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CONSERVAÇÃO DA BIODIVERSIDADE

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ÁREAS PRIORITÁRIAS PARA CONSERVAÇÃO E RESTAURAÇÃO DO HABITAT DA PREGUIÇA-DE-COLEIRA (*Bradypus torquatus*, ILLIGER, 1811) NA MATA ATLÂNTICA, BRASIL.

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ÁREAS PRIORITÁRIAS PARA CONSERVAÇÃO E RESTAURAÇÃO DO HABITAT DA PREGUIÇA-DE-COLEIRA (*Bradypus torquatus*, ILLIGER, 1811) NA MATA ATLÂNTICA, BRASIL

RESUMO

Historicamente as florestas, e mais especificamente a Mata Atlântica, enfrentam um processo de conversão de uso da terra em agricultura, pastagem e áreas urbanas que culminam em uma floresta reduzida e altamente fragmentada. Assim, ações de conservação das florestas remanescentes e restauração da paisagem são estratégias chave e prioritárias no âmbito da conservação da biodiversidade. No caso da preguiça-de-coleira (*Bradypus torquatus*), uma espécie endêmica da Mata Atlântica, classificada como vulnerável à extinção, identificar áreas importantes para a conservação e restauração do seu habitat (florestas) são algumas das principais ações listadas no plano de ação nacional para conservação da espécie. Nesse contexto, o presente estudo teve como objetivos estimar a distribuição e área de ocorrência potencial da preguiça-de-coleira; quantificar a atual área de habitat florestal remanescente e sobre proteção na sua área de ocorrência e; identificar áreas prioritárias para a conservação e restauração do habitat para a espécie. Para isso, primeiramente foram construídos modelos preditivos de nicho ecológico, um climático e outro de paisagem, a partir de pontos de ocorrência e variáveis ambientais de clima e paisagem a fim de predizer a distribuição potencial da espécie. Em seguida os dois modelos foram combinados por meio da análise *EcoLand* e o resultado foi categorizado em oito classes distintas sendo assim delimitadas as áreas prioritárias para conservação e restauração do habitat, especificando diferentes níveis de prioridade (média e alta) e objetivos de priorização. O modelo climático binário, baseado no limite mais restritivo, previu condições climáticas adequadas em quatro áreas descontínuas totalizando uma área de potencial ocorrência de 65.968 km². Os resultados da análise *EcoLand* indicaram alta adequabilidade de paisagem em ~30% desta área, concentradas no sul da Bahia e região serrana do Espírito Santo, onde recomendam-se medidas de conservação do habitat. Em 68% da área de potencial ocorrência da espécie, são recomendadas medidas de restauração, sendo que 35% têm paisagens que estão mais próximas de se tornarem adequadas para a espécie. Estas estão concentradas no norte da Bahia, Sergipe, extremo sul da Bahia e Rio de Janeiro, onde ações de restauração devem ser priorizadas. Ambientes florestados (florestas e plantações sombreadas de cacau) atualmente ocupam 43% da distribuição potencial da espécie, estando aproximadamente 6% em unidades de conservação de uso restrito. O norte da Bahia, Sergipe e Espírito Santo são as regiões menos protegidas por unidades de conservação, onde é urgente a ampliação das áreas protegidas nessas regiões. Esse estudo traz novas percepções sobre o estado de conservação da preguiça-de-coleira e indica áreas prioritárias para a conservação e restauração do habitat da preguiça-de-coleira na Mata Atlântica, objetivando a conservação desta espécie. Os resultados podem ser utilizados como ferramenta de planejamento ambiental e decisão a fim de auxiliar na conservação da espécie.

Palavras-chave: Modelagem de nicho ecológico. *EcoLand*. Preguiça-de-três-dedos. Espécie endêmica. Espécie ameaçada de extinção.

PRIORITY AREAS FOR CONSERVATION AND RESTORATION OF MANED SLOTH (*Bradypus torquatus*, ILLIGER, 1811) HABITAT IN ATLANTIC FOREST, BRAZIL.

ABSTRACT

Historically, forests, and more specifically the Atlantic Forest, face a process of land-use conversion in agriculture, pasture, and urban areas that culminates in a reduced forest, and highly fragmented. Thus, conservation actions, adequate management of remaining forests, and landscape restoration are key and priority strategies in the context of biodiversity conservation. In the case of the maned sloth (*Bradypus torquatus*), an endemic species of the Atlantic Forest, classified as vulnerable to extinction, identifying important areas for the conservation and restoration of its habitat are some of the main actions listed in the national action plan for the species conservation. In this context, the present study aimed to estimate the distribution and potential occurrence area of the maned sloth; quantify the current area of remaining forest habitat and under protection and; identify priority areas for habitat conservation and restoration for the species. Thus, firstly, predictive models of ecological niche were built, one climatic and other landscape-based, from points of occurrence and environmental variables of climate and landscape in order to predict the distribution of the species. Then the two models were combined through EcoLand analysis, and the result was categorized into eight distinct classes, delimiting priorities areas for habitat conservation and restoration, specifying different priority levels (medium and high) and prioritization objectives. The binary climate model, based on the most restrictive limit, predicted suitable conditions in four discontinuous areas totaling a potential occurrence area of 65,968 km². The results of the EcoLand analysis indicated high landscape suitability in 30% of this area, concentrated in southern Bahia and the mountainous region of Espirito Santo, where habitat conservation measures are recommended. In 68% of the species' distribution, restoration measures are recommended, with 35% having landscapes that are closer to becoming suitable for the species. These are concentrated in the north of Bahia, Sergipe, the extreme south of Bahia and Rio de Janeiro, where restoration actions should be prioritized. Forested environments (forests and shaded cocoa plantations) currently occupy 43% of the species distribution, with approximately 6% being in strictly protected areas. As the north of Bahia, Sergipe and Espirito Santo are the regions least covered by protected areas, it is urgent to expand the protected areas in these regions. This study brings new insights into the conservation status of the maned sloth and indicates the priorities areas for the conservation and restoration of the maned sloth's habitat in the Atlantic Forest, aiming at the conservation of this species. The results can be used as an environmental planning and decision tool in order to assist in the conservation of the species.

Keywords: Ecological niche modeling. EcoLand. Three-toed sloth. Endemic species. Endangered species.

SUMÁRIO

II. CAPÍTULO 1:

I. INTRODUÇÃO GERAL

As florestas tropicais abrigam a maior biodiversidade existente no planeta, no entanto elas vêm diminuindo consideravelmente (KEENAN et al., 2015) e junto dois terços da biodiversidade terrestre abrigada nelas (GARDNER et al., 2009). Historicamente as florestas, e mais especificamente a Mata Atlântica, enfrentam um processo de conversão de uso da terra em agricultura, pastagem e áreas urbanas que culmina em florestas reduzidas, e altamente fragmentadas. A perda e fragmentação de habitats naturais são as principais ameaças à biodiversidade, responsáveis também por seu declínio (FAHRIG, 2003). Afetando diretamente a capacidade de movimentação e dispersão dos indivíduos e o funcionamento do ecossistema (TUCKER et al., 2018), podendo levar inclusive, espécies ao risco de extinção (REED; FRANKHAM, 2003). Diante de um cenário alarmante como esse, ações de conservação e restauração do habitat, a fim de maximizar a conectividade e funcionalidade da paisagem, são extremamente necessárias para a conservação da biodiversidade e manutenção e recuperação dos serviços ecossistêmicos florestais, processos evolutivos e viabilidade das espécies (MORITZ, 2002).

Ações de conservação e manejo adequado das florestas remanescentes são essenciais para a manutenção da biodiversidade (GIBSON et al., 2011), além de serem as ações mais econômicas na maioria dos casos (POSSINGHAM et al., 2015). Para isso, a criação e manejo adequado de áreas protegidas, incluindo unidades de conservação, são historicamente reconhecidas como ferramentas essenciais (ARROYO-RODRÍGUEZ et al., 2020). Entretanto, embora a atual rede de áreas protegidas na Mata Atlântica seja valiosa na proteção da diversidade, estimativas mostram que ela é insuficiente para atingir metas de proteção e mitigar efeitos das mudanças climáticas para algumas espécies (ZWIENER et al., 2017). Neste sentido, uma paisagem mais permeável também é fundamental para o bom funcionamento das unidades de conservação, já que o entorno das reservas influencia diretamente seu interior, bem como, apenas as unidades de conservação podem ser insuficientes para manter populações viáveis em longo prazo. Uma combinação de estratégias é o ideal, como por exemplo, promover a conservação do habitat e implementar corredores ecológicos, trampolins ecológicos e sistemas agroflorestais fora de áreas protegidas (ARROYO-RODRÍGUEZ et al., 2020). Em consonância, a restauração da paisagem e da conectividade, são tidos, atualmente, como estratégias chave e prioritárias no âmbito da conservação da biodiversidade. Em virtude disto, atualmente estamos vivenciando a década da restauração instituída pela Organização das Nações Unidas (ONU) (www.decadeonrestoration.org/pt-br).

A preguiça-de-coleira (*Bradypus torquatus*, Illiger, 1811) é uma espécie de mamífero arborícola endêmico da Mata Atlântica (HIRSCH; CHIARELLO, 2011) que se distribui do sul do Rio de Janeiro ao norte de Sergipe com algumas lacunas de distribuição já registradas na literatura (HIRSCH; CHIARELLO, 2011; MOREIRA et al., 2014). A espécie é classificada como "vulnerável" à extinção (CHIARELLO; MORAES-BARROS, 2014; CHIARELLO, 2018), principalmente devido a sua restrita área de ocupação e contínua perda e fragmentação de seu habitat (CHIARELLO et al., 2015). Esta é uma espécie estritamente folívora e altamente dependente de florestas (SANTOS et al., 2019), vivendo nos estratos superiores de ambientes florestais com alta densidade de vegetação (FALCONI et al., 2015). Devido a extrema adaptação à vida arborícola e folívora, preguiças do gênero *Bradypus* possuem baixa capacidade e velocidade de dispersão através de ambientes não florestados (SANTOS et al., 2019, GARCÉS-RESTREPO et al., 2018) e quando acabam atravessando por essas áreas se tornam bastante vulneráveis ao ataque de predadores, caça e atropelamentos (CHIARELLO et al. 2004). Tais características intrínsecas e sua alta exigência ambiental, as tornam bons modelos para estudos e planos de conservação e conectividade de habitat, podendo servir como espécie "guarda-chuva" em ações de restauração da conectividade funcional da paisagem (GARCÉS-RESTREPO et al., 2018), uma vez que ações voltadas para esta espécie podem contemplar outras que dividem espaço com ela e que tenham maior capacidade de dispersão. As populações de preguiça-de-coleira estão declinando consideravelmente em ambientes nos quais a paisagem no entorno (500 m) possui coberturas vegetais menores que 35%, e raramente ocorrem em paisagens com coberturas menores que 20% (SANTOS et al., 2019). Além disso, na região de ocorrência desta espécie estima-se que exista ~17% de habitat remanescente, os quais mais de 80% são pequenos em tamanho (<50 ha) e podem ser rapidamente perdidos nos próximos anos (RIBEIRO et al., 2009, GINÉ; FARIA, 2018).

