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DIVERSIDADE DE MAMÍFEROS DE MÉDIO E GRANDE PORTE EM PAISAGENS ANTROPIZADAS DA CAATINGA

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Esta tese foi julgada e aprovada para obtenção do Grau de
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RESUMO

A exploração de áreas naturais tem se intensificado com o aumento da população humana, notadamente com o objetivo de satisfazer suas necessidades de produção de alimento, através da agricultura e pecuária. Este processo tem causado a introdução de espécies exóticas e alterações nas características da paisagem que, por sua vez, determinam mudanças na estrutura das comunidades de médios e grandes mamíferos. Visando o preenchimento de lacunas acerca das consequências da alteração da paisagem sobre a mastofauna da Caatinga, o objetivo deste estudo foi identificar o efeito da perturbação antrópica na diversidade das comunidades de médios e grandes mamíferos da Caatinga em duas regiões com distintos regimes de precipitação e graus de proteção: o Parque Nacional do Catimbau (PNC), PE, uma das maiores unidades de conservação da Caatinga no estado de Pernambuco, e o Cariri paraibano (CAR), a região mais seca do país, incluindo um núcleo de desertificação da Caatinga. A principal hipótese testada foi que a perda de habitat conduz ao empobrecimento e homogeneização das comunidades de médios e grandes mamíferos nativos, enquanto favorece as espécies exóticas. Foram realizadas técnicas de sensoriamento remoto para determinação da cobertura florestal em 18 paisagens no PNC e 4 paisagens no CAR e utilizadas armadilhas fotográficas para o registro de médios e grandes mamíferos durante 24h/dia ao longo de cinco meses em Pernambuco e nove meses na Paraíba. Com estas informações foram descritos os padrões de composição e dominância das espécies ao longo do gradiente de perturbação e estimadas as diversidades alfa, beta e gama das comunidades. Como esperado, no PNC a perda de habitat reduziu a diversidade alfa das espécies nativas e aumentou a diversidade das exóticas. No CAR isto também ocorreu, porém a redução da diversidade de nativas e aumento da diversidade de exóticas nas paisagens mais perturbadas se deu de forma não linear. Adicionalmente, a diversidade beta regional foi muito baixa em ambas as regiões, o que sugere que a Caatinga tem sofrido um processo de homogeneização biótica. A diversidade gama de nativas também foi extremamente baixa (8 espécies no PNC e 10 no CAR) dado o total de 183 espécies com registros para a Caatinga. Isto é ainda mais preocupante quando se observa que cerca 75% dos registros (593 no PNC e 2808 no CAR) foram de espécies exóticas. Em realidade, há uma tendência geral de que as comunidades nas paisagens mais perturbadas convirjam taxonomicamente para apenas duas espécies: *Capra hircus* (cabras) e *Cerdocyon thous* (cachorros-do-mato), ainda que espécies raras como *Mazama gouazoubira* e *Herpailurus yagouaroundi* ainda possam persistir. De modo geral, os resultados indicam que ambas as regiões abrigam novas comunidades de mamíferos sob um padrão de dominância das espécies exóticas. Isto é preocupante, uma vez que as espécies exóticas são predominantemente herbívoras e podem ocasionar um considerável impacto biomassa vegetal, com efeitos cascata no funcionamento do ecossistema. Para reverter o quadro e evitar uma descaracterização ainda maior da mastofauna nativa, sugere-se implementar ações de restauração florestal, combater a caça e o comércio ilegal, reintroduzir espécies nativas eliminadas localmente e desenvolver um novo modelo de pecuária sustentável.

Palavras-chave: Distúrbio, mastofauna, novas comunidades, pecuária.

