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High mammal species turnover in forest patches immersed in biofuel plantations

Gabrielle Beca^a, Maurício H. Vancine^a, Carolina S. Carvalho^a, Felipe Pedrosa^a, Rafael Souza C. Alves^a, Daiane Buscarior^a, Carlos A. Peres^b, Milton Cezar Ribeiro^a, Mauro Galetti^{a,c,*}

^a Departamento de Ecologia, Instituto de Biociências, Universidade Estadual Paulista (UNESP), 13506-900 Rio Claro, São Paulo, Brazil

^b Center for Ecology, Evolution and Conservation, School of Environmental Sciences, University of East Anglia (UEA), Norwich Research Park, NR47TJ, Norwich, UK

^c Department of Bioscience, Ecoinformatics and Biodiversity, Aarhus University, Ny Munkegade 114-116, 8000 Aarhus C, Denmark

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ABSTRACT

Remnant habitat patches immersed within biofuel cropland matrices can retain considerable species diversity, although the effects of land use change on species persistence in historically modified landscapes remain unclear. The Atlantic Forest is one of the most fragmented South American biodiversity hotspots and retains about 12% of its original vegetation cover. Most of these remnants are distributed in small isolated fragments immersed mainly within pastures and sugarcane monocultures. Here we examine how species richness and composition of medium and large-sized mammals are explained by forest cover, structural area and forest edge amount at the landscape scale. We sampled 22 fragmented landscapes dominated by sugarcane plantations along a wide gradient of forest cover (3% to 96%) in southeastern Brazil. We recorded 88% of terrestrial mammal species expected for this region, but many likely local extirpations were detected at the landscape scale, with losses between 50% to 80% of species. Most of the landscapes were highly depleted of forest-specialist species, with replacements by exotics and/or species typical of non-forest habitats. We found that total mammalian species richness, which includes forest-specialists, generalists, exotics and non-forest dwelling species, was not affected by landscape metrics, such as forest cover, structural area and forest edge amount. Nevertheless, forest cover was important predictor of the presence of three ungulates, a medium-sized rodent, and an armadillo. Local mammalian communities exhibited a high degree of species turnover between landscapes, representing 95% of the total β -diversity. In this region, where there was no regional extinction, landholder compliance with the Brazilian Forest Bill and restoration measures will enhance habitat connectivity and mammal persistence across the wider unprotected countryside.

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1. Introduction

The replacement of native vegetation by agriculture, pastures and urban areas is a central conservation concern throughout the tropics (Schipper et al., 2008). Land conversion to agricultural ecosystems accounts for 80% of deforestation globally (Kissinger et al., 2012), and is the leading driver of current rates of global biodiversity loss (Tschamtko et al., 2005; Green et al., 2005), and degradation of ecosystem functioning and services (Turner et al., 2007). About 53% of all assessed terrestrial vertebrates are threatened due to the negative impacts of agricultural intensification (Ceballos et al., 2015). These impacts have already been documented at regional and landscape scale for insects (Benton et al., 2002), birds (Donald et al., 2001), and mammals (Muylaert et al., 2016; Ribeiro et al., 2016).

Due to the current energy crisis, emergent developing countries have shown growing interests in biofuel production. Sugarcane

(*Saccharum* spp.) is cultivated in over 100 countries and represents one of the major biofuel crops worldwide. In most tropical areas, native forest remnants largely persist within private landholdings, embedded within matrices of sugarcane and pasture (Tabarelli et al., 2004). These agricultural areas act as a selective filter on animal movements across the landscape (Gascon et al., 1999; Chiarello, 2000), affecting matrix fluxes according to the dispersal capacity of each species (Lees and Peres, 2009). As such, highly resilient species gradually dominate ecological communities at the expense of native species that do not tolerate high levels of human disturbances (Tabarelli et al., 2012). This variation in community composition can result in either the reduction or increase in beta-diversity across multiple spatial scales (Wearn et al., 2016). Habitat fragmentation induced by agricultural expansion can also lead to species extinctions or population collapses due to edge effects (Lyra-Jorge et al., 2010), characterized by rapid biotic and abiotic transitions from forest areas to adjacent agricultural systems (Laurance et al., 2002). Forest edges can also influence native species responses to habitat changes (Lyra-Jorge et al., 2010), as they facilitate access to domestic dogs and other invasive predators and competitors into fragments, resulting in the reorganization of native assemblages (Lessa et al., 2016).

* Corresponding author.

E-mail address: mgaletti@rc.unesp.br (M. Galetti).

The Brazilian Atlantic Forest is an ideal study system to understand the long-term impacts of human activities on natural areas. Only 12% of the original Atlantic Forest vegetation cover currently persists, 84% of which consisting of forest remnants smaller than 50 ha (Ribeiro et al., 2009). These remnants are mostly isolated due to agricultural expansion, influencing the number of species that can survive within fragments (Magioli et al., 2015). The combined effects of these multiple factors have resulted in high levels of defaunation throughout the Atlantic Forest (Canale et al., 2012; Galetti et al., 2016a), especially the loss of large-bodied vertebrates, which may lead to severe consequences in forest composition and function through ecological cascades (Dirzo et al., 2014; Young et al., 2016).

