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Losing our palms: The influence of landscape-scale deforestation on Arecaceae diversity in the Atlantic forest

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ABSTRACT

Understanding the effects of habitat loss on biodiversity has gained pronounced importance to inform conservation planning. Palms are a characteristic, important component of forest structure and the functionality of tropical forests, yet fragmentation-related studies have been poorly investigated in deforested landscapes. Here, we examine the influence of forest loss at the landscape scale on the entire palm community by evaluating species turnover at nine 16 km^2 landscapes in the Brazilian Atlantic Forest with 9–71% forest cover. Additionally, we examine the influence of canopy openness at the local scale. We identified all live palms at the species level within 50×100 m forest plots at each site and classified species into categories based on their habitat occurrence ("forest-interior" and "open-area" species). The number of Arecaceae species and stems greatly declined with lower amounts of forest cover at the landscape scale, with the power-law model best explaining these relationships. The community composition was also affected by forest cover, in which higher species dissimilarity was observed among severely deforested landscapes. Additionally, our results showed that palm assemblages have been shaped by non-random processes, with forest-interior species being negatively affected by reduced forest cover at the landscape scale. Landscapes embedded within less than 40% forest cover harbored fewer than 10 palm species, mainly consisting of open-area forest species. Our study therefore demonstrates the pervasive influence of habitat loss on palm diversity in severely deforested landscapes in the Brazilian Atlantic Forest hotspot. Extensive management actions, including forest restoration and the reintroduction of animal dispersers, are urgent and serve as important tools to permit the successful recruitment, reproduction and establishment of palm species in the unique Atlantic Forest biome.

1. Introduction

Anthropogenic activities have modified tropical forest landscapes over centuries, leading to a cascade of species extinctions mostly driven by habitat loss at the landscape scale (Wright, 2010; Arroyo-Rodríguez et al., 2013). Along the eastern Brazilian coast, the Atlantic Forest is one of 35 global biodiversity hotspots, harboring a large number of endemic species that are threatened by forest loss (Martini et al., 2007; Myers et al., 2000). The Atlantic Forest was colonized as long ago as the 1500s, and it has been drastically transformed by the impact of human colonization. Currently, only 12% of the original forest cover remains intact in a mosaic of old growth and secondary forest stands (Ribeiro et al., 2009).

Habitat loss and fragmentation has led to several changes in landscape structure and configuration, greatly affecting population and community dynamics (Fahrig, 2003). For instance, forest loss alone has proven to drive plant and animal species extinctions at the landscape scale in tropical forests (Banks-Leite et al., 2012; Lima and Mariano-Neto, 2014; Morante-Filho et al., 2015). Additionally, the remaining patches are prone to decrease over time, as they are more isolated and very close to the forest edge and therefore susceptible to forest fragmentation effects; indeed, recent analyses have shown that 70% of remaining forest worldwide is within 1 km of a forest boundary (Haddad et al., 2015). However, empirical studies have demonstrated that habitat loss leads to more pervasive effects on forest biodiversity than habitat

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fragmentation *per se* (see Fahrig, 2003). Forest cover at the landscape scale can thus be considered a proxy for habitat loss, with non-linear relationships usually observed between the amount of habitat and diversity metrics for different forest biota (Pardini et al., 2010; Estavillo et al., 2013; Ochoa-Quintero et al., 2015). Species richness and compositional similarity in several tropical plant families have been strongly and positively related to forest cover, with forest sites surrounded by a greater amount of forest cover exhibiting a higher number of species and greater similarity than severely deforested landscapes (Lima and Mariano-Neto, 2014; Andrade et al., 2015). Additionally, forest loss is expected to cause alterations to local forest structure, leading forest patches to retain early successional local attributes, including a reduction in the overall basal area and increasing canopy openness (Rocha-Santos et al., 2016).

Arecaceae is an essential botanical family for tropical frugivorous animals because it provides a high abundance of fleshy fruits and seeds (Zona and Henderson, 1989; Galetti et al., 2013). Additionally, palms are key components of the forest structure, and many species have been extensively harvested by humans in the tropics (Scariot, 1999). This family is widespread in both intact and fragmented tropical forests and includes species well-adapted to a wide range of environmental conditions (Uhl and Dransfiled, 1987). South America is center of endemism for Arecaceae (Pintaud et al., 2008), with studies revealing that environmental factors such as humidity, temperature and soil fertility strongly control species distributions and are therefore likely to affect family richness and composition (Bjorholm et al., 2005, 2006; Salm et al., 2007). Most Arecaceae forest species cope well with moderate levels of anthropogenic disturbance (Scariot, 2001; Bjorholm et al., 2005, 2006), yet alterations including reduced seedling recruitment, competition with alien species, and disruptions to mutualistic relationships with fauna can modify population dynamics and community composition (Scariot, 1999; Wright and Duber, 2001; Fleury and Galetti, 2004). Specifically, in the Brazilian Atlantic Forest, although some species can be found in disturbed areas (e.g., *Bactris* spp.; Silva and Tabarelli, 2001), others are extremely sensitive to forest disturbance (e.g., *Geonoma* spp.) and usually exhibit reduced rates of population growth in altered environments (Svenning, 2001). As a result, habitat loss, fragmentation and palm harvesting have been considered the main threats to palms (Scariot, 1999; Tabarelli et al., 2004; Galetti et al., 2006). However, no study has investigated the community and species-specific responses to habitat loss until recently.