ABSTRACT

The exploration of natural areas has intensified with the increasing of human population, notably because their needs for food production through agriculture and livestock. This process has caused exotic species introduction and changes in landscape characteristics which, in turn, determine structural changes in medium and large mammal communities. In order to fill the gaps about the consequences of change landscape on Caatinga mamalian fauna, this study aimed to identify the effect of anthropogenic disturbance on the diversity of medium and large mammals communities of Caatinga in two regions with different precipitation regimes and different conservation efforts: Catimbau National Park (CNP), PE, one of the largest conservation units in Caatinga, Pernambuco State, and Cariri (CAR), the driest region in Brazil, including a desertification nucleus of Caatinga. The main hypothesis tested was if the forest loss leads to impoverishment and homogenization of medium and large native mammals communities, favoring exotic species. Remote sensing techniques were used to determine forest coverage in 18 landscapes in CNP and 4 landscapes in CAR and camera traps were used to record medium and large mammals for 24 hours/day over five months in Pernambuco and nine months in Paraíba. Species composition and dominance patterns were described along the disturbance gradient and alpha, beta and gamma patterns of diversity were also estimated for the communities. As expected, the forest loss decreased the alpha diversity of native species and increased exotic species diversity in CNP. This also occurred in CAR, but the reduction of native species diversity as well as increasing of exotic species diversity in the most disturbed landscapes were non-linear. In addition, regional beta diversity was very low in both regions, suggesting that Caatinga is going through a biotic homogenization process. The gamma diversity of native species was also extremely low (8 species in CNP and 10 in CAR), given that 183 species have been recorded in Caatinga. Raising the concerns, about 75% of the records (593 in the PNC and 2808 in the CAR) were of exotic species. In fact, there is a general tendency for communities in the most disturbed landscapes being taxonomically diminished to only two species: Capra hircus (goats) and *Cerdocyon thous* (foxes), albeit rare species such as *Mazama gouazoubira* and *Herpailurus yagouaroundi* may still persist. Overall, the results indicate that both regions harbor novel mammal communities under a pattern of exotic species dominance. This is concerning once exotic species are predominantly herbivorous and can cause a considerable impact on plant biomass, with cascade effects on ecosystem functioning. To reverse this condition and avoid a greater mischaracterization of native mammalian fauna, we suggested that forest restoration actions should be implemented to control hunting and illegal trade, that native species should be reintroduced in locally extinct areas and the development of new models of sustainable livestock.

Keywords: Disturbance, mammalian fauna, novel communities, livestock.

SUMÁRIO

1. INTRODUÇÃO

A exploração de áreas naturais tem se intensificado com o aumento da população humana, notadamente com o objetivo de satisfazer suas necessidades de produção de alimento, através da agricultura e pecuária. Estima-se que, em uma escala global, metade da superfície da Terra já é composta por habitats alterados e com elevada tendência à ampliação, constituindo assim os antromas ou biomas antropogênicos (ELLIS et al., 2010). Os efeitos das ações humanas na dinâmica dos ecossistemas provocam sérios riscos à manutenção de espécies animais e vegetais, com destaque para aquelas sensíveis à modificação da paisagem. De um modo geral, os padrões de diversidade, processos ecológicos e a estrutura das comunidades podem ser alterados pelas condições da paisagem (BOGONI et al., 2016; GALETTI et al., 2009).

As mudanças ambientais, sobretudo aquelas que envolvem alterações na paisagem, afetam a mastofauna de modos diferentes. Pequenos, médios e grandes mamíferos exibem, por exemplo, respostas distintas à fragmentação e perda de habitats (KEINATH et al., 2017). As espécies de maior porte tendem a ser mais sensíveis às alterações pois apresentam maiores áreas de uso, requerem mais recursos e energia para completar seus longos ciclos de vida e possuem baixa densidade populacional (CARDILLO et al., 2005; MORRIS et al., 2008). As características da paisagem são, portanto, determinantes para a persistência destas espécies e responsáveis pelas mudanças na estrutura das comunidades de médios e grandes mamíferos. As ameaças, no entanto, não se restringem às condições ambientais, mas também incluem a pressão de caça exercida usualmente pela população rural, seja para o consumo alimentar ou para a resolução de conflitos com a produção agrícola ou pecuária (ALVES et al., 2016; BODMER; EISENBERG; REDFORD, 1997; PESSOA; WAGNER; LANGGUTH, 2013).

