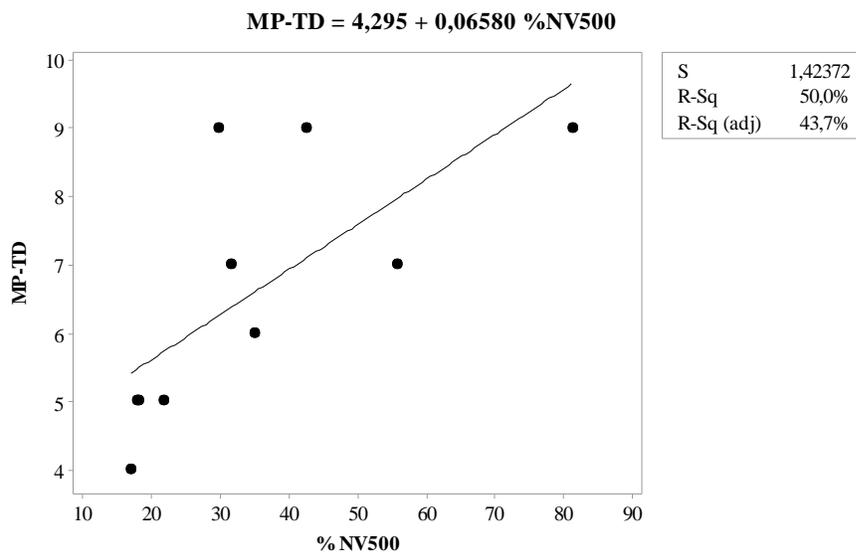
| Correlation (Pearson) | $r^2$ | p-value |
|-----------------------|-------|---------|
| NDVI50 x Biomass50    | 0.282 | 0.029   |
| MP-TD x MP-FD         | 0.681 | 0.030   |



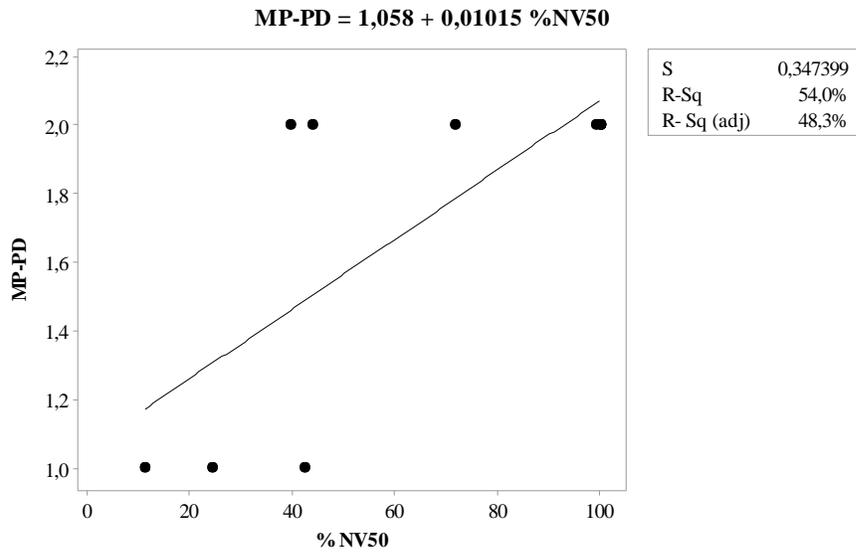
**Figure 1.** Location of Fazenda Três Lagoas, in Angatuba municipality, São Paulo State, Southeastern Brazil. Black bold dots represent sampling units (*Eucalyptus* plantation (Eu), Abandoned pasture (Ap), Native vegetation (Nv)).