Análises de DNA nuclear e mitocondrial indicam a existência de pelo menos duas unidades evolutivamente significativas (ESU) formadas por clados (linhagens) que atualmente são representadas por populações de preguiças-de-coleira do sul (Rio de Janeiro + Espírito Santo) e norte (Sul Bahia + Norte da Bahia e Sergipe) (SCHETINO et al., 2017). Estas linhagens sul e norte, porém, divergiram em sublinhagens, e atualmente existem quatro sublinhagens representadas pelas populações do Rio de Janeiro, Espírito Santo, Sul da Bahia e Norte da Bahia + Sergipe (SCHETINO et al., 2017). Estas divisões resultam de eventos históricos de dispersão, vicariância, mudanças climáticas e de vegetação, mas também mais recentemente, de questões antrópicas, como desmatamento (LARA-RUIZ et al., 2008; SCHETINO et al., 2017). A unidade que se localiza mais ao norte do país, na Bahia e Sergipe, é a população menos estudada e que ocupa, muito provavelmente, uma das regiões mais ameaçadas por sua pequena cobertura vegetal e altíssima fragmentação (MOREIRA et al., 2014).

Preguiça-de-coleira (*Bradypus torquatus*, Illiger, 1811). Foto: Camila A. Souto

Um objetivo emergente da biologia da conservação é priorizar locais para conservação com base na biodiversidade (MARGULES; PRESSEY, 2000; SARKAR; MARGULES, 2002). Entretanto, um dos grandes gargalos do planejamento para a conservação atualmente é o fato de que a distribuição geográfica de muitas espécies é pouco conhecida, possuindo inúmeras lacunas de conhecimento, um problema conhecido como déficit Wallaceano (BINI et al., 2006; WHITTAKER et al., 2005). Uma das maneiras de contornar esse déficit é o uso de mapas preditivos de distribuição, gerados a partir de modelos de distribuição de espécies (SDM) ou modelos de nicho ecológico (ENM). Os modelos de nicho ecológico (ENM), sobre uma abordagem correlativa, relacionam dados de localização conhecida das espécies com fatores ambientais para predizer espacialmente a distribuição de plantas e animais (MILLER, 2010).

Com isso é possível descrever e medir a importância de fatores específicos e prever a distribuição das espécies em áreas não amostradas (MILLER, 2010).

Com o objetivo de aprimorar as ações de conservação e restauração e diminuir eventos de extinção é que surge a proposta de integrar processos de pequena e grande escala que influenciam na distribuição das espécies (ex. paisagem e clima) a fim de entender impactos e necessidades de atuação para a conservação destas, proposta adotada no método conhecido como *EcoLand* (SOBRAL-SOUZA et al., 2021). Tal método analítico integra modelos climáticos (escala grossa) com modelos de paisagem (escala fina) e com isso permite identificar áreas prioritárias para conservação (áreas com alta adequabilidade climática e de paisagem) e restauração (áreas com alta adequabilidade climática e baixa adequabilidade de paisagem) ou outras categorias de interesse estabelecidas pelo pesquisador (SOBRAL-SOUZA et al., 2021). Neste método os pixels dos mapas são classificados de acordo com sua adequabilidade climática e de paisagem e é possível plotar os resultados em um gráfico de dispersão usando no eixo x, a adequabilidade climática, no eixo y, a adequabilidade de paisagem e os pixels distribuídos em diferentes combinações categóricas de adequabilidade, possibilitando identificar em cada região qual ação deve ser tomada.

Atualmente a literatura, por meio de registros de pontos de ocorrência, polígono entorno dos pontos de ocorrência e modelos preditivos, relata que a distribuição da preguiça-de-coleira se estende da região central do Rio de Janeiro à região central do Sergipe, abrangendo uma área em torno de 71,000 km^2 (CHIARELLO; MORAES-BARROS, 2014; HIRSCH; CHIARELLO). A área de habitat remanescente estimada é de 16.000 km² (MOREIRA et al., 2014) sendo a área de ocupação estimada de 1.000 km² (CHIARELLO; MORAES-BARROS, 2014). Ao longo da distribuição ainda são reportadas duas lacunas, a primeira entre o norte do Rio de Janeiro e sul do Espírito Santo, e a segunda entre o rio Doce, no norte do Espírito Santo, e o rio Mucuri, no sul da Bahia, muito provavelmente associadas a processos históricos relacionados às mudanças climáticas e consequente retração florestal (MOREIRA et al., 2014; SCHETINO et al., 2017). No entanto, até o momento nenhum trabalho propôs uma abordagem utilizando variáveis de paisagem complementares à variáveis climáticas para predizer sua distribuição em escala mais fina e as possíveis lacunas geográficas. Além disso, nenhum estudo analisou as possíveis áreas prioritárias para restauração do habitat com enfoque em aumento de habitat e de conectividade para a espécie.

Identificar áreas importantes para a conservação e restauração do habitat da preguiça-da-coleira é uma das primeiras ações (1.1) listadas no plano de ação nacional para a

Conservação dos Primatas da Mata Atlântica e da Preguiça-da-coleira (PAN PPMA) (ICMBio, 2018). Considerando o déficit no conhecimento da distribuição desta espécie, especialmente no que tange sua relação com características de paisagem, os quais são conhecimentos importantes para avaliar e propor o estabelecimento de áreas prioritárias para a conservação e restauração do habitat, o presente estudo tem por objetivo: 1. Avaliar a distribuição da preguiça-de-coleira e quantificar a área de ocorrência potencial da espécie; 2. Avaliar e quantificar a atual área de habitat florestal remanescente e sobre proteção presente em sua área de ocorrência e; 3. Identificar áreas prioritárias para a conservação e restauração do habitat para a espécie ao longo de sua distribuição. Para isso, primeiramente foram construídos e apresentados modelos preditivos de nicho ecológico, um climático e outro de paisagem, a partir de pontos de ocorrência da espécie e de variáveis ambientais de clima e paisagem a fim de predizer a distribuição da espécie. Em seguida os dois modelos foram combinados por meio da análise *EcoLand* (FERRO; SILVA et al., 2018) e o resultado foi categorizado em oito classes distintas sendo assim recomendadas quais áreas devem ser priorizadas para conservação e restauração do habitat, especificando diferentes níveis de prioridade (média e alta) e objetivos de priorização. Por fim, ambos modelos climáticos e de adequabilidade foram sobrepostos a camadas espaciais de remanescentes florestais e áreas protegidas.

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II. CAPÍTULO 1

Priority areas for conservation and restoration of maned sloth habitat in the Atlantic Forest, Brazil.

Maned sloth in Bahia, Brazil. Photo by: Gabriel S. Lopes

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Highlights

- The potential occurrence area of the maned sloths was predicted in four discontinuous areas from Rio de Janeiro to Sergipe totaling an area of 65,968 km² along the Atlantic Forest biome.

- Forested remnants (including native forest and shaded cocoa plantations) in the regions of high climatic and landscape suitability total approximately 16,972 km^2, occupying 25.72% of the species' potential occurrence area.

- The highest priority regions for habitat conservation actions occupied ~30% of species range and are concentrated in the cocoa producing region of Bahia and the mountain region of Espirito Santo.

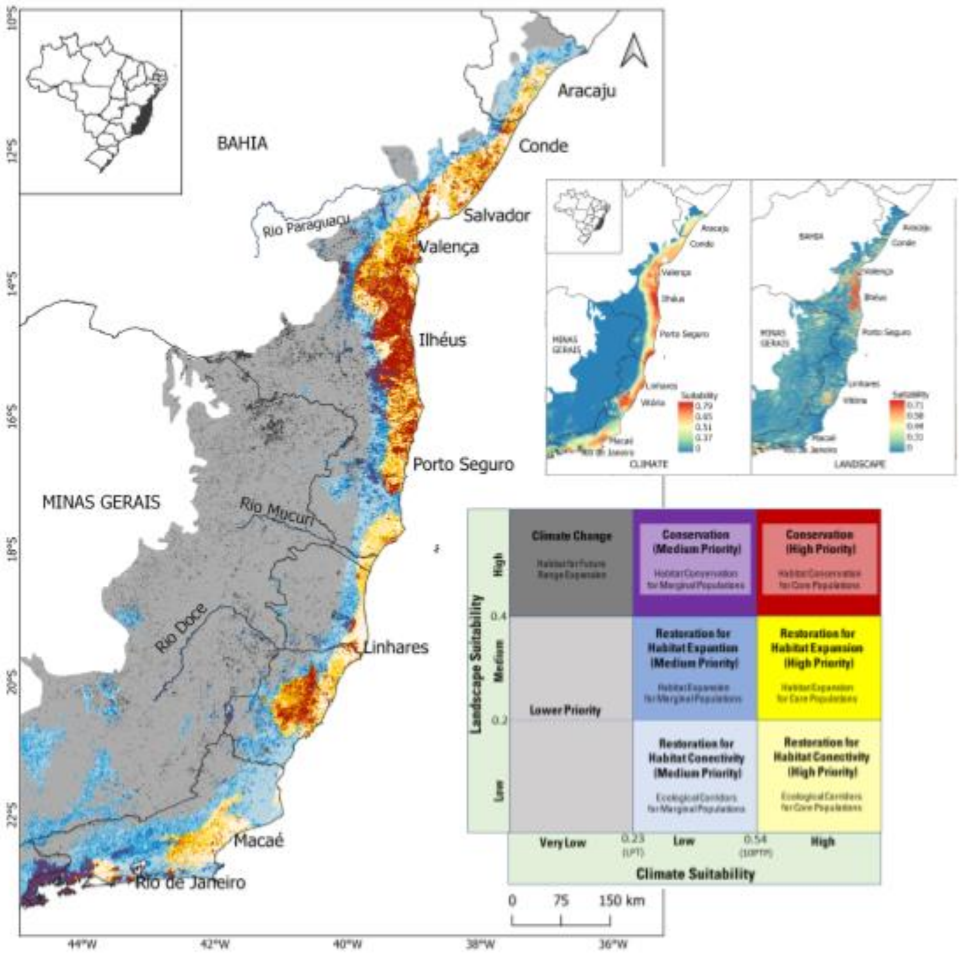
- The landscapes from Rio de Janeiro, northern Bahia and Sergipe are the most worrisome and deserve special attention for habitat restoration.