Embora os antromas estejam espalhados por todo o planeta, há uma grande lacuna de conhecimento acerca de seu papel como repositório de biodiversidade, especialmente de mamíferos terrestres. Antromas caracterizados por populações humanas pobres e diretamente dependentes dos recursos naturais, como a Caatinga, estão entre os mais desconhecidos. Albuquerque et al. (2012) ressaltam que, apesar dos avanços, várias localidades na Caatinga ainda são deficientes quanto às informações sobre riqueza, distribuição, ecologia e comportamento de mamíferos nativos. Além disso, a presença massiva de animais exóticos como alto valor cultural e econômico, como os gados bovino, equino e ovinocaprino criados extensivamente, assim como a íntima relação dos moradores com cães e gatos, criam novas comunidades de mamíferos terrestres cujas características também são desconhecidas. Nesse sentido, investigar a mastofauna de espécies nativas e exóticas em paisagens modificadas torna-se prioridade no cenário atual da Caatinga, que figura como um dos ecossistemas mais ameaçados do Brasil (CARMIGNOTTO; ASTÚA, 2018).

Visando o preenchimento de lacunas acerca das consequências da alteração da paisagem sobre a mastofauna da Caatinga, o objetivo deste estudo foi identificar o efeito da perturbação antrópica na diversidade das comunidades de médios e grandes mamíferos da Caatinga. A tese está estruturada em dois capítulos e apresenta os resultados da investigação em dois contextos distintos quanto às condições climáticas de precipitação e aridez. O primeiro, intitulado “Landscape-scale patterns and drivers of novel mammal communities in a human-modified protected area”, discute como a mastofauna de médio e grande porte responde às alterações na cobertura florestal e ao isolamento de áreas mais conservadas no interior do Parque Nacional do Catimbau, PE, uma das maiores unidades de conservação de proteção integral da Caatinga. O segundo, intitulado “Foxes and goats: is that the future of the Caatinga?”, apresenta os resultados sobre como a diversidade de mamíferos nativos e exóticos responde às modificações da paisagem na região mais seca do Brasil, o Cariri paraibano.

2. FUNDAMENTAÇÃO TEÓRICA

2.1 Alterações nos ecossistemas naturais

A exploração de áreas naturais tem se intensificado com o aumento da população humana, notadamente com o objetivo de satisfazer suas necessidades de produção de alimento, através da agricultura e pecuária. Ellis et al. (2010) define o conjunto destes habitats alterados como antromas ou biomas antropogênicos. Este conceito não surge em substituição ao sistema de biomas convencional, mas se configura como uma visão alternativa que pondera os padrões de uso do solo e a densidade populacional humana (ELLIS; RAMANKUTTY, 2008). A definição também apresenta um caráter operacional no que tange o estabelecimento de áreas protegidas. Martin et al. (2014) indicam que estas áreas não estão regularmente distribuídas ao longo dos antromas, sendo menos frequentes naqueles mais populosos.

A necessidade de investigação de padrões e processos biológicos, além da definição de estratégias para a conservação são, portanto, imperativas no atual cenário de ameaça. Os efeitos das ações humanas na dinâmica dos ecossistemas provocam sérios riscos à manutenção de espécies animais e vegetais, com destaque para aquelas sensíveis à modificação da paisagem. Neste contexto, muito tem se avançado na definição conceitos e métricas que avaliam como a estrutura e a composição da paisagem interferem na manutenção da biodiversidade (METZGER, 2006).

