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Increased anthropogenic disturbance and aridity reduce phylogenetic and functional diversity of ant communities in Caatinga dry forest

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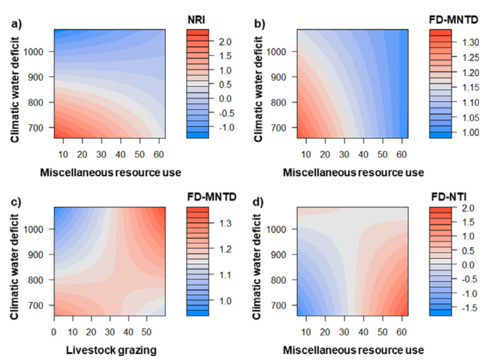
HIGHLIGHTS

- Ant biodiversity patterns under global change drivers are assessed in Caatinga.
- Functional and phylogenetic diversity decrease with aridity and human disturbances.
- Human disturbance and aridity interact in complex ways to endanger biodiversity.
- Aridity can intensify the negative effects of disturbance on biodiversity.
- Concerns about the future of biodiversity in neotropical semi-arid regions.

GRAPHICAL ABSTRACT



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ABSTRACT

Anthropogenic disturbance and climate change are major threats to biodiversity. The Brazilian Caatinga is the world's largest and most diverse type of seasonally dry tropical forest. It is also one of the most threatened, but remains poorly studied. Here, we analyzed the individual and combined effects of anthropogenic disturbance (three types: livestock grazing, wood extraction, and miscellaneous use of forest resources) and increasing aridity on taxonomic, phylogenetic and functional ant diversity in the Caatinga. We found no aridity and disturbance effects on taxonomic diversity. In spite of this, functional diversity, and to a lesser extent phylogenetic diversity, decreased with increased levels of disturbance and aridity. These effects depended on disturbance type: livestock grazing and miscellaneous resource use, but not wood extraction, deterministically filtered both components of diversity. Interestingly, disturbance and aridity interacted to shape biodiversity responses. While aridity sometimes intensified the negative effects of disturbance, the greatest declines in biodiversity were in the wettest areas. Our results imply that anthropogenic disturbance and aridity interact in complex ways to endanger biodiversity in seasonally dry tropical forests. Given global climate change, neotropical semi-arid areas are habitats of concern, and our findings suggest Caatinga conservation policies must prioritize protection of the wettest areas, where biodiversity loss stands to be the greatest. Given the major ecological relevance of ants, declines in both ant phylogenetic and functional diversity might have downstream effects on ecosystem processes, insect populations, and plant populations.

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1. Introduction

Anthropogenic disturbance and global climate change are key threats to biodiversity (Bellard et al., 2012) because they have significant impacts on biological populations and community organization. This is especially true in seasonally dry tropical forests (SDTFs), which are experiencing increased rates of both acute and chronic disturbance. Major acute disturbances include habitat loss and fragmentation (Miles et al., 2006). Major chronic disturbances (hereafter referred to as CADs—chronic anthropogenic disturbances [sensu Singh, 1998]) include livestock grazing, wood extraction, and the exploitation of miscellaneous forest resources. These activities all result in the removal of significant amounts of biomass. In STDFs, few efforts have been made to understand the impacts of CADs on biodiversity, but negative impacts have been described in communities of both plants (Sagar et al., 2003; Ribeiro et al., 2015, 2016; Rito et al., 2017) and animals (Ribeiro-Neto et al., 2016; Oliveira et al., 2017). Climate change also threatens SDTFs (Dirzo et al., 2011) and might even exacerbate the effects of anthropogenic disturbances (Hirota et al., 2011; Ponce-Reyes et al., 2013; Gibb et al., 2015a; Frishkoff et al., 2016). Hot and arid environments are likely at the greatest risk (Anderson-Teixeira et al., 2013; Gibb et al., 2015a).

Studies of biological communities have generally focused on patterns of species diversity, which are often quantified using species richness and/or composition (Pavoine and Bonsall, 2011). However, new diversity metrics that incorporate information about phylogenetic diversity (PD) and functional diversity (FD) can reveal more information about community organization in different contexts (Faith, 1992; Webb et al., 2002; Petchey and Gaston, 2006; Swenson, 2014), including those marked by anthropogenic disturbance and climate change (Mouillot et al., 2013). While phylogenetic diversity reflects the accumulated evolutionary history of a community (Webb et al., 2002), functional diversity reflects the diversity of morphological, physiological, and ecological traits found therein (Petchey and Gaston, 2006). It is generally accepted that PD and FD can increase with taxonomic diversity by chance, since the presence of more species should mean that more lineages and functions are represented. However, these relationships are not always linear. Two communities with equal taxonomic diversity might greatly differ in PD and FD (Petchey and Gaston, 2006; Safi et al., 2011; Arnan et al., 2015, 2017) due to different levels of functional redundancy, different evolutionary histories, and/or contrasting environmental conditions. However, a strong correlation between FD and PD would be expected if the functional traits that allow species to persist in the environment are evolutionarily conserved, that is to say, they display phylogenetic signals (Webb et al., 2002; Cavender-Bares et al., 2009). Remarkably, very little is known about how PD and the functional composition of animal communities change in response to disturbance and environmental conditions, especially in SDTFs.