- Less than 6% of the species habitat is protected by strictly protected areas, especially with low coverage of protected areas in northern Bahia and Sergipe.

Abstract

Given the current scenario of intense habitat loss, habitat fragmentation, and species extinction rates, implementing conservation strategies has never been more urgent in tropical forest biomes. Maned sloth is a lethargic forest-specialist and threatened species from Atlantic Forest, sensitive to forest loss and fragmentation. The identification of important areas for the conservation and restoration of its habitat, as well as other actions aimed at expanding the habitat and its connectivity, are actions recognized as necessary and urgent. In this study we aim to predict the current geographic distribution of the maned sloth, identify priority areas for the conservation and restoration of the habitat for the maned sloth and estimate the amount of remaining protected and unprotected habitat in their potential distribution and within the priority areas for habitat conservation. We first build consensual based-climate distribution models and overlapped on remnants forest and protected area layers in order to achieve the first two goals. Then, we apply the EcoLand analysis method combining consensual climate and landscape-based distribution models to identify strategic areas and designate spatially appropriate management actions for maned sloth conservation. Our results showed suitable climate conditions in four discontinuous areas, totaling 65,968 km². Currently, 43% of forested vegetation remains in this area , of which 26% is inserted in landscapes of high suitability. Finally, the analysis indicated areas with high climatic and landscape suitability are concentrated mainly in the cocoa-producing region of southern Bahia and the mountainous region of Espirito Santo where habitat conservation should be priorized, while an extensive area (~69%) is indicated as a priority for restoration throughout the species distribution, being mainly urgent in Rio de Janeiro, northern Bahia e Sergipe states.

Graphical Abstract



Keywords: Ecological niche modeling, EcoLand, Three-toed sloth, endemic species, endangered species.

Introduction

Implementing conservation strategies has never been more urgent in tropical forest biomes (Arroyo-Rodríguez, 2020; Washington, 2013), given the current scenario of intense habitat loss, habitat fragmentation, and species extinction rates. In 2021, we enter the decade of ecosystem restoration, led by UNEP and FAO and supported by various entities around the world. It is a call for the protection and restoration of ecosystems around the world to achieve global treaties. Brazil participates in international agreements, such as the Initiative 20x20 (Latin America and Caribe) and the Bonn Challenge and has national objectives, such as the Pact for the Restoration of the Atlantic Forest, which aims to restore 15 million hectares by 2050 (www.pactomataatlantica.org.br).

The use of quantitative techniques to generate spatial information on the prioritization of conservation helps decision-makers decide where and how to distribute conservation and restoration actions within a region of interest, allowing greater efficiency in the allocation of limited resources (Lehtomaki and Moilanen, 2013; Sánchez-Cordero et al., 2005; Sobral-Souza et al., 2021). Ecological niche models (ENM) are useful tools for indicating the potential distribution of species and help in the spatial planning of conservation strategies (Ferraz et al., 2012; Lemes and Loyola, 2013; Sánchez-Cordero et al., 2005). The combination of information generated by ENMs based on climate and landscape data allows identifying areas that present high climatic and landscape suitability for a species, where the implementation of habitat conservation strategies can be valuable to maintain the functional landscape and consequently the viability of the target species populations. As well as, areas with high climatic suitability and low landscape suitability, where habitat restoration actions can be prioritized to increase the amount of available habitat and landscape connectivity (Rezende et al., 2020; Sobral-Souza et al., 2021).

The spatial prioritization and targeting habitat conservation and restoration strategies using this technique, known as EcoLand (Sobral-Souza et al., 2021), can be especially useful for the conservation of forest-dependent species with low dispersal capacity and located in highly deforested and fragmented areas (Rezende et al., 2020). This is the case of the maned sloth (*Bradypus torquatus*, Xenarthra: Pilosa), a strictly arboreal and folivore species, endemic to the Atlantic Forest from the state of Sergipe to the state of Rio de Janeiro (Hirsch and Chiarello, 2011), a biome that has lost approximately 72% of its original forest cover (Rezende et al., 2018). Estimates indicate a distribution area of 71,000 to 71,427 km^2 (Hirsch and

Chiarello, 2011; Chiarello and Moraes-Barros, 2014), with a remaining habitat of 16,000 km^2 (Moreira et al., 2014) and an area of 1,000 km² (Chiarello and Moraes-Barros, 2014). Maned sloth distribution is discontinuous, with two main gaps differentiating at least two evolutionarily significant units (ESU) represented by populations from the south (Rio de Janeiro + Espírito Santo) and north (South Bahia + North Bahia and Sergipe (Schetino et al., 2017). However, the southern and northern lineages diverged into sublineages, currently, there are four sublineages represented by the populations of Rio de Janeiro, Espírito Santo, southern Bahia, and Northern Bahia + Sergipe, which should preferably be managed independently (Schetino et al., 2017).

The maned sloth is classified as vulnerable in the international list of threatened species (Chiarello and Moraes-Barros, 2014), mainly due to its restricted area of occupancy and continued loss and fragmentation of its habitat [criterion B2ab(ii,iii), Chiarello and Moraes-Barros, 2014]. Sloths prefer environments with high vegetation complexity, including patches with high tree density and canopy density, and large trees (Falconi et al., 2015). Moreover, they tend to be rare in landscapes with forest cover lower than 35% and are absent when it is below 20% (Santos et al., 2019a). Given the physiological restrictions imposed by the low-calorie diet and extreme locomotor adaptations for arboreal life, the sloths are lethargic mammals with have low mobility, speed, and limited ability to disperse through non-forested environments (Falconi et al., 2015; Peery and Pauli, 2014; Santos et al., 2019a). When dispersing in such environments, they are vulnerable to attack by predators (eg., canids, felines), human hunting, and roadkill (Chiarello et al., 2004). As a result of their dependence on forested areas and poor dispersal ability compared to other mammal species, sloths tend to be sensitive to forest loss and fragmentation (Peery and Pauli, 2014), with the potential of small populations in highly fragmented landscapes to be driven into the vortex of extinction, ultimately compromising species persistence (Hoehn et al., 2007; Tanaka, 2000). Therefore, actions aimed at habitat conservation and restoration can favor the species in the long term (Schetino et al., 2017). In addition, the dependence on forest and locomotor limitations make this species a good candidate to serve as an "umbrella species" when defining priority areas for conservation and restoration, since measures adopted for the conservation of this species can benefit other forest-dependent mammals that are more adept and faster to disperse through anthropogenic matrices, such as threatened species of primates and the thin-spined porcupine, recurrent in this central region of the Atlantic Forest.

The identification of important areas for the conservation and restoration of habitat for the maned sloth are actions recognized as necessary and urgent in the National Action Plan

(PAN) for the conservation of this species (ICMBio, 2018). So far, no spatial prioritization scheme for the conservation of this species has been presented or published. In addition, despite previous efforts to assess the geographical distribution of the maned sloth (Hirsch and Chiarello, 2011; Moreira et al., 2014), no analysis has included landscape variables to predict its distribution, remaining habitat and protected habitat, which is essential to understand the conservation status of the species. Seeking to fill these gaps, we combined species climate and landscape modeling to: (1) Predict the potential limits of the current geographic distribution of the maned sloth by estimating the climatically suitable area for this target species; (2) Identify priority areas for the conservation and restoration of the habitat for the maned sloth; and (3) Estimate the amount of remaining protected and unprotected habitat in the potential distribution of the maned sloth and within the priority areas for habitat conservation.

Material and Methods

Study area.— On a broader scale (Figure 1), we assess the species distribution and priority areas within the Atlantic Forest domain (Muylaert et al., 2018) between the south of the state of Rio de Janeiro (-23°38'33”) and the north of Sergipe (-9°92'49"), a region that includes confirmed and unconfirmed records of the occurrence of the species (Chiarello and Moraes-Barros, 2014; Hisch and Chiarello, 2011; Moreira et al., 2014). The predominant climate in the region is tropical without a dry season (Alvares et al., 2013), with average annual temperature ranging between 12°C and 25.7°C and average annual precipitation between 560 to 2357 mm (Fick and Hijmans, 2017). This region has a forest cover predominantly composed of ombrophilous dense forests in the eastern portion (closer to the coast) and semi-deciduous and deciduous forests in the western portion (Fundação SOS Mata Atlântica; INPE, 2021).

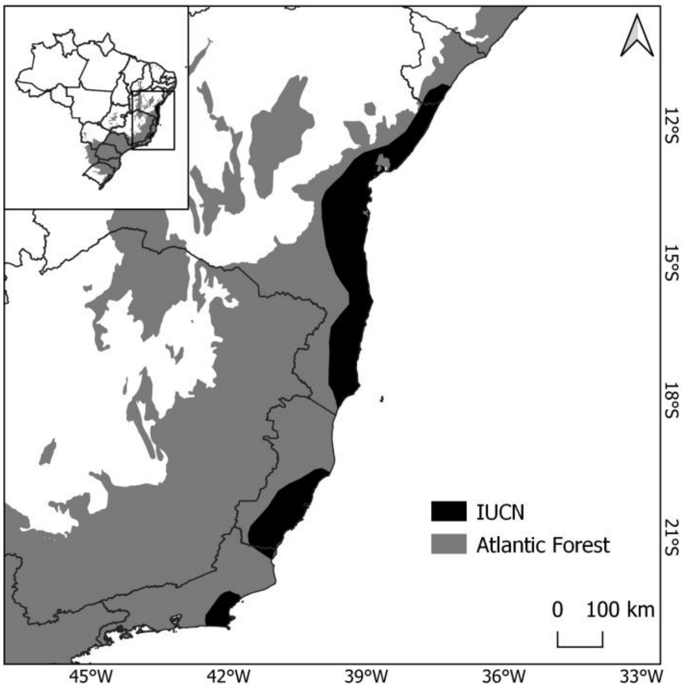


Fig. 1. Maned sloth distribution and study area. The area of the biome considered in the modeling and prioritization analysis, the extension of occurrence (black) of the maned sloth according to IUCN (2021) and Atlantic Forest domain (gray) according to Muylaert et al. (2018).