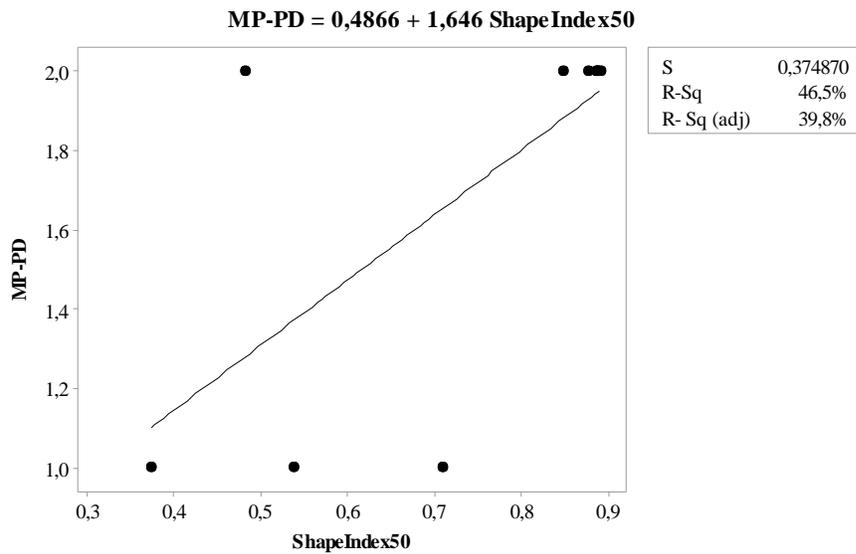
**Figure 2.** Regression equation between the taxonomic diversity of small mammals (y) and the percentage of native vegetation (buffer 250 m diameter) of the landscape (x):  
 $y = 4.481 + 0.0473x$  ( $p=0.037$ ,  $r_{adj}^2=0.369$ ,  $df=9$ ).



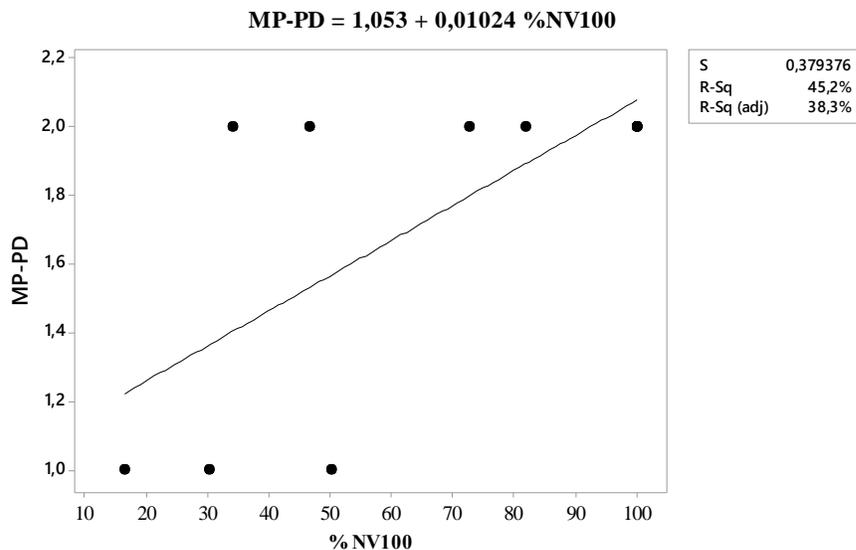
**Figure 3.** Regression equation between the taxonomic diversity of small mammals (MP-TD) and the percentage of native vegetation (buffer 500 m diameter) of the landscape (%NV50):  
 $y = 4.295 + 0.0658x$  ( $p=0.022$ ,  $r_{adj}^2=0.437$ ,  $df=9$ ).