Here, we investigated the responses of the Arecaceae family to habitat loss at the landscape scale by evaluating species turnover in nine 16 km^2 landscapes ranging from 9% to 71% forest cover in the Brazilian Atlantic Forest. Additionally, we examined the influence of canopy openness on local diversity patterns. We specifically evaluated the overall species richness, composition and abundance of palms to both a forest cover gradient at the landscape scale and canopy openness at the local scale. We also classified palm species based on their habitat type and occurrence preferences to assess the responses of both groups to a reduction in forest cover. We hypothesized that palm assemblages will become heavily affected by reduced forest cover and canopy openness, with contrasting groups ("open-area" and "forest-interior" species) responding oppositely depending on the forest cover gradient. We predicted that (i) species richness and composition similarity will increase in landscapes surrounded by a higher amount of forest cover, following similar responses from other floristic groups (Rigueira et al., 2013; Lima and Mariano-Neto, 2014; Andrade et al., 2015); (ii) the overall abundance will not be affected by forest cover, given that certain ecological groups will be favored by disturbance and consequently compensate for the reduction in others (Scariot, 1999; Andreazzi et al., 2012); (iii) species richness will also increase in areas exhibiting lower canopy openness, as these areas exhibit a better-structured canopy (Hilário and Toledo, 2016; Rocha-Santos et al., 2016); and (iv) palm species will exhibit different levels of vulnerability to habitat loss, with forest-interior species and stems greatly increasing in more forested landscapes, whereas open-area species and stems will decline in landscapes containing higher amounts of forest cover.

2. Materials and methods

2.1. Study area

This study is part of the REDE SISBIOTA, a research network designed to investigate how landscape-scale forest loss affects patterns of regional biodiversity and processes in anthropogenic landscapes. In this context, Landsat TM images of southern Bahia from 2011 (orbits 215/70 and 215/71) were first digitalized and used to select landscapes. The obtained map was then divided into cells of 4×4 km (16 km^2) to estimate the percentage of forest cover based on the sum of old growth and secondary forests at different successional stages. From the wide number of selected landscapes, all indigenous lands, mountainous areas and sites with limited accessibility were excluded, the calculated amount of forest cover was then intensively validated in field expeditions, and each landscape was subsequently grouped into forest cover classes (in percentages). For further details regarding the study area, see Andrade et al. (2015).

We performed stratified sampling from the pre-categorized groups and randomly selected nine 16 km^2 areas to subsequently perform Arecaceae surveys, which were immersed in landscapes ranging from 9 to 71% forest cover (Fig. 1). We established that each surveyed site needed to be spaced at least 1 km from the other sites to avoid overlapping. The minimum and maximum distances between plots were 6.3 km and 75.1 km, respectively. The surveyed forest sites were located within the municipalities of Belmonte, Mascote and Una (center coordinates: 15°28′S and 39°15′W). Una is situated in the northern area and exhibits large tracts of continuous forest protected by the Una Biological Reserve and Una Wildlife Refuge, two forest reserves encompassing 34,804 ha. All surveyed sites comprised a mixture of mature and secondary forests embedded within a matrix of pastures and shade cacao and/or rubber plantations sharing the same phytophysiognomy and similar soil and topography (Thomas, 2003; Faria et al., 2006). The vegetation is classified as tropical evergreen forest, exhibiting a great abundance of epiphytes, ferns, bromeliads and lianas (Thomas et al., 1998). The climate is warm and humid with annual precipitation over 1300 mm, which is typical of tropical forests.

2.2. Arecaceae sampling

In each selected landscape, we identified all old growth and late secondary forest fragments and randomly chose one fragment to establish a 50×100 m (0.5 ha) forest plot. The location of each plot was also randomly selected, maintaining a minimum distance of 50 m from the nearest forest border to minimize edge effects. All live adult individuals from the Arecaceae family in each forest plot were marked and samples were collected based on different criteria due to the morphological and demographic diversity of Arecaceae: [1] among arborescent species presenting underground stems (e.g., *Attalea humilis*), individuals exhibiting an external and visible stipe; [2] among arborescent species whose stem grows externally in diameter (e.g., *Euterpe edulis*), individuals with a diameter at breast height (DBH) $\geqslant$ 5 cm; and [3] among understory species and shrubs (e.g., from the genera *Desmoncus, Geo-*