Distribution modeling and environmental suitability for the species

Occurrence data. — We compiled species occurrence data from scientific literature (Chagas et al., 2009; Lara-Ruiz and Chiarello, 2005; Moreira et al., 2014; Santos et al., 2019b), scientific collections, and field observations (G. Gine, personal observation). Data from scientific collections were obtained in the online databases: Global Biodiversity Information Facility (GBIF: http://www.gbif.org), Biodiversity Information Serving Our Nation (BISON: https://bison.usgs.gov), Vertnet database (http://vertnet.org/), Integrated Digitized Biocollections (IDGBIO: https://www.idigbio.org), iNaturalist (INAT: http://www.inaturalist.org/) and SpeciesLink (http: //www.splink.org.br/). Afterward, we filter the data removing duplicate occurrence locations, locations outside the Atlantic Forest biome, and locations with notoriously erroneous geographic coordinates. To avoid spatial redundancy of the data (Veloz, 2009), only points distant from each other (> 1 km) were randomly selected using the spThin package (Aiello-Lammens, 2015). We used this filtered data set to construct climate-based model and further removed points with declared precision less than 1 km to construct landscape based models, to obtain results faithful to the landscape variables. In total, 303 and 67 occurrence points were maintained to be used in the development of climate and landscape-based niche models, respectively.

Environmental variables. — To build the climate-based models, we downloaded data from 19 climate variables available on the Worldclim platform version 2.1 (www.worldclim.org) with a resolution of 30 arc-seconds (~1 km²) for the extension of Atlantic Forest (Muylaert et al., 2018), which are average annual values obtained between the years 1970 and 2000 (Fick and Hijmans, 2017). For the construction of the landscape-based models, we used digital layers, with the same resolution (~1 km²), obtained between the years 2013 and 2015, kindly provided by the Laboratory of Spatial Ecology and Conservation (LEEC/UNESP), which reflect the variables: patch size, percentage of forest cover, edge distance, elevation, and functional connectivity, considering 180 m of maximum dispersion distance between fragments by the matrix, value that reflects the species ability to disperse. For each set of variables (climate and landscape), we performed the principal component analysis using the prcomp and RStoolbox package (R Core Team, 2021; Leutner et al., 2019) to reduce the dimensionality of the variables. We selected the four main components as they explained 95 and 93% of the total variation of the climate and landscape model, respectively (Table S1 and S2 Supplementary material).

Ecological Niche Modeling Process (ENM). — We built the climate and landscape-based niche models separately, following the same modeling procedure, differing only about the occurrence records database and environmental variables considered, as mentioned above. For both, we use ensemble models resulting from the application of different algorithms, to encompass different forms of forecasting and reduce prediction uncertainties (Araujo and New, 2007). We use the MaxEnt version 3.4.1 (Phillips et al., 2006, 2017, 2018), Bioclim (Nix, 1986), Random Forest (Breiman, 2001), GLM (Lee et al., 2018), and Support Vector Machine (SVM) (Tax and Duin, 2004) algorithms. We used a different number of pseudo-absences and background points to model fitting, as recommended by Barbet-Massin et al. (2012), i.e. considering the ratio of 1:1 (presence:pseudo-absence) for the Random forest algorithm, 1:10 for SVM, 10,000 pseudo-absences for GLM and 10,000 background points for MaxEnt. We created the pseudo-absences using the BIOMOD2 package (Thuiller et al., 2021), with a minimum distance of 50 km from the known presences. We build 50 models (10 replicates x 5 algorithms) through the dismo package (Hijmans et al., 2020) and in the R program, using the default settings. The calibration area of the models was preliminary delimited through a buffer expanding 20% of the area of the minimum convex polygon involving all occurrence points (Barve et al., 2011). For each model, we randomly separated the occurrence points into 70% for training and 30% for testing the models. We evaluated the models by the value of the True Skill Statistics (TSS, Allouche et al., 2006) based on the “maximum specificity and sensitivity threshold” (Liu et al., 2016), and by the value of AUC (Area under the ROC Curve) (Fielding and Bell, 1997), widely used and recommended methods (Allouche et al., 2006; Fielding and Bell, 1997). After calibrating and evaluating the models, we projected for the Atlantic Forest domain (Muylaert et al., 2018) between the south of the state of Rio de Janeiro and north of Sergipe, an area that encompasses the entire range of occurrence of the species previously described in the literature (Chiarello and Moraes-Barros, 2014; Hirsch and Chiarello, 2011; Moreira et al., 2014). Next, we selected the models with TSS greater than 0.6 (Allouche et al., 2006), and we created a weighted average continuous model, weighted by the respective TSS values (Hao et al., 2019). In this way, we generated a consensual continuous model of climate suitability and another of landscape suitability. The ensemble continuous climate-based model was composed of 47 models, which presented TSS values ranging from 0.6 and 0.99, and AUC ranging from 0.84 to 0.99 (S3 Table Supplementary material). The ensemble landscape-based model was composed of 28 models, which presented TSS values ranging from 0.6 and 0.84 and

AUC ranging from 0.83 to 0.97 (S4 Table Supplementary material). The TSS and AUC values indicated a potential high predictive performance of the models.

From these ensemble continuous models, we generated binary models, to differentiate between suitable and unsuitable areas, based on the lowest presence thresholds (LPT), and 10 percentile training presence thresholds (10ptp), which corresponds to the lowest predicted suitability value for the occurrence data and the suitability value that omits 10% of the known occurrence locations of the species present at the ends of the distribution, respectively (Pearson et al., 2007; Peterson et al., 2011).

Identification of priority areas for habitat conservation and restoration. — We applied the EcoLand analytical ensemble method (Ferro and Silva et al., 2018; Rezende et al., 2020, Sobral-Souza et al., 2022) combining the consensual climate and landscape-based continuous models to identify the strategic areas and designate spatially appropriate management actions for the maned sloth conservation, focused mainly on the habitat conservation and restoration. In practice, we build a scatter plot that combines the cell's values of climate suitability (on the x-axis) and landscape suitability (on the y-axis) from the models. Afterward, we used the thresholds values LPT and 10ptp to distinguish areas of very low (< LPT), low (≥ LPT and < 10ptp), and high (≥ 10ptp) climate suitability, as well as, we used 0.2 and 0.4 values to distinguish areas of low (< 0.2), medium (≥ 0.2 and < 0.4) and high (≥ 0.4) landscape suitability. We considered these two values as thresholds (0.2 and 0.4) of landscape suitability because preliminary analysis indicated that forest cover was highly correlated (0.86) with the predicted landscape suitability and these values were closer to 20 and 35% of forest cover, respectively, which were estimated as forest-cover thresholds that distinguished the minimum (0) and maximum (1) probability of landscape occupancy by the maned sloths (Santos et al., 2019). We then geographically mapped the combinations of these nine categories (3 x 3 categories, Figure 4) to identify spatially each situation and to discuss the degree of priority and specific management appropriate for the habitat management of each region aiming at species conservation.

We defined the appropriate action and degree of priority for each combined category, firstly adopting a precautionary approach considering as candidates to conservation and restoration the entire area predicted by climate model based on the LPT threshold, which includes all the known places of the target species. However, we assumed that the zones with high climate suitability (≥ 10ptp) are of higher priority, as this contains 90% of known occurrences. Within these zones, we consider areas with high landscape suitability (≥ 0.4) as priorities for habitat conservation management (with the aim of avoiding habitat loss and disturbance). Areas with medium landscape suitability (≥ 0.2 and < 0.4) were considered a priority for restoration aimed at habitat expansion, since a minor gain in suitability may be necessary to make landscape suitable, while areas with low landscape suitability (< 0.2) were considered potentially a priority for restoration aimed at increasing landscape connectivity, since a restoration actions aiming to connect forest fragments in more restricted areas (specific sites of the landscape matrix), may be currently more viable and effective in the short term. Areas with very low climate suitability (< LPT) were considered non-priority, although those with high landscape suitability may be relevant, if necessary, for future dispersion in the face of climate change.

Potential geographic distribution area, forested and protected areas. — We estimated the total area contained in the binary climate-based model based on the more restrictive (10ptp) and less restrictive threshold (LPT), and in the area of high-priority for habitat conservation identified by EcoLand analysis. In addition, we estimated the total area covered by forested vegetation and the protected area within these three areas and calculated their relative coverage. To estimate the amount of forested vegetation in these areas, we used the land use and vegetation map provided by Mapbiomas collection 5 (Projeto MapBiomas https:// mapbiomas.org/ download), rescaled to 1 km², considering the category “natural forest formation”, which does include native forests and shaded cocoa plantations, both vegetation types used by the maned sloths (Cassano et al., 2011; Chiarello et al., 1998; Falconi et al. 2015, Santos et al., 2019a). We estimated the total protected area considering the limits of Brazilian Federal, State, and Municipal Conservation Units (http://mapas.mma.gov.br /i3geo / datadownload.htm) classified as "strictly protected areas" and “sustainable use protected areas”. Finally, we identify and highlight the forested fragments contained in areas identified as priorities for habitat conservation currently within protected areas, as well as those outside these areas.