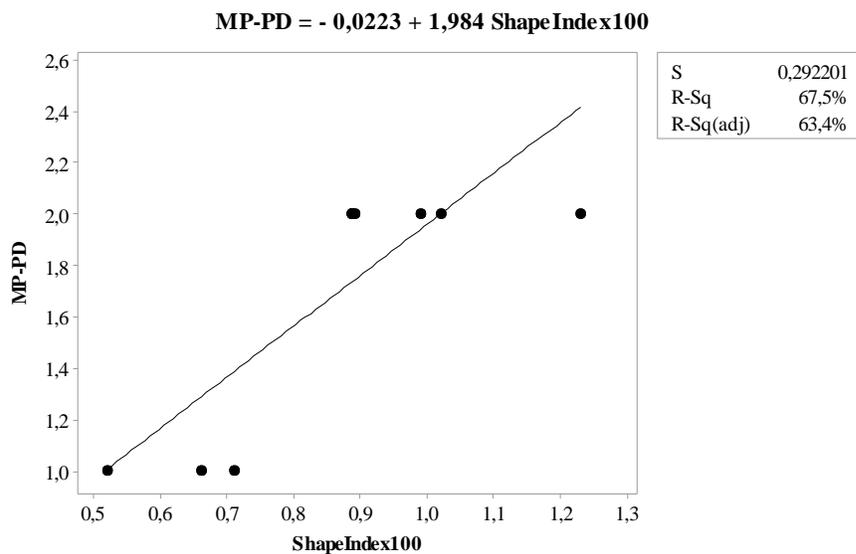
**Figure 4.** Regression equation between the phylogenetic diversity of small mammals (families) (MP-PD) and the percentage of native vegetation (buffer 50 m diameter) of the landscape (%NV50):  $y = 1.058 + 0.01015x$  ( $p=0.015$ ,  $r_{adj}^2=0.483$ ,  $df=9$ ).



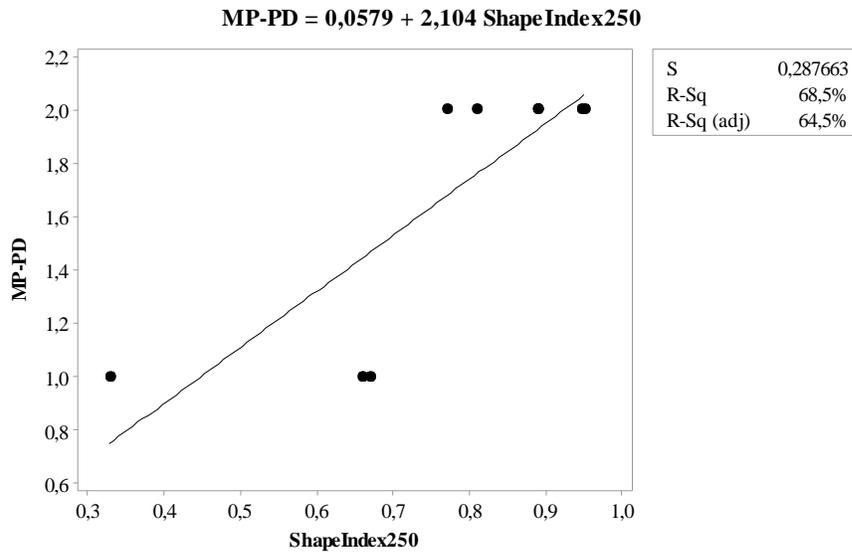
**Figure 5.** Regression equation between the phylogenetic diversity of small mammals (families) (MP-PD) and shape index in a buffer of 50 m diameter (IndForm50):  $y = 0.4866 + 1.646x$  ( $p=0.030$ ,  $r_{adj}^2=0.398$ ,  $df=9$ ).



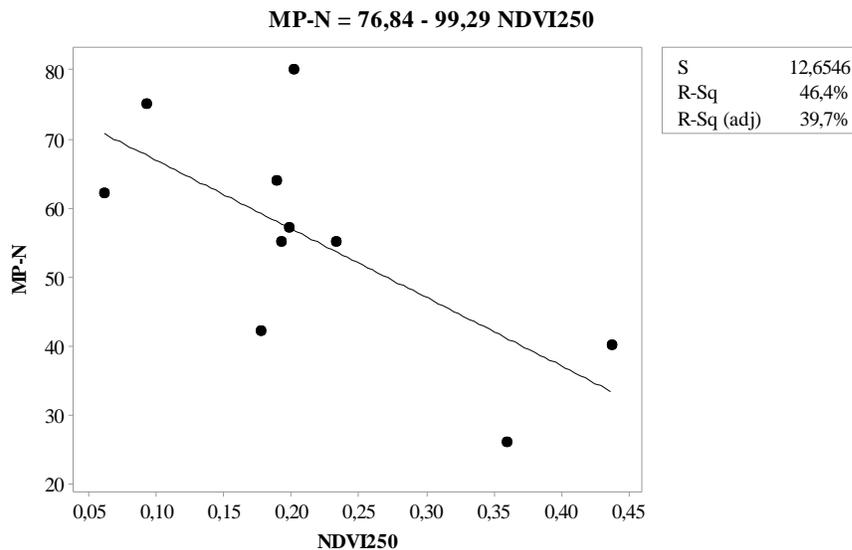
**Figure 6.** Regression equation between the phylogenetic diversity of small mammals (families) (MP-PD) and the percentage of native vegetation (buffer 100 m diameter) of the landscape (%NV100):  $y = 1.053 + 0.01024x$  ( $p=0.033$ ,  $r_{adj}^2=0.383$ ,  $df=9$ ).