When examining biodiversity patterns, ants are a good study group—they are among the most diverse and abundant terrestrial organisms on earth and they are highly sensitive to environmental change (Hölldobler and Wilson, 1990). Moreover, ants play an important role in many basic ecosystem services (Bihn et al., 2010, Del Toro et al., 2012). In particular, ants are crucial contributors to soil cycling and aeration, organic matter decomposition, seed dispersal, and plant protection (Del Toro et al., 2012). Ants are extremely phylogenetically diverse, especially in the tropics (Hölldobler and Wilson, 1990), and ant morphological traits have frequently been used to infer ecosystem services (Weiser and Kaspari, 2006; Gibb et al., 2015b; Parr et al., 2017; Salas-López, 2017).

In this study, we analyzed the effects of CADs and climate change, notably increasing aridity, on the phylogenetic and functional diversity of ants in the Brazilian Caatinga, the largest and most diverse of the world's SDTFs (Leal et al., 2005). The Caatinga is the third most-threatened Brazilian ecosystem and yet is the most poorly studied and understood (Overbeck et al., 2015; Oliveira and Bernard, 2017). The 27 million people living in the Caatinga are highly dependent on its natural resources for their livelihoods, which has resulted in its slow degradation over time (Leal et al., 2005; Ribeiro et al., 2015). Moreover, the Caatinga is one of the six ecosystems with the greatest intrinsic vulnerability to climate variability (Seddon et al., 2016); climate models consistently predict a reduction in rainfall levels (22%) and an increase in temperature (3–6 °C) (Magrin et al., 2014).

In this context, the Caatinga is a good model system with which to investigate the effects of anthropogenic disturbance and climate change (i.e., increased aridity) on the biological communities of dry forests. It can also be used to characterize changes in community organization arising from transformations in SDTFs. Previous studies in the Caatinga found no or small differences in ant species richness along CAD gradients; however, large changes in species composition were observed (Ribeiro-Neto et al., 2016; Oliveira et al., 2017). This finding suggests shifts in phylogenetic and functional diversity along CAD gradients. We therefore first corroborated that species diversity is not modulated by CAD and aridity gradients, and hypothesize the following: (a) PD and FD will decrease as anthropogenic disturbance and aridity increase; (b) PD and FD will decrease even more sharply in areas that are both highly disturbed and arid; and (c) PD and FD patterns along gradients of disturbance and aridity will be driven by deterministic processes rather than by stochasticity.

2. Materials and methods

2.1. Study area

This study was conducted in Catimbau National Park (8°24′00″ and 8°36′35″ S; 37°0′30″ and 37°1′40″ W, state of Pernambuco, Brazil), which cover an area of 607 km^2 of Caatinga vegetation (Sociedade Nordestina de Ecologia, 2002). The climate is hot. Mean annual temperature is 25 °C, and mean annual rainfall ranges between 1100 mm in the southeast to 480 mm in the northwest (Rito et al., 2017). However, the park experiences substantial interannual and spatial variability in conditions (Sociedade Nordestina de Ecologia, 2002). Most of the park has quartzolic sandy soils (70%), but planosols (15%) and lithosols (15%) are also present (Sociedade Nordestina de Ecologia, 2002). The dominant families of woody plants are Fabaceae, Euphorbiaceae, and Boraginaceae; on the surface of the forest floor, Cactaceae, Bromeliaceae, Malvaceae, Asteraceae, and Fabaceae dominate (Rito et al., 2017).

The park was established in 2002 (Sociedade Nordestina de Ecologia, 2002), but its original human inhabitants remain; they continue to hunt, graze livestock, extract timber, collect firewood, and harvest other plant resources (Rito et al., 2017). Their historical presence has resulted in an extensive mosaic of differential land use and anthropogenic pressure on biota. This fact means Catimbau represents an excellent opportunity for examining how anthropogenic disturbance (e.g., farming, livestock grazing, extraction of timber, firewood gathering, and hunting) affects the biota of the Caatinga. Also, the considerable variation in precipitation within the park (100%) can help reveal whether high levels of aridity can intensify the negative effects of human disturbance.

2.2. Characterization of disturbance and aridity gradients

We sampled 20 0.1-ha plots (20 × 50 m; separated by at least 2 km) located within areas dominated by old-growth vegetation; the plots occurred along an aridity gradient and experienced varying degrees of CAD (Fig. 1). Thanks to aerial photographs and preliminary interviews with locals, we could confirm that the plots had not experienced any acute disturbances over the past 80 years. All plots were located in areas with the same soil type (sandy soil), slope (flat terrain), and vegetation type (dry forest with short-stature trees) (Rito et al., 2017).