Results

Species distribution and landscape suitability. — In general, the continuous climate-based model predicted a decreasing gradient of climate suitability from the coast to the interior, except in some coastal regions as in the extreme south and north of the state of Rio de Janeiro, extreme south of Espirito Santo, in the extreme south of Bahia and north of Sergipe, where the climate suitability was predicted to be low (Figure 2a). The binary ensemble model based on the more restrictive threshold (10ptp) predicted suitable conditions in four discontinuous areas (shown in red, Figure 2b), totaling 65,968 km². The three largest discontinuous areas of suitable conditions were located in the center of the Rio de Janeiro, in the center of the Espirito Santo to the southern Bahia, and between the southern Bahia and center of the Sergipe state (the most extensive). In addition, a small suitable area was predicted in southern Rio de Janeiro. The binary model based on the less restrictive threshold (LPT), predicted suitable climatic conditions for the maned sloth in a continuous area from south of Rio de Janeiro to the northern of Sergipe (shown in yellow, Figure 2b), totaling 152,998 km^2.

The landscape-based model indicated higher suitability in landscapes concentrated in southern Bahia (Figure 2 c,d), between the municipalities of Santa Luzia and Valença, and in some landscapes of the interior of Espirito Santo, between the municipalities of Santa Teresa and Alfredo Chaves. Outside of the area predicted by the 10ptp climate-based binary model (zone of high climate suitability), higher landscape suitability was predicted concentrated in the northeastern of Minas Gerais and extreme south of Rio de Janeiro state. Other places had lower landscape suitability or more dispersed high-suitability landscapes.

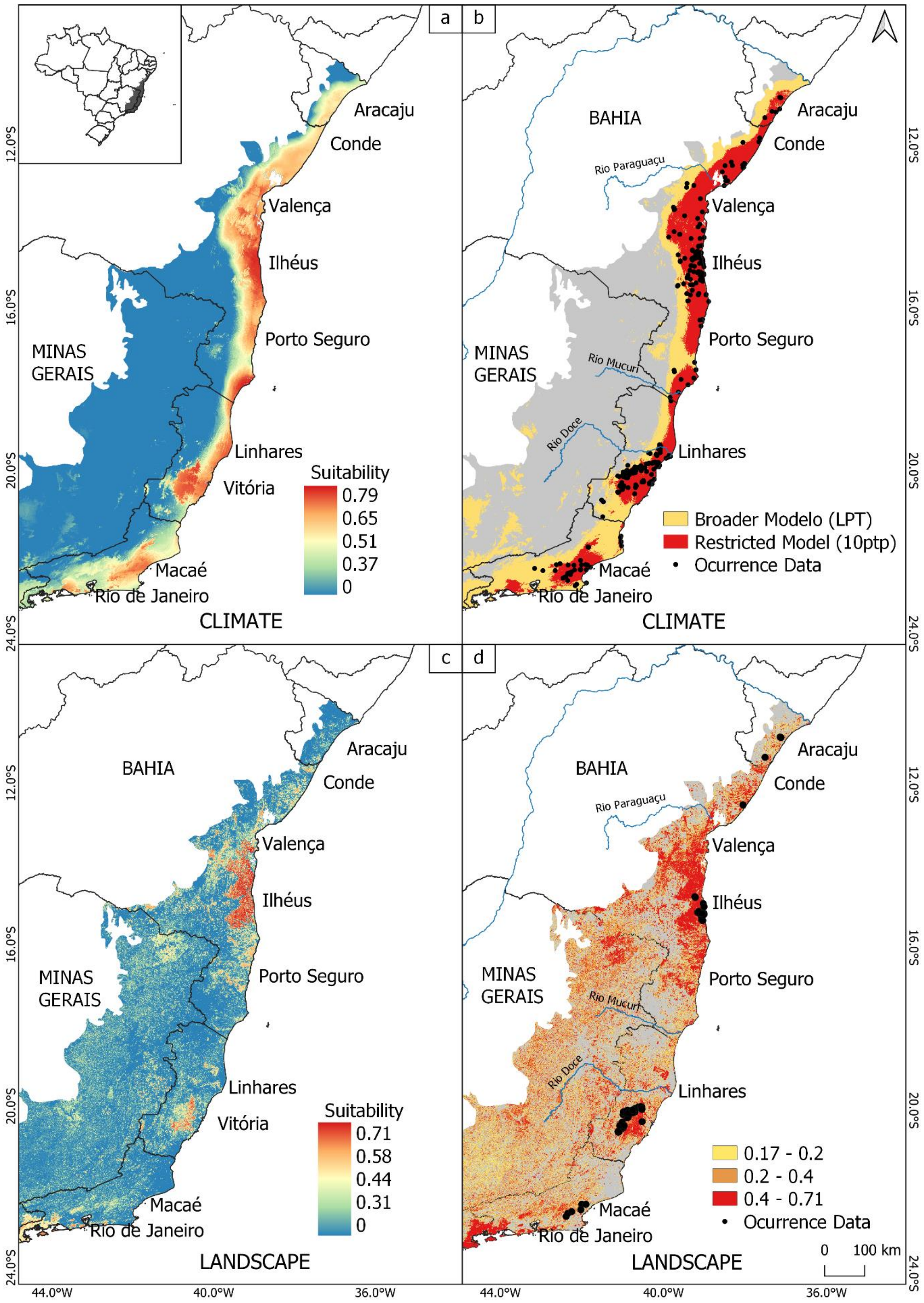


Fig. 2. Climate and landscape-based ecological niche models. Continuous (a) and binary (LPT 0.23 and 10ptp 0.53) (b) climate-based model, and continuous (c) and binary (0.2 and 0.4) (d) landscape-based models for *Bradypus torquatus* in the Atlantic Forest, Brazil. Continuous models were restricted based on the lowest presence threshold (LPT)

Identification of priority areas for habitat conservation and restoration. — The results of the EcoLand analysis indicated areas with high climate and landscape suitability (here considered of high priority for habitat conservation) concentrated mainly in the cocoa producing region of the southern Bahia and mountainous region of the Espirito Santo (red; Figure 3), while smaller and dispersed areas were predicted in others regions, totaling 20,427 km² (Table 1). These represent 30,96% of the most suitable area predicted by the 10ptp climate-based binary model and 13,35% of the total area predicted by the LPT climate-based binary model. Our results also indicated an area of 44,871 km^2 (Table 1) with high climate suitability and medium to low landscape suitability (bright and light yellow; Figure 3), where restoration actions should be prioritized, representing 68% of the most suitable area predicted by the 10ptp climate-based binary model. This is more than twice the size of the areas recommended for habitat conservation (red) and is predominant mainly in the northern and southern portion of the maned sloth's distribution, and the extreme southern Bahia. Half of this total (23,699 km^2, Table 1) has medium landscape suitability (bright yellow, Figure 3) where habitat restoration actions have a greater potential to improve the landscape suitability and expand the habitat for the species. The remaining area (21,172 km^2, Table 1) has lower landscape suitability but may be considered for restoration strategies if they have value for connecting isolated and more suitable landscapes.

Table 1. Extension occupied by each priority area management category identified in the EcoLand analysis.

Priority Management of the habitat	Area (km²)
Conservation (high priority)	20,427
Restoration for habitat expansion (high priority)	23,699
Restoration for habitat connectivity (high priority)	21,172
Conservation (medium priority)	11,642
Restoration for habitat expansion (medium priority)	28,298
Restoration for habitat connectivity (medium priority)	47,703
Climate change	15,342
Lower priority	236,405

In the zone of low climate suitability, landscapes were predominantly of low suitability for the maned sloths (54.4%; shown in light blue in Fig. 3), followed by medium (32.3%; shown in bright blue) and high suitability values (13.3%; shown in purple). These areas may contain marginal populations, although they must be confirmed before carrying out any actions, therefore, these areas were considered of medium priority for all strategies. Finally, where very low (or no) climate suitability was predicted by climate-based models (shown in dark and light gray colors), the EcoLand analysis indicated that only 3,8% of this vast area has high landscape suitability to the maned sloth and may be useful as habitat to range shifts face to climate change.

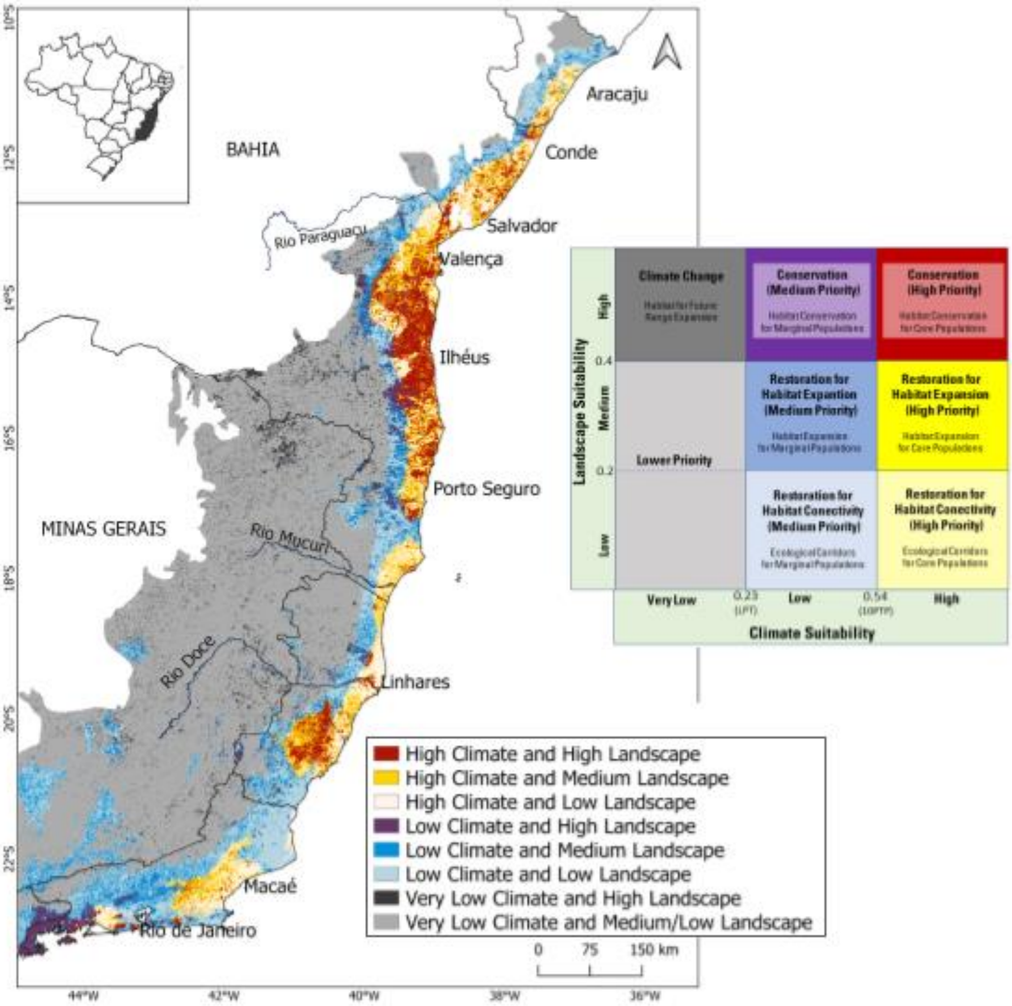


Fig. 3. Ecoland map. EcoLand analysis identifying priority actions. In red high conservation priority areas, in purple medium conservation priority areas, in bright yellow high restoration priority areas for habitat expansion, in light yellow high restoration priority for habitat connectivity, in dark blue medium restoration priority for habitat expansion, in light blue medium restoration priority areas for habitat connectivity, in dark gray priority areas in climate change scenarios and light gray lower priority areas.