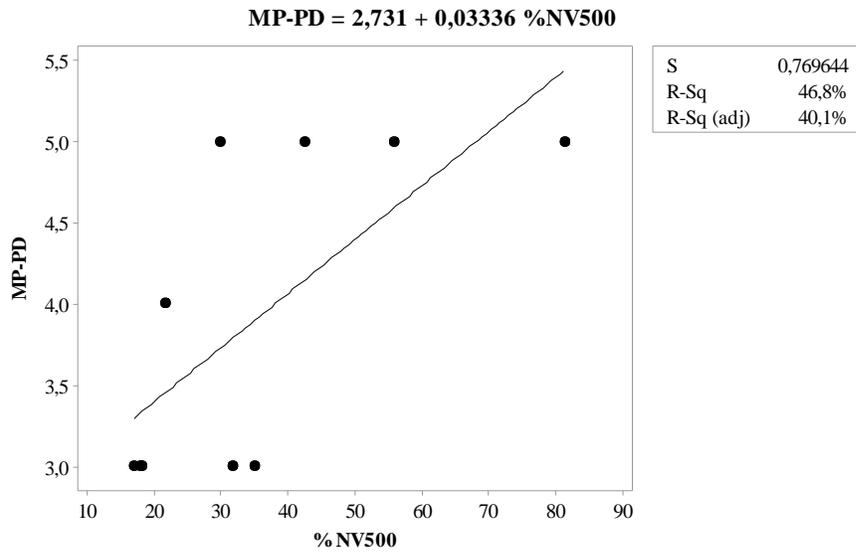
**Figure 7.** Regression equation between the phylogenetic diversity of small mammals (families) (MP-PD) and shape index in a buffer of 100 m diameter (IndForm100):  $y = 0.0223 + 1.984x$  ( $p=0.004$ ,  $r_{adj}^2=0.634$ ,  $df=9$ ).



**Figure 8.** Regression equation between the phylogenetic diversity of small mammals (families) (MP-PD) and shape index in a buffer of 250 m diameter (IndForm250):  $y = 0.0579 + 2.104x$  ( $p=0.003$ ,  $r_{adj}^2=0.645$ ,  $df=9$ ).



**Figure 9.** Regression equation between the abundance of small mammals (MP-N) and the NDVI in a buffer of 250 m diameter (NDVI250):  $y = 76.84 + 99.29x$  ( $p=0.030$ ,  $r_{adj}^2=0.397$ ,  $df=9$ ).



**Figure 10.** Regression equation between the phylogenetic diversity of small mammals (tribes) (MP-PD) and the percentage of native vegetation (buffer 500 m diameter) of the landscape (%NV500):  $y = 2.731 + 0.03336x$  ( $p=0.029$ ,  $r_{adj}^2=0.401$ ,  $df=9$ ).