Usualmente fragmentação e perda de habitat são fatores discutidos em associação, mas é fundamental apontar que eles apresentam distintas definições e não necessariamente são mutuamente condicionantes. Fragmentação de habitat é um processo no qual um habitat inicial contínuo é transformado em pequenas manchas desconectadas, ou seja, ocorre a perda da continuidade (CARVALHO; DE MARCO; FERREIRA, 2009; PIRES; FERNANDEZ; BARROS, 2006). Para que haja fragmentação é necessária a redução de habitat, causando implicações tanto na conectividade como também no efeito de borda e amplitude da matriz (MICHALSKI; PERES, 2007; NORRIS et al., 2008). Entretanto, o inverso nem sempre ocorre, uma vez que dada área pode se manter conectada mesmo com a perda de habitat. Logo, perda de habitat não pressupõe fragmentação.

Os efeitos das alterações nas características da paisagem são direcionados à biodiversidade no nível populacional como também de comunidades, podendo afetar desde o número e a distribuição dos indivíduos até a composição taxonômica das comunidades e a riqueza de espécies (CHIARELLO, 1999; FAHRIG, 2003; SANTOS-FILHO et al., 2012). Fahrig (2003) ressalta que as espécies mais sensíveis à matriz são afetadas diretamente pela fragmentação, pois permanecem isoladas nos pequenos fragmentos e estão sujeitas a constante efeito de borda que, por sua vez, pode condicionar a saída destas espécies do fragmento e assim aumentar sua vulnerabilidade à morte ou reduzir sua taxa reprodutiva. Além disso, a redução da heterogeneidade do habitat causada pela substituição da vegetação original por novas formas de uso do solo pode ocasionar mudanças nos recursos disponíveis e, consequentemente, levar a homogeneização das comunidades naturais (LION et al., 2016). Estas alterações na biodiversidade, no tocante ao declínio ou desaparecimento de algumas espécies, podem ser observadas em curto ou longo prazo (KUUSSAARI et al., 2009). As escalas de fragmentação de uma paisagem afetam de diferentes formas as espécies que ali habitam. A Caatinga, por exemplo, ainda permanece bem conectada para espécies com moderada ou alta capacidade de dispersão, embora apresente 90% de seus remanescentes com tamanho inferior a 500 ha e com forte pressão antrópica (ANTONGIOVANNI; VENTICINQUE; FONSECA, 2018).

A hipótese proposta por Fahrig (2013) discute que a quantidade de habitat é o principal preditor da biodiversidade de espécies nativas, estando a fragmentação em segundo plano. Assim, é possível que as respostas da das espécies nativas à fragmentação sejam positivas, negativas ou neutras e sua intensidade mude conforme a escala, caso a quantidade de habitat seja controlada (FAHRIG, 2017). Espécies generalistas tendem a ser favorecidas pela redução da quantidade de habitat, bem como pela fragmentação, dado que são mais tolerantes às perturbações e movimentam-se livremente pela matriz (BANKS-LEITE et al., 2014; HARRISSON et al., 2014). De modo oposto, as espécies que possuem maior fidelidade ao habitat e capacidade limitada de movimento na matriz, são mais suscetíveis à perda de habitat e fragmentação (PFEIFER et al., 2017). Neste contexto, surge o paradigma de que as espécies sensíveis às ações antrópicas (*losers*) estão em declínio e progressivamente sendo substituídas por espécies com grande capacidade de expansão em áreas perturbadas, sendo estas definidas como *winners*, o que desencadeia o processo de homogeneização biótica (MCKINNEY; LOCKWOOD, 1999; TABARELLI; PERES; MELO, 2012).