Remaining forested vegetation and protected areas. — According to our estimates, currently, a total of 28,238 km^2 (42.8%) of forested vegetation remains in the climatically most suitable area for the species (10ptp climate-based binary model), of which 16,972 km^2 (25.72%) is inserted in landscapes of high suitability (Table 2). Approximately 7.33% of the forested remnants with high climate and landscape suitability are protected by strictly protected areas, 22.29% by sustainable use conservation areas, and 70, 4% are not included in protected areas. Protected areas are sparse in the northern portion of the species range, which includes the northern states of Bahia and Sergipe (Figure 4), where only 0.14% of the forested area is within strictly protected areas. On the other hand, such protected areas are more abundant in the state of Rio de Janeiro, including 13.3% of forested remnants from this region, followed by southern Bahia (7.8%) and Espirito Santo (2.5%).

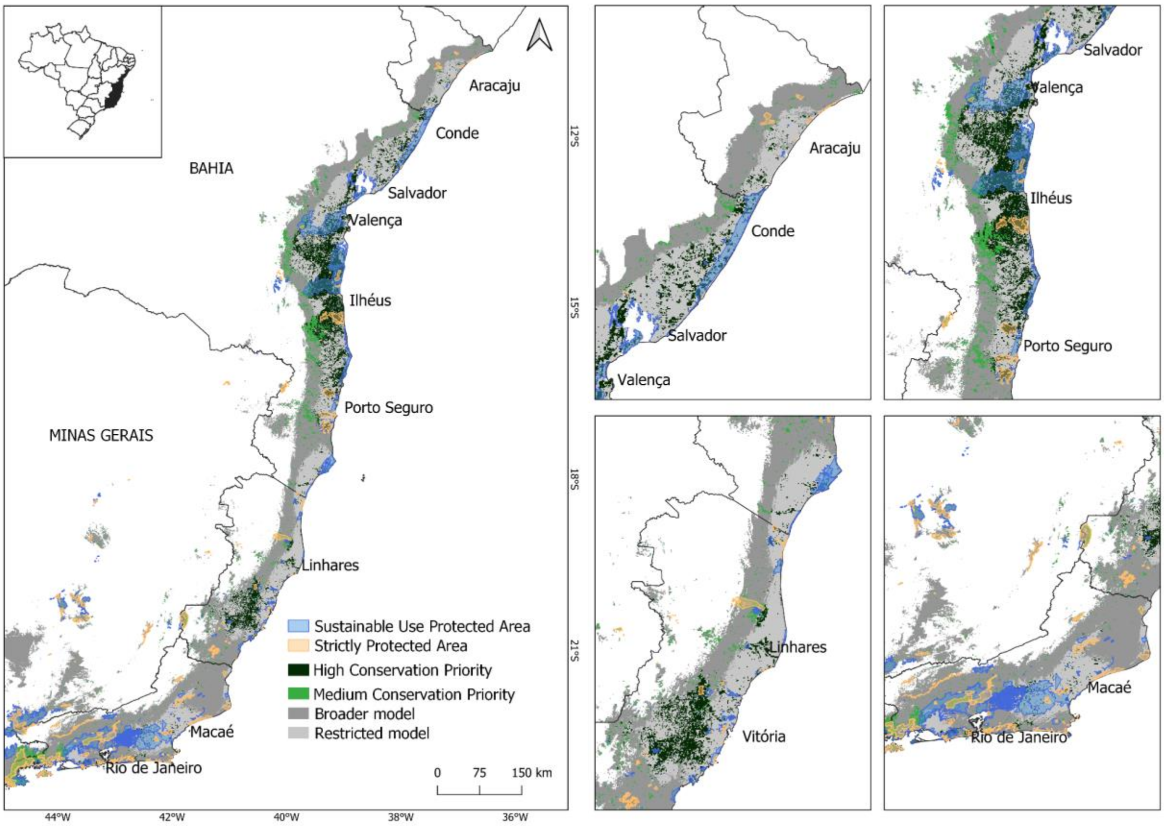


Fig. 4. Conservation priority. Remnants of high priority habitat conservation (dark green) and medium priority habitat conservation (light green), and strictly protected areas (orange) and sustainable use protected areas (blue) federal, state and municipal.

Table 2. Suitable area, remaining forested vegetation and protected areas. Values of potentially suitable area, remaining habitat, forested areas within protected areas.

	Broader model (LPT[a])	Restricted model (10ptp[b])
Suitable climate (km²)	152,998	65,968
Suitable landscape (km²)	100,518	33,139
Remaining forested vegetation (km²)	51,756 (33.82%)	28,238 (42.8%)
Forested vegetation in conservation priority area (km²)	26,410 (17.26%)	16,972 (25.72%)
Protected areas - Strictly Protected (km²)	6,942 (13.41%)	2,113 (7.48%)
Protected areas - Sustainable use (km²)*	17,569 (33.94%)	10,543 (37.33%)
Forested vegetation at a strictly protected area (km²)	5,334 (10.3%)	1,651 (5.84%)
Forested vegetation in sustainable use area (km²)*	10,116 (19.54%)	6,129 (21.7%)

[a] Binary model based on the “lowest presence” threshold

[b] Binary model based on “10. percentile training presence” threshold

* Concerning the total of remaining forested vegetation

Discussion

Ecological niche models. —The potential distribution estimated by the 10ptp climate-based binary model (restricted model), which includes 90% of known species occurrence, is the one that most resembles the disjoint geographical distribution adopted by IUCN (Chiarello and Moraes-Barros, 2014; Figure 1) and defined in previous publications (Hirsch and Chiarello, 2011), while the area predicted by the LPT model was continuous and apparently overestimated. The disjoint distribution of the maned sloth has been recently supported by molecular genetic analysis, which identified four different and genetically structured sublineages, located in Rio de Janeiro, Espirito Santo, Southern Bahia, and Northern Bahia (Schetino et al., 2017).

Two larger gaps in maned sloth's distribution are suggested in previous studies, the first between northern Rio de Janeiro and southern Espirito Santo, and the second between the Doce river, in northern Espirito Santo, and Mucuri river, in southern Bahia. Here we found low or no climate and landscape suitability in the region of the first gap and low landscape suitability in the second. Although older historic processes associated with climate change and consequent forest retraction may have been responsible by the isolation of the sublineages (Moreira et al., 2014; Schetino et al., 2017) and the current absence of the maned sloth in gap regions, our models suggest that current climate and landscape conditions should reinforce such isolation in the first gap region, while the low landscape suitability reinforce in the second. Previous climate-based model performed by Moreira et al. (2014) predicted suitable climate in both gap regions, this difference may be related to differences in the methodology building the ENMs.

Our results based on the combined climate and landscape model may be useful to understand where potentially occur the boundaries of the gaps and sublineages, indicating sites where these issues should be investigated in the field and suggesting that other isolated subpopulations may exist. For example, although less obvious, we observed that near to Paraguaçu river there is a narrowing of the climate-suitable area for the species and a low suitability of the landscape, where potentially may be located the gap region separating the northern and southern Bahia sublineages. Furthermore, similar to that predicted by Moreira et al. (2014), our climate-based model indicated unsuitable climate conditions near Prado and Alcobaça municipality, in southern Bahia. The extreme south of Bahia usually appears in other studies as an integral part of the southern Bahia unit, but in our analyses, the climatically suitable area from this region was disconnected from other regions of Bahia. We emphasize that the population of the extreme south of Bahia should receive attention to understand if, in fact, it is isolated from other populations, and receive conservation actions if needed. Until now, no genetic analysis has been conducted with this population and, in addition to predominantly containing landscapes of low to medium suitability, it is in a region of intense silvicultural activity (Projeto MapBiomas collection 5) that can directly impact the local population since this type of vegetation does not serve as a habitat for the species.

Considering the most reliable 10ptp binary model, we estimated that the maned sloth is distributed potentially on an area of 65,968 km^2, values lower than previously estimated using polygons involving confirmed occurrence locations (71,427 km^2, 71,000 km^2; Hirsch and Chiarello, 2011; Chiarello and Moraes-Barros, 2014). In addition, we estimated that 16,972 km^2 (25%) of forested vegetation remains in landscapes with high suitability in the potential geographical distribution of the maned sloth, similar to previous estimates of the amount of forest present in the distribution of the species (16,000 km^2, Moreira et al., 2014). However, it is reasonable to consider that the maned sloths probably occupy a smaller portion of this available forested vegetation. For example, the vegetation database used in the present study (Projeto MapBiomas), despite being the one currently with the greatest precision for the biome, does not differentiate areas of native forests and shaded cocoa plantations (cabruca). Although shaded cocoa plantations are used by the species (Cassano et al., 2011, Falconi et al., 2015), they likely are more occupied when close to large forest fragments, and it is possible that such plantations are the habitat of lower quality and do not support populations where native forests are scarce (Falconi et al., 2015). Additionally, most cocoa plantations have a low density of shading trees, (35 to 173 trees/ha; Sambuichi, 2006; Giné et al. 2015) compared to forests (1481 to 3620 trees/ha, Rocha-Santos et al. 2016), which may be inappropriated for this species that prefer forested patches with higher tree density (≥2000 trees/ha) and connected trees (Falconi et al. 2015). Previous estimations indicated that these plantations occupied approximately 6370 km^2 in southern Bahia (Landau et al. 2008), equivalent to 37.5% of the forested area estimated currently in the zone of the high climate and landscape suitability in the sloth's potential distribution area. Therefore, its probable that the amount of habitat occupied by species and the amount of forested vegetation estimated here is much smaller, especially in the south of Bahia, since not all the shaded cacao plantations should not function as habitat for the species.