## 4 FINAL CONSIDERATIONS

Agricultural landscapes are dominated by agricultural fields (i.e., agroecosystems) surrounded by a variety of habitats: remaining fragments of native vegetation, riparian habitats, pastures, roads and human settlements; that are inhabited by different rodent species (VERDADE *et al.*, 2014; GOROSITO *et al.*, 2018). Given the extent of these areas, efficient research methods are needed to assess its ecological value in terms of local diversity, such as the use of biological indicators (VERDADE *et al.*, 2014). Currently, landscape metrics are common tools used as indicators for landscape functions and can be used to evaluate mammal species richness in two and three dimensions (RAMESH; KALLE; DOWNS, 2016; UUEMAA *et al.*, 2009). 2D-metrics are related to patterns of patch shape and are based on perimeter-area relationships (i.e., shape index and percentage of native vegetation patches) whereas 3D-metrics are related to the volume (i.e., biomass) of the native vegetation (MCGARIGAL, 2015). In this context, the main goal in this study was evaluate the possible relationship between plant biomass and the diversity of small mammals in the São Paulo state of Brazil.

To reach this goal, the first chapter helped evaluating the distribution and abundance patterns of small mammals. Although the primary mission of agricultural landscapes is the production of domesticated species or their commodities (VERDADE *et al.*, 2014), in this study we corroborate the idea that agricultural landscapes can support some wild species. Approximately half of the total species detected are characteristic of the Cerrado biome (MARES *et al.*, 1986; ALHO, 2005; GARDNER, 2007; CARMIGNOTTO *et al.*, 2014; PATTON *et al.*, 2015) and even semiaquatic rodents were detected. The maintenance in the long term of an understory vegetation within the *Eucalyptus* plantation may help supporting an abundant small mammal community, because these patches can increase available niches which would enhance carrying capacity of the silvicultural landscape as a whole for the present species (CARRILHO *et al.*, 2017).

Likewise, according to the results obtained, abandoned pastures (habitat which resembles a shrubland) have a high availability of food and shelter for small mammals, whereas *Eucalyptus* plantations had the smallest species richness and relative abundance. However, these environments represent not only refuges for the fauna but also important providers of ecosystem services at the landscape level (BARLOW *et al.*, 2007; BONECKER *et al.*, 2009;

LINDENMAYER; FRANKLIN, 2002) and may also enhance connectivity if permeable (MARQUES *et al.*, 2015).

The specific composition of the small mammal assemblages varied in terms of relative abundance between different environments of the matrix. In agriculture landscapes the heterogeneity of the landscape matrix and surrounding habitats type may determine species presence and persistence (SCOTT *et al.*, 2008; SPONCHIADO *et al.*; 2012). Furthermore, in this study the specific composition of the small mammal assemblages is dynamic. The species responses appear to be related to their life-history (Kelly *et al.*, 2013); *i.e.*, whether it is generalist or opportunistic (STEPHENS *et al.*, 2012) and reproductive patterns (BERGALLO; MAGNUSSON, 1999). However, other processes may also affect the abundance of small mammals, like competition, habitat heterogeneity and resource availability (HANNIBAL *et al.*, 2016).

In the second chapter, the main goal was to evaluate the relation between landscape metrics and patterns of diversity, distribution and abundance of small mammals in a silvicultural landscape. Specifically, the taxonomic and phylogenetic diversity of small mammals have been predominantly correlated to the percentage of native vegetation. Thus, the patches of native vegetation in the matrix, may increase conservation values of agricultural landscapes. Also, the phylogenetic diversity has been affected by the landscape shape index. In this way, the interaction of patch shape and size may influence several important ecological processes, for example in the dispersal of small mammals between patches (BUECHNER, 1989). In addition, the abundance of small mammals has been determined by an indirect estimate of the native vegetation biomass (*i.e.*, NDVI), which can be considered a 3D landscape metric as it is related to volume. This result supports the use of native vegetation biomass as a proxy of small mammal abundance in agricultural landscapes and suggests small mammals are good indicators of sustainable forest management (TEDER *et al.*, 2007; TRIVELLONE *et al.*, 2014).

Therefore, to succeed in assessing the value of agricultural landscape, future studies should consider landscape context, as well as the landscape metrics associated with geospatial data analysis and the distinct responses of species. Due to the important economic and ecological role of agriculture landscape and its close dependence on human activities, there is an urgent need to establish the public environmental and agricultural policies that would assure the multi-functionality of agricultural landscapes. Additionally, preserving small mammals will increase

the conservation value of agroecosystems given their crucial role in ecosystem functioning and food webs. Thus, such studies should be prioritized, given the findings described in this study.

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