Não obstante, a captura ilegal de animais silvestres é uma ameaça constante à manutenção de muitas espécies, mesmo no interior de áreas protegidas (CASTILHO et al., 2019). Geralmente as atividades de caça ocorrem para satisfazer necessidades alimentícias, terapêuticas, comerciais e também recreativas (ALVES, 2012; PESSOA; WAGNER; LANGGUTH, 2013). Mamíferos compõem um dos principais grupos de vertebrados cinegéticos de importância alimentar, bem como possui altos valores de uso como animais de companhia (LUNA DE OLIVEIRA et al., 2017; PESSOA; WAGNER; LANGGUTH, 2013). A captura excessiva constitui um dos impactos mais significativos para a redução das populações naturais, ocasionando sérios efeitos na estrutura das comunidades e nas suas funções ecológicas (RIBEIRO; SILVA, 2007). Assim, a caça ilegal pode mascarar efeitos das características da paisagem sobre a diversidade de mamíferos, já que paisagens bem conservadas podem apresentar poucas espécies em função de alta pressão de caça.

A introdução de espécies exóticas, apesar de ser um impacto indireto, também causa forte pressão na biodiversidade dos ecossistemas naturais (MILARDI et al., 2020), podendo levar a perda da diversidade de espécies nativas (BELLARD; CASSEY; BLACKBURN, 2016; BLACKBURN; BELLARD; RICCIARDI, 2019). Cães e gatos, por exemplo, são carnívoros invasores distribuídos amplamente pelo mundo e têm sido responsáveis pela extinção de inúmeras espécies da fauna nativa (DOHERTY et al., 2016; LOSS; MARRA, 2017; MELLA-MÉNDEZ et al., 2019; SPOTTE, 2014), notadamente por seus efeitos negativos como predadores, vetores de parasitos e doenças, bem como determinantes para hibridização (VANAK; GOMPPER, 2009; ZAPATA-RÍOS; BRANCH, 2016). Mamíferos nativos de médio porte são apontados como o grupo mais afetado por cães e gatos ferais (HUGHES; MACDONALD, 2013; LESSA et al., 2016). A pecuária extensiva através da criação de grandes rebanhos de vacas, cabras e ovelhas, sem confinamento e com acesso livre aos remanescentes de habitat natural, também promove o contato direto entre fauna nativa e exótica, modificando a estrutura e composição das comunidades existentes e eventualmente criando novos ecossistemas.

Neste complexo cenário de alterações na paisagem e na biodiversidade é necessário distinguir entre ecossistemas estruturalmente e funcionalmente degradados e novos ecossistemas. Há mais de uma década pesquisadores revisam este conceito e sua aplicação em contextos urbanos e não-urbanos (TEIXEIRA; FERNANDES, 2019). Um novo ecossistema é, portanto, definido como um sistema que difere do original por mudanças na composição biótica, abiótica, social, bem como nas interações entre elas, podendo se manter e apresentar novas características sem a interferência humana (HOBBS; HIGGS; HALL, 2013). A correta identificação e distinção entre ecossistemas históricos, híbridos e novos é necessária, uma vez que possui implicações nas estratégias de conservação e restauração biológica (HOBBS; HIGGS; HARRIS, 2009; HOBBS; HIGGS; HALL, 2013; MORSE et al., 2014).

2.2 Padrões de diversidade alfa, beta e gama

O termo diversidade biológica foi cunhado inicialmente em meados dos anos 50 e passou a ser amplamente utilizado após a década de 60, todavia apenas em 1986 foi decomposto em três elementos: diversidade genética, diversidade de espécies e diversidade ecológica. Em 1985 surgiu a contração “biodiversidade”, que atualmente é utilizada de modo intercambiável com “diversidade biológica” (MAGURRAN, 2013). Por definição, o conceito abrange toda a variabilidade de organismos vivos, seja dentro e entre espécies ou mesmo de ecossistemas (SECRETARIAT OF THE CONVENTION ON BIOLOGICAL DIVERSITY, 2005).

A biodiversidade tem se tornado, progressivamente, assunto de preocupação pública e debate político, o que endossa o aumento da sensibilização para as atuais taxas de perda de espécies e para estratégias de conservação que atenuem este cenário. O crescente interesse nas questões relacionadas à biodiversidade tem dirigido também o desenvolvimento de métodos para mensuração, notadamente através do avanço computacional e das técnicas de amostragem (MAGURRAN, 2013).