The maned sloth is categorized as “vulnerable” particularly because its occupancy area is considered to be lower than 1,000 km^2, and one occupancy area of less than 2000 km^2 is sufficient to include a determined species in this category. Roughly, discounting the approximate area of shaded cocoa plantation, the remaining native forests in the species' area of occurrence (in region of high landscape and climate suitability) should total around 9600 km^2, value well above that those estimated as the occupancy area of the species. Therefore, if less than 20% of these remaining forests are occupied, the species can in fact be considered vulnerable according to this criterion. Unfortunately, we are still not able to understand the area of occupation of the species for decisions, and given the species' sensitivity to forest fragmentation and loss, we do not recommend changing its conservation status. Instead, we highlighted that more studies on habitat occupancy and species requirement are needed for a better understanding of this issue since only one study published and conducted in only one region from Espirito Santo state is available (see Santos et al., 2019a). In addition, mapping differentiating forest and different cocoa plantations systems are needed to estimate with better precision the total amount of remaining habitat currently available for the species and their occupancy area.

Conservation and Restoration Strategies. — Combining models, we were able to identify areas where landscape and climate suitability is predominantly high for the maned sloth, which are concentrated mainly in the mountain region of the Espirito Santo and southern Bahia (between Porto Seguro and Valença municipalities), here highlighted as areas where habitat conservation is a high priority. These areas overlap with those established as being of extreme priority for conservation action by the Brazilian Ministry of the Environment (Brasil, 2018). The more extensive area is in southern Bahia, a region that dwells on one of the largest and most genetically diverse populations of the target species (Chiarello and Lara-Ruiz, 2004; Lara-Ruiz et al., 2008). In regions such as these and others identified as priorities for habitat conservation, should be encouraged legal measures such as the establishment of strict protection areas, payment for ecosystem services, and habitat compensation, in which owners receive financial support in exchange for preserving the forested habitats (Banks-Leite et al., 2014). In addition, the monitoring of areas and environmental education measures, which aim to reduce deforestation, hunting, and fires, are essential joint measures for the maintenance of the remnants.

Protected areas in Brazil are divided into two categories in which the core of strictly protected areas is to protect biodiversity, while sustainable use areas must reconcile conservation and economic activities (Locke and Dearden, 2005). Along with the distribution, the sustainable use protection areas are more predominant concerning the strict ones. Strictly protected areas include less than 6% of the forested remnants of high conservation priority, revealing a worrying situation and a need to establish additional strict protection areas. In a complementary way, although sustainable use protected areas are less able to ensure the protection of biodiversity, such protected areas may be important to better the connectivity between the strictly protected areas, acting as connection zones (Crouzeilles et al., 2013), as well as, dwelling populations outside of strictly protected areas.

We observed a better network of protected areas in southern Bahia and Rio de Janeiro, however, the populations of Espirito Santo, northern Bahia, and Sergipe are not protected in the same way. Particularly, the northern region of Bahia and Sergipe has few areas of federal, state and municipal strict protection, being non-existent in the high-priority conservation areas identified in such region. The northern region presents intense tourist activity and urban expansion, being under constant human pressure, and efforts to protect such genetically differentiated populations are extremely urgent. In addition, the regions with extensive areas of high conservation priority, such as southern Bahia and the mountain region of the Espirito Santo, have an aggregated and relatively low coverage of strictly protected areas (7.8 and 2.5%, respectively) that need attention.

Except for the mountain region of the Espirito Santo and southern Bahia, our analysis revealed that the other regions have predominantly landscapes less suitable for the maned sloth, where restoration actions should be prioritized in addition to habitat conservation. Particularly, our analysis indicated that restoration actions are needed in the Rio de Janeiro, northern Bahia, and Sergipe, as well as in the coastal region of the Espirito Santo and extreme south of the Bahia. We defined four different priority categories for restoration, separated between core (higher priority) and marginal populations, and between a restoration focused on increasing habitat and one focused on connecting the landscape. Priority areas for restoration focused on increasing habitat are regions of medium landscape suitability where a minor gain in forest cover can make landscapes suitable. In such conditions, natural regeneration can be a viable alternative as it is the cheapest way to achieve a large-scale restoration, which is facilitated by less intensive land use and more forested landscapes (Brancalion et al., 2012; Chazdon and Guariguata, 2016; Rodrigues et al., 2009a). In this context, it is worth noting that approximately 68% of the species range needs restoration actions and 35% has landscapes with medium suitability, bringing hope that restoration actions in such landscapes can considerably become part of these suitable and help in the conservation of the species.

Priority areas for restoration focused on connecting the landscape, are regions of low landscape suitability where a greater increase in habitat cover would be needed to make landscapes suitable and therefore the forest restoration should be targeted to more spatially restricted areas in order to increase connectivity between forested remnants, i.e. through the planning and implementation of ecological corridors and stepping stones. In such conditions, more active restoration measures likely must be employed. For these regions may be an opportunity the conservation and restoration of riparian forests and legal forest reserves, which are guaranteed by Brazilian law (Federal Law 12,727/2012) and have already been previously shown that the first is useful for the dispersion of three-toed sloths (Garcés-Restrepo et al., 2018). Considering that isolated sloth populations may be locally extinct in such highly fragmented and deforested areas (Chiarello, 2004), restoration actions aiming to increase the landscape connectivity are potentially important. In addition, these areas should be the focus of actions that promote the conversion of inhospitable environments into more "friendly" forms of land use, such as agroforestry systems (Garcés-Restrepo et al. 2018), which can favor a greater permeability of the landscape. It is important to emphasize that the strategic actions for each zone are not excluded, they must be complementary and used as needed in any area.

Our results indicate that more than one-third of the maned sloth's distribution is covered by forested remnants. Considering that the proxy of the forest cover threshold for the species' persistence is around 35% (Santos et al. 2019), similar to other vertebrates (Banks-Leite et al., 2014), in general, the results bring hope for the maned sloth conservation if actions of habitat conservation and restoration are carried out. It is important to note, however, that heterogeneous environmental conditions were found in the maned sloth's distribution. While the southern Bahia (between the municipalities of Santa Luzia and Valença) and mountain region of the Espírito Santo apparently provide important refuges for the species, with high climate and landscape suitability, these landscape conditions do not comprise the entire range of the species distribution and consequently, all existing sublineages identified by Schetino et al. (2017). Particularly the sublineages from southern and northern regions of the species' distribution are under strong threat if there are no effective restoration actions that promote habitat increase and connectivity, consequently, these may not have suitable landscapes capable of sustaining this population in the long term. In particular, we have to emphasize the northern region of the species range (northern Bahia and Sergipe) that, in addition to the need for restoration, there is still an urgent need to create protected areas, but the southern region (Rio de Janeiro) similarly needs restoration actions.

There are currently opportunities for habitat restoration in these regions. For example, Strassburg et al. (2020) showed that the Atlantic Forest is among the most prioritized regions for restoration with a global view planning considering aspects of biodiversity, costs, and climate change, being in line with many of the areas obtained in our results. Fortunately, restoration actions are already being used more heavily and it is estimated that more than 1 million hectares of Atlantic Forest have been restored, and the forecast for 2050 is 15 million hectares if the Atlantic Forest Restoration Pact is fulfilled (Crouzeilles et al., 2019; Rodrigues et al., 2009b).

Finally, forest conservation actions should receive continued attention, since there are a low representation of protected areas and a continuous loss of forest cover in the maned sloth's distribution. Even in southern Bahia, the main stronghold of the maned sloth, habitat loss and degradation are continued threats. The Bahia state has lost approximately 47,500 ha of forest in the last 10 years (SOS MATA ATLÂNTICA; INPE, 2021) and the municipalities from southern Bahia are among those with higher deforestation rates in the Atlantic Forest. The expansion of agriculture, forestry (e.g., eucalyptus and rubber plantations), livestock, urban areas, and infrastructure projects, as well as reducing the density of shade trees in cocoa plantations are examples of activities that threaten their populations in this and other regions. We recommended the follow actions: 1) restauration actions in Rio de Janeiro state, 2) restauration and implementation of protected areas in northern Bahia+Sergipe 3) researches (mainly genetic) on populations in extreme south of the Bahia and 4) habitat conservation actions mainly in the southern region of Bahia and interior of Espirito Santo. We hope that our results will help to plan and prioritize habitat conservation and restoration for protecting these threatened species and their sublineages.

Supporting information

S1 Table. Climate PCA

S2 Table. Landscape PCA

S3 Table. Climate models evaluation

S4 Table. Landscape models evaluation

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Supporting information

SUPPORTING INFORMATION S1. Values of the first four axes of principal component analysis of the 19 climate variables.

Variable		**PC1**	**PC2**	**PC3**	**PC4**
Annual Mean Temperature	**bio 1**	0.27	0.14	0.22	0.05
Mean Diurnal Range	**bio 2**	0.23	0.27	0.09	0.11
Isothermality	**bio 3**	0.05	0.21	0.29	0.67
Temperature Seasonality	**bio 4**	0.25	0.04	0.24	0.33
Max Temperature of Warmest Month	**bio 5**	0.19	0.29	0.35	0.01
Min Temperature of Coldest Month	**bio 6**	0.3	0	0.07	0.05
Temperature Annual Range	**bio 7**	0.25	0.21	0.17	0.07
Mean Temperature of Wettest Quarter	**bio 8**	0.23	0.2	0.32	0.15
Mean Temperature of Driest Quarter	**bio 9**	0.29	0.06	0.14	0.17
Mean Temperature of Warmest Quarter	**bio 10**	0.26	0.15	0.3	0.05
Mean Temperature of Coldest Quarter	**bio 11**	0.29	0.11	0.16	0.08
Annual Precipitation	**bio 12**	0.13	0.37	0.34	0.18
Precipitation of Wettest Month	**bio 13**	0.23	0.11	0.32	0.31
Precipitation of Driest Month	**bio 14**	0.18	0.38	0.06	0.03
Precipitation Seasonality	**bio 15**	0.22	0.28	0.11	0.24
Precipitation of Wettest Quarter	**bio 16**	0.24	0.12	0.33	0.28
Precipitation of Driest Quarter	**bio 17**	0.18	0.38	0.04	0.03
Precipitation of Warmest Quarter	**bio 18**	0.25	0.18	0.23	0.05
Precipitation of Coldest Quarter	**bio 19**	0.18	0.32	0.08	0.31
Standard Deviation		3.2998	2.0074	1.414	1.08779
Proportion of variance		0.5731	0.2121	0.1063	0.06228
Cumulative proportion		0.5731	0.7852	0.8915	0.95376

SUPPORTING INFORMATION S2. Values of the first four axes of principal component analysis of the five landscape variables.

Variable	**PC1**	**PC2**	**PC3**	**PC4**
Area	0.37	-0.66	0.47	-0.44
Edge	-0.47	-0.25	0.53	0.40
Forest cover	0.55	0.03	-0.24	0.80
Connectivity	0.46	-0.26	-0.06	0.8
Slope	0.36	0.65	0.66	0.04
Standard Deviation	1,56	0,9296	0,8473	0,7882
Proportion variance	0,4891	0,1728	0,1436	0,1243
Cumulative proportion	0,4891	0,619	0,8055	0,9298

SUPPORTING INFORMATION S3. Climate models evaluation

	Specie	Algorithm	TSS	AUC	kappa
1	Bradypus torquatus	Bioclim	0.679	0.891	0.557
2	Bradypus torquatus	Bioclim	0.688	0.895	0.639
3	Bradypus torquatus	Bioclim	0.528	0.796	0.526
4	Bradypus torquatus	Bioclim	0.616	0.858	0.608
5	Bradypus torquatus	Bioclim	0.620	0.845	0.513
6	Bradypus torquatus	Bioclim	0.597	0.834	0.539
7	Bradypus torquatus	Bioclim	0.579	0.804	0.490
8	Bradypus torquatus	Bioclim	0.679	0.902	0.662
9	Bradypus torquatus	Bioclim	0.600	0.847	0.583
10	Bradypus torquatus	Bioclim	0.643	0.851	0.553
11	Bradypus torquatus	GLM	0.888	0.977	0.586
12	Bradypus torquatus	GLM	0.861	0.976	0.648
13	Bradypus torquatus	GLM	0.881	0.980	0.639
14	Bradypus torquatus	GLM	0.902	0.982	0.633
15	Bradypus torquatus	GLM	0.869	0.975	0.625
16	Bradypus torquatus	GLM	0.882	0.981	0.630

17	Bradypus torquatus	GLM	0.875	0.976	0.691
18	Bradypus torquatus	GLM	0.881	0.972	0.589
19	Bradypus torquatus	GLM	0.844	0.966	0.663
20	Bradypus torquatus	GLM	0.857	0.968	0.576
21	Bradypus torquatus	Random Forest	0.973	0.997	0.973
22	Bradypus torquatus	Random Forest	0.933	0.994	0.933
23	Bradypus torquatus	Random Forest	0.918	0.993	0.917
24	Bradypus torquatus	Random Forest	0.921	0.994	0.921
25	Bradypus torquatus	Random Forest	0.947	0.998	0.946
26	Bradypus torquatus	Random Forest	0.986	0.997	0.986
27	Bradypus torquatus	Random Forest	0.947	0.995	0.947
28	Bradypus torquatus	Random Forest	0.973	0.997	0.973
29	Bradypus torquatus	Random Forest	0.933	0.995	0.933
30	Bradypus torquatus	Random Forest	0.906	0.990	0.906
31	Bradypus torquatus	Maxent	0.889	0.985	0.844
32	Bradypus torquatus	Maxent	0.935	0.993	0.928
33	Bradypus torquatus	Maxent	0.913	0.990	0.873
34	Bradypus torquatus	Maxent	0.887	0.976	0.843
35	Bradypus torquatus	Maxent	0.895	0.987	0.857
36	Bradypus torquatus	Maxent	0.875	0.980	0.845
37	Bradypus torquatus	Maxent	0.908	0.987	0.894
38	Bradypus torquatus	Maxent	0.910	0.985	0.855
39	Bradypus torquatus	Maxent	0.906	0.986	0.864
40	Bradypus torquatus	Maxent	0.855	0.972	0.836
41	Bradypus torquatus	SVM	0.960	0.998	0.940
42	Bradypus torquatus	SVM	0.973	0.999	0.982
43	Bradypus torquatus	SVM	0.951	0.995	0.932
44	Bradypus torquatus	SVM	0.941	0.991	0.916
45	Bradypus torquatus	SVM	0.972	0.999	0.956
46	Bradypus torquatus	SVM	0.971	0.994	0.957
47	Bradypus torquatus	SVM	0.949	0.993	0.948
48	Bradypus torquatus	SVM	0.947	0.993	0.938
49	Bradypus torquatus	SVM	0.968	0.997	0.947
50	Bradypus torquatus	SVM	0.956	0.995	0.915

SUPPORTING INFORMATION S4. Landscape models evaluation

	Specie	Algorithm	TSS	AUC	kappa
1	Bradypus torquatus	Bioclim	0.602	0.881	0.381
2	Bradypus torquatus	Bioclim	0.405	0.737	0.297
3	Bradypus torquatus	Bioclim	0.455	0.781	0.307
4	Bradypus torquatus	Bioclim	0.307	0.712	0.261
5	Bradypus torquatus	Bioclim	0.605	0.842	0.347
6	Bradypus torquatus	Bioclim	0.544	0.804	0.309
7	Bradypus torquatus	Bioclim	0.310	0.699	0.220
8	Bradypus torquatus	Bioclim	0.303	0.686	0.174
9	Bradypus torquatus	Bioclim	0.304	0.671	0.175
10	Bradypus torquatus	Bioclim	0.552	0.808	0.365
11	Bradypus torquatus	GLM	0.625	0.839	0.453
12	Bradypus torquatus	GLM	0.711	0.907	0.638
13	Bradypus torquatus	GLM	0.778	0.941	0.558
14	Bradypus torquatus	GLM	0.768	0.917	0.414
15	Bradypus torquatus	GLM	0.865	0.959	0.558
16	Bradypus torquatus	GLM	0.772	0.920	0.362
17	Bradypus torquatus	GLM	0.661	0.874	0.520
18	Bradypus torquatus	GLM	0.806	0.932	0.520
19	Bradypus torquatus	GLM	0.757	0.931	0.536
20	Bradypus torquatus	GLM	0.804	0.956	0.638
21	Bradypus torquatus	Random Forest	0.647	0.772	0.647
22	Bradypus torquatus	Random Forest	0.824	0.979	0.824
23	Bradypus torquatus	Random Forest	0.471	0.737	0.471
24	Bradypus torquatus	Random Forest	0.588	0.827	0.588
25	Bradypus torquatus	Random Forest	0.588	0.792	0.588
26	Bradypus torquatus	Random Forest	0.353	0.685	0.353
27	Bradypus torquatus	Random Forest	0.765	0.893	0.765
28	Bradypus torquatus	Random Forest	0.588	0.827	0.588
29	Bradypus torquatus	Random Forest	0.588	0.792	0.588
30	Bradypus torquatus	Random Forest	0.706	0.848	0.706
31	Bradypus torquatus	Maxent	0.773	0.916	0.515
32	Bradypus torquatus	Maxent	0.691	0.856	0.433

33	Bradypus torquatus	Maxent	0.700	0.903	0.506
34	Bradypus torquatus	Maxent	0.829	0.963	0.589
35	Bradypus torquatus	Maxent	0.804	0.934	0.549
36	Bradypus torquatus	Maxent	0.776	0.929	0.567
37	Bradypus torquatus	Maxent	0.756	0.920	0.597
38	Bradypus torquatus	Maxent	0.844	0.964	0.691
39	Bradypus torquatus	Maxent	0.718	0.885	0.454
40	Bradypus torquatus	Maxent	0.645	0.872	0.436
41	Bradypus torquatus	SVM	0.412	0.605	0.567
42	Bradypus torquatus	SVM	0.345	0.526	0.457
43	Bradypus torquatus	SVM	0.505	0.689	0.541
44	Bradypus torquatus	SVM	0.570	0.736	0.601
45	Bradypus torquatus	SVM	0.583	0.762	0.597
46	Bradypus torquatus	SVM	0.470	0.638	0.480
47	Bradypus torquatus	SVM	0.501	0.685	0.572
48	Bradypus torquatus	SVM	0.679	0.860	0.699
49	Bradypus torquatus	SVM	0.616	0.734	0.548
50	Bradypus torquatus	SVM	0.467	0.653	0.597

III. CONCLUSÕES

Os resultados do nosso estudo elucidam sobre os possíveis limites para as atuais lacunas de distribuição da preguiça-de-coleira e possíveis locais de separação entre as sublinhagens previamente estabelecidas por análises de DNA. Além disso, indicamos áreas onde a combinada adequabilidade de paisagem e clima é predominantemente alta para a preguiça-de-coleira, onde medidas de conservação devem ser priorizadas, como no sul da Bahia e região serrana do Espírito Santo. No entanto evidenciamos que essa adequabilidade não é homogênea ao longo da distribuição da espécie e dessa forma não contempla todas as sublinhagens existentes. Sendo assim, devemos dar atenção principalmente para os extremos da distribuição da espécie, assim como para o extremo sul da Bahia, onde medidas de restauração são prioritárias e urgentes já que podemos não ter paisagens adequadas capazes de sustentar essas populações a longo prazo. Esse estudo traz novas percepções sobre a distribuição e o estado de conservação da preguiça-de-coleira, com isso os resultados podem ser utilizados como ferramenta de planejamento ambiental e decisão a fim de auxiliar na conservação da espécie.