Due to the negative effects of habitat alteration on biodiversity, there is an urgent need for information regarding the potential consequences of increased agricultural expansion on wildlife. In addition, there is an urgent need to evaluate the role of small forest patches in conservation planning. Here we set out to explain the species richness and composition of medium and large-sized mammals in fragmented forest landscapes dominated by sugarcane plantations. We aim to identify how landscape structure influences the number, composition and beta-diversity of mammal species across these landscapes. We therefore address three related hypotheses: (1) overall habitat amount is a robust proxy of habitat loss and should be a good predictor of mammal species richness (Andr en, 1994; Pardini et al., 2010; Fahrig, 2013). We should therefore expect higher overall species richness in response to the total amount of remaining natural habitat. On the other hand, (2) the amount of forest edge should have a neutral or ambivalent effect on mammal species richness, since it can either benefit generalists adapted to disturbed habitats or be detrimental to forest-specialists that are more sensitive to habitat loss and fragmentation (Kremsater and Bunnell, 1999; Lyra-Jorge et al., 2010). We also expect that (3) mammal communities embedded in a sugarcane matrix should experience a process of nestedness (Baselga, 2010), due to habitat loss and fragmentation, that leads to deterministic species losses, thereby creating nested species subsets of the larger community (Fern andez-Juricic, 2002). Finally, we propose restoration measures to enhance connectivity, especially in landscapes containing greater amounts of forest cover and low opportunity-cost matrix habitats, such as abandoned cattle pastures to boost local mammal diversity.

2. Material and methods

2.1. Study area

This study was carried out at 22 anthropogenic landscapes (of 1257 ha each) dominated by sugarcane plantations distributed in a large (450 km to 500 km) region of semideciduous seasonal forest remnants in the state of S o Paulo, Brazil (Fig. 1). The state of S o Paulo is located in the Southeastern of Brazil (19 46'45" - 25 18'43" S; 44 09'38" - 53 06'35" W), has an area of approximately 248,210 km², and a population of about 42 million (21.5% of the Brazilian population).

We selected the landscapes using a recent map of forest remnants of southeastern Brazil, which was derived from 30 m spatial resolution Landsat 5 images at the scale 1:25,000, and corrected using Google Earth images using the Open Layer plug-in within QGIS 1.8.0 (QGIS Development Team 2014). Albers Projection and SAD69 Datum were used to organize the spatial database. Although the original vegetation of the state of S o Paulo is highly heterogeneous, we restricted sampling to semideciduous forest remnants only. These forests are the most threatened forest type in the whole biome, with only 7% of the vegetation was left (Ribeiro et al., 2009). These forests differ from dense ombrophilous (evergreen) forest due to the combination of rainfall gradients that becomes more seasonal farther from the ocean, elevation and temperature, which change in montane areas (Salis et al., 1995). This forest type holds 31 species of medium and large size terrestrial mammal species (Cullen et al., 2004; Galetti et al., 2009). These landscapes ensured a wide gradient of forest cover (from 3% to 96% considering a 2 km buffer

around the landscape centroids) and a dominant matrix type consisting of sugarcane monoculture. We selected this spatial extent because large vertebrate responses to landscape metrics were best explained at the 2 km spatial extent (Lyra-Jorge et al., 2010). To minimize spatial autocorrelation between our study landscapes, the external boundaries of their buffer zones were spaced apart by at least 10 km (Fortin and Dale, 2005).

2.2. Mammal sampling

We used two main sampling techniques – camera trapping and sign surveys – to assess species richness and composition of medium to large-sized mammals (≥ 1 kg, see Srbek-Araujo and Chiarello, 2005). We selected these methods because they can record species with a wide range of ecological and behavioral characteristics and activity periods (i.e. diurnal, nocturnal and cathemeral). Surveys using camera traps were carried out from January 2014 to September 2015, using eight unbaited cameras per landscape, that were placed at different positions, which could be in the same fragment or in different fragments, depending on the patch size of the central forest remnant within each 2 km radius buffer. We used a mosaic-level sampling protocol with sample points restricted to semideciduous forest, while attempting to sample the most number of fragments within each landscape, rather than just one (Bennett et al., 2006). The camera traps were exposed over a period of 30 days and spaced apart by distances ranging from 200 m to 1500 m. Cameras were installed on tree trunks at 30 cm above ground at sites with similar local features (e.g. local animal activity, such as natural tracks, but avoiding roads). Sampling effort at each landscape was standardized at 240 camera trap/days (5760 camera trap/hours). Animal sign surveys included systematic searches for fecal material, tracks, burrows and carcasses, all of which were carried out along the edge of each of the sampled fragments within all 22 landscapes.

2.3. Landscape metrics

For each landscape, we calculated the forest cover (%), the amount of forest edges (ha), and the structural area (ha) of the fragments. Forest cover and forest edge amount were calculated within a radial buffer of 2 km (Supplementary Material, Fig. S1). Forest cover (%) was calculated by considering the area of all remaining semideciduous forest patches within the 2 km buffer, divided by the landscape size and multiplied by 100. To calculate forest edge amount, we first selected all peripheral 30 m forest pixels from our raster map from the forest-matrix boundary of all fragments in each landscape, considering the entire 2 km buffer around all fragments, and then calculated their aggregate area. Assuming that terrestrial mammals can move beyond the boundaries of the 2 km buffer area, particularly when forest patches straddled this boundary, we defined the structural area as the cumulative fragment area that was intercepted by the 2 km buffer within another buffer of 10 km radius (see Supplementary Material, Fig. S1). To check for collinearity between explanatory variables, we then calculated the correlation matrix between all landscape metrics, but none of which were strongly inter-correlated (Pearson's $r < 0.7$; Zar, 2010). We also used Mantel tests (Fortin and Dale, 2005) to check if the species richness values across our 22 study landscapes presented spatial autocorrelation.

We used a set of CBERS 2B (spatial resolution of 20 and 3 m) and Landsat 7 (spatial resolution of 30 m) imagery to aid in the process of landscape selection. We used a set of CBERS 2B (spatial resolution of 20 and 3 m) and Landsat 7 (spatial resolution of 30 m) imagery to aid in the process of landscape selection.

2.4. Data analysis

2.4.1. Total species richness

We define total mammal species richness as the number of species recorded at each of our 22 landscapes. To examine the degree to

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