Inicialmente deve-se assumir que a diversidade biológica não é uniforme, pois cada ambiente apresenta diferentes espécies com também distintas abundâncias, o que constitui uma comunidade biológica (BASELGA; GÓMEZ-RODRÍGUEZ, 2019). Identificar e compreender as diferenças entre estas comunidades tem sido tema de interesse de pesquisadores, dada a recorrente necessidade de priorização e direcionamento de recursos para a conservação ambiental.

Mensurar a riqueza de espécies é o meio mais simples e direto de avaliar a diversidade biológica (SANJIT; BHATT, 2005; WILSEY et al., 2005), mas possui limitações derivadas do fato das comunidades serem unidades abertas ao fluxo de migrantes e a relação de dependência que esta medida mantém com o tamanho da área, dificultando assim a comparação entre comunidades (CHASE et al., 2019). Para superar estes entraves surgem os índices de riqueza e os de diversidade. Estes últimos associam a riqueza de espécies com a equitabilidade, para a qual consideram abundância relativa das espécies (MELO, 2008).

Os padrões de diversidade alfa, beta e gama foram propostos por Whittaker (1960), que definiu a riqueza de espécies local como diversidade alfa (α), a regional como diversidade gama (γ) e a relação entre elas, que indica as variações na composição das comunidades, como diversidade beta (β). Esta última revela quantas comunidades completamente distintas existem em uma dada região, variando do mínimo de diferenciação (quando todas as comunidades são idênticas; $\gamma = \alpha$ e $\beta = 1$) ao máximo (quando todas as comunidades são totalmente diferentes; ; $\gamma = \alpha * N$, onde N é o número de comunidades locais; e $\beta = N$). Existem uma variedade de índices que podem ser utilizados para mensurar estes padrões de diversidade (MAGURRAN, 2013; MAGURRAN; MCGILL, 2011), mas é necessário apontar que a diferença entre as comunidades biológicas pode ser determinada por fatores também distintos, tais como substituição (*turnover*), aninhamento (*nestedness*) ou ambos (BASELGA, 2010; BASELGA; GÓMEZ-RODRÍGUEZ, 2019). A correta identificação destes fatores possui implicações na conservação, pois comunidades estruturadas por substituição de espécies são complementares e deve-se então assumir medidas que incluam a complexidade de áreas. Por outro lado, se o padrão de aninhamento é predominante, deve-se priorizar a conservação das comunidades que abrigam mais espécies (BASELGA; GÓMEZ-RODRÍGUEZ, 2019).

As medidas tradicionais de diversidade são, de fato, medidas de entropia, pois não consideram a uniformidade na distribuição das abundâncias (equitabilidade) entre as espécies. A diversidade taxonômica verdadeira, designada como o número efetivo de espécies em uma dada comunidade, só pode ser acessada quando se atribui a cada espécie um valor consensual distinto de modo a satisfazer o princípio matemático da replicação (JOST, 2006, 2007), que promove a duplicação da métrica de diversidade caso o número de espécies de uma comunidade também dobre, mantendo assim a equitabilidade entre as espécies.

Além da diversidade taxonômica de espécies, existem ainda a diversidade filogenética e a funcional, mas requerem informações e procedimentos analíticos distintos para mensuração. Para o enfoque filogenético, a diversidade de uma comunidade é maior conforme ela apresente espécies com poucas relações de parentesco. Já na diversidade funcional considera-se os fenótipos (características funcionais) que determinam os processos nas comunidades (CIANCIARUSO; SILVA; BATALHA, 2009).

2.3 Mamíferos de médio e grande porte da Caatinga

No Brasil são conhecidas mais de 700 espécies de mamíferos, com percentual de endemismo em torno de 30% (PAGLIA et al., 2012). A mastofauna da Caatinga é atualmente representada por 183 espécies, das quais 45 correspondem a mamíferos de médio e grande porte (CARMIGNOTTO; ASTÚA, 2018) e 10 são endêmicas: seis roedores, um primata e três morcegos (GUTIÉRREZ; MARINHO-FILHO, 2017). As ordens mais representativas são Chiroptera e Rodentia, porém Artiodactyla, Carnivora e Cingulata abrigam grande número de espécies inclusas na mastofauna brasileira, provavelmente devido a ampla distribuição geográfica destas espécies (CARMIGNOTTO; ASTÚA, 2018). Nos últimos anos foram registradas duas novas espécies no domínio da Caatinga: *Speothos venaticus*, identificado em um enclave florestal no Ceará (FERNANDES-FERREIRA et al., 2011) e *Lycalopex vetulus* (MARINHO-FILHO; RODRIGUES; JUAREZ, 2002). Por outro lado, algumas espécies que outrora apresentavam ampla distribuição, agora estão praticamente extintas, como *Tayassu pecari*, *Panthera onca* e *Tapirus terrestris* (CARMIGNOTTO; ASTÚA, 2018).

Sabe-se que os mamíferos da Caatinga apresentam adaptações comportamentais para lidar com os períodos intensos de alta temperatura e escassez de água, muito embora não seja compreendido exatamente como eles respondem às flutuações. Mudanças comportamentais normalmente envolvem o deslocamento para outros habitats, alteração da dieta ou mesmo da forma de obtenção e processamento do alimento, como é descrito para *Sapajus libidinosus* e seu uso de ferramentas (ABREU et al., 2016; DE MORAES; DA SILVA SOUTO; SCHIEL, 2014).

Contudo, apesar dos avanços, várias localidades na Caatinga ainda são deficientes quanto às informações sobre riqueza, distribuição, ecologia e comportamento de mamíferos (ALBUQUERQUE et al., 2012). No Parque Nacional do Catimbau, por exemplo, foram registradas nove espécies de pequenos mamíferos, incluídas nas ordens Didelphimorphia e Rodentia (GEISE et al., 2010), todavia o conhecimento sobre a mastofouna de médio e grande porte na localidade ainda permanece uma incógnita. Este desconhecimento provavelmente é resultado das baixas densidades, hábitos noturnos e comportamento esquivo de algumas espécies (MARINHO et al., 2018), bem como a visão pretérita de que a mastofauna da Caatinga seria depauperada (MARES et al., 1981). Assim, informações acerca de parâmetros ecológicos básicos ainda são escassas sobretudo para mamíferos de médio e grande porte, como também para morcegos (CARMIGNOTTO; ASTÚA, 2018).

Nesse sentido, investigar a mastofauna de áreas com dados incipientes torna-se prioridade no cenário atual da Caatinga, que figura como um dos ecossistemas mais ameaçados do Brasil (CARMIGNOTTO; ASTÚA, 2018). Partindo da premissa que mamíferos de médio e grande porte exercem papeis fundamentais nos ecossistemas, tais como predação e dispersão de sementes (CUARON, 2000), pode-se inferir que são bons modelos para a compreensão da dinâmica da paisagem em um contexto de modificação da paisagem (DURÁN et al., 2014). Além disso, embora a compreensão sobre a Caatinga tenha aumentado nas últimas décadas, o conhecimento acerca do possível surgimento de ecossistemas novos em resposta às alterações na paisagem ainda é limitado.

2.4 Ameaças a conservação dos mamíferos de médio e grande porte da Caatinga

Os mamíferos executam serviços ecossistêmicos chave, tais como o controle populacional de herbívoros, dispersão de sementes, predação, polinização e manutenção da ciclagem de nutrientes por meio da herbivoria (CHIARELLO, 1999; LACHER et al., 2019; SOBRAL et al., 2017). Entretanto, os humanos têm transformado os ecossistemas de tal modo que muitas destas funções são comprometidas pela remoção de algumas espécies, sobretudo predadores de topo (LACHER et al., 2019). Neste contexto, aproximadamente 25% dos mamíferos conhecidos sofrem algum grau de ameaça e metade das populações naturais estão em declínio (SCHIPPER et al., 2008). Além disso, as taxas de extinção permanecem muito altas, prejudicando o funcionamento dos ecossistemas e os serviços necessários à manutenção da população humana (CEBALLOS; EHRLICH; DIRZO, 2017). No Brasil existem 110 espécies de mamíferos ameaçados de extinção, dos quais praticamente 50% correspondem a animais de médio e grande porte (ICMBIO, 2016).

Médios e grandes mamíferos apresentam considerável sensibilidade às condições da paisagem (BOGONI et al., 2016; KEINATH et al., 2017), podendo ser afetados negativamente por diversos fatores, tais como a perda da cobertura vegetal, redução do tamanho do fragmento e ausência de remanescentes florestais adjacentes (BOGONI et al., 2018). De modo mais específico, a diversidade vegetal exerce também influência na diversidade taxonômica, filogenética e funcional de mamíferos, ocasionando assim homogeneização biótica em efeito cascata (PARK; RAZAFINDRATSIMA, 2019). Embora a perda de habitat se caracterize como um fator imperativo nesse processo de defaunação, a mortalidade direta ocasionada através de atividades de caça e, em menor escala, pela introdução de espécies exóticas, também é uma ameaça constante sobretudo aos mamíferos de maior porte da América do Sul (TILMAN et al., 2017). A pressão de caça é comum mesmo no interior de áreas protegidas (CASTILHO et al., 2019; LESSA et al., 2016), reduzindo assim a sua efetividade para fins de conservação ambiental (XAVIER DA SILVA et al., 2018). Sob um efeito sinérgico, todos estes fatores direcionam os mamíferos à condição de grupo de vertebrados mais ameaçado do Brasil (BERNARD et al., 2019).

Na Caatinga o histórico de alterações perdura desde o século XVII com o desmatamento para implantação das fazendas de gado (DIAS; MASSARA; BOCCHIGLIERI, 2019; SILVA; BARBOSA, 2017). Os longos períodos de seca, característicos deste domínio, reduzem a produtividade agrícola, somando consequências para o empobrecimento da população rural (SAMPAIO; BATISTA, 2004), que desenvolveu uma estreita e intensa relação de uso com os recursos naturais disponíveis na região (ALVES et al., 2009). Entre as maiores ameaças a sua biodiversidade estão o corte e a queima da vegetação nativa, o desmatamento para pastagens e a caça predatória. A pecuária itinerante de bovinos, caprinos e ovinos tem sido a principal atividade econômica da região, uma vez que o clima semiárido restringe as tradicionais práticas de agricultura (ALVES; ARAÚJO; NASCIMENTO, 2008). Neste contexto surgem vários impactos às comunidades de mamíferos nativos, sobretudo a competição por espaço e água com estes grandes herbívoros domésticos (ACEBES et al., 2016; ATTUM; EL NOBY; HASSAN, 2009). Por conseguinte, o domínio da Caatinga inclui 17 mamíferos ameaçados de extinção, dos quais 15 correspondem a espécies de médio e grande porte. Este número representa mais de 30% de toda a mastofauna de médio e grande porte da Caatinga (CARMIGNOTTO; ASTÚA, 2018; ICMBIO, 2016).

As mudanças ambientais, sobretudo aquelas que envolvem alterações na paisagem, afetam a mastofauna de modos diferentes. Pequenos, médios e grandes mamíferos exibem, por exemplo, respostas distintas à fragmentação de habitats (KEINATH et al., 2017). A espécies de maior porte tendem a ser mais sensíveis às alterações, pois apