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Bat diversity in Carajás National Forest (Eastern Amazon) and potential impacts on ecosystem services under climate change

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ABSTRACT

Anthropogenic climate change is one of the main current threats to biodiversity, and it has been linked to species decline. Bats deserve attention because they occupy different trophic niches and perform different functions in nature, acting as flower pollinators (nectarivores), seed dispersers (frugivores), and pest controllers (insectivores). The effects of climate change on the distribution of bat species occurring in the Carajás National Forest (Eastern Amazon, southeastern Pará state, Brazil) was examined by modeling species distributions. A total of 83 species of bats providing the above mentioned services were analyzed for the years 2050 and 2070 to answer the following two questions: (i) Which species are potentially more sensitive to climate changes and will not be able to find suitable areas in Carajás in the future, and (ii) Which are the priority areas that protect the greatest number of species from climate change. Of the total species analyzed, 47 (57%) will potentially not find suitable areas in Carajás under the scenarios employed. Pollinators, seed dispersers, and more-generalist (omnivorous) bats will potentially be the most affected, suffering a 28–36% decrease in suitable area under the 2070 scenario, which may have implications for the plants with which those species interact. According to the scenarios employed, the Carajás National Forest, as well as other conservation units in Pará, will not protect most species in the future. The most suitable areas are located mainly to the north and west of the state and under varying degrees of conservation: from well-preserved protected areas to areas degraded due to different anthropogenic impacts. This study emphasizes that the possible effect of climate change and the location of species protection areas need to be analyzed together to ensure that the areas that will act as potential climate refuges for species in the future are indeed protected.

1. Introduction

Climate change induced by anthropogenic activities has rapidly altered the conditions to which species have adapted locally and, along with deforestation, it is one of the main threats to biodiversity (Titeux et al., 2017). Changes in the area of occurrence of some species were already reported, suggesting some patterns, such as changes in distribution toward the poles (Warren et al., 2001; Tamis et al., 2005) and higher altitudes (Chen et al., 2011). However, more complex, sometimes unexpected, changes have been reported (Gillson et al., 2013); therefore, detailed studies are needed to assess multiple species and regions. Moreover, climate changes affect not only the occurrence of species but also their interactions (Valiente-Banuet et al., 2015). It may alter the structure of interaction networks (Tylianakis et al., 2008), resulting in changes in phenological synchronization (Memmott et al., 2007) or in the geographic distribution of interacting species (Schweiger et al., 2008).

Biodiversity forms the basis of the ecosystem services that support life on the planet (Mace et al., 2012), which have been defined as the benefits that humankind derives, directly or indirectly, from ecosystem functions (Costanza et al., 1997). Ecosystem services have been recognized as resulting from the interactions between several biotic and abiotic components, being necessary to ensure support for society's increasing demands for basic resources such as food, medicines, drinking water, and climate regulation (MEA (Millennium Ecosystem Assessment), 2005). This concept has been widely used to reorganize existing knowledge of biological systems and to guide new research, as it constitutes a key tool to clarify the interface between the use of

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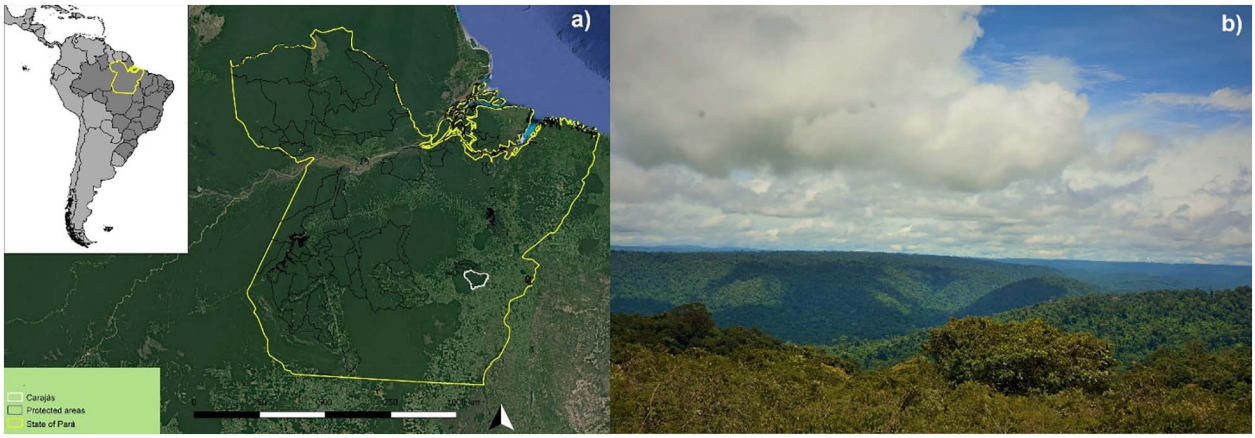

Fig. 1. (a) Carajás National Forest (highlighted in white), located in the southeast of the state of Pará (Brazil), in the Amazon Biome. Black lines on the map indicate conservation units (see also Supplementary Material 3). (b) Photograph of Carajás (author: C.E.P. Silva).

Fig. 2. Examples of bat species occurring in Carajás: (a) *Sturnira lilium* E. Geoffroy, (b) *Anoura geoffroyi* Gray, and (c) *Carollia perspicillata* Linnaeus. Photographs by Robson de Almeida Zampaulo.

natural resources and the need to conserve them (Costanza et al., 2014).

Studies with mobile agents providing ecosystem services (Kremen et al., 2007) (such as bees, birds, and bats that act as pollinators, seed dispersers, and pest controllers) are justified. Those species are particularly sensitivity to spatially operating ecological factors, which makes the services provided by them highly contextual (Kremen, 2005; Mitchell et al., 2015). Pollination and seed dispersal play an important role in determining plant diversity and distribution (Wang and Smith, 2002). Bats have been reported to be associated with hundreds of plant species whose nectar or fruit they consume (Kunz et al., 2011; Ghanem and Voigt, 2012). Frugivorous bats act complementarily with birds that have the same trophic habits, acting together to diversify the microhabitat where those seeds are deposited, thus contributing a significant service when considering the quantity and quality of dispersion (Jacomassa and Pizo, 2010; Sarmento et al., 2014). The initial establishment of plant populations from the action of seed dispersers was also emphasized in cases of forced dispersal due to changes in the climate (Hampe, 2011), land use (McConkey et al., 2012; Ripperger et al., 2015), or restoration of degraded lands (Wunderle Jr., 1997; Hougner et al., 2006; Silveira et al., 2011), Pollinators and seed dispersers are also important for agricultural production, and more than 60 economically relevant species have been listed that may potentially benefit from bats (Kunz et al., 2011). The proximity of forests, as well as caves, was a successful factor in the production of an agricultural crop (*Durio zibethinus* L.) in areas in Thailand, demonstrating the relevance of those habitats as sources of species of nectarivorous and frugivorous bats (Sritongchuay et al., 2016). Insectivorous bats, in turn, include species that are voracious predators of various insects and, hence, act in biological control (Puig-Montserrat et al., 2015). Among bats, species exist with dietary habits that vary from more specialist to more generalist and encompass many insect prey of various sizes and taxonomic groups, such as Lepidoptera, Coleoptera, Diptera, Homoptera, and Hemiptera (Kunz et al., 2011). The importance of bats in the control of pests that lead to losses in the agricultural production of cacao (Maas et al., 2013), coffee (Karp and Daily, 2014), and corn (Maine and Boyles, 2015) has also been demonstrated. In this last example, the value of this service, in terms of the costs saved on pesticides, was estimated at US$ 1 billion per year.

Ongoing changes that affect current and future temperature and rainfall regimes have been identified to be a consequence of the emission of greenhouse gases, and temperature changes may reach, for example, average increases of 2–4 °C by 2050 depending on the scenario analyzed (IPCC, 2014). Local analyses suggest up to a 6 °C increase in temperature by 2070 for the Eastern Amazon region (PBMC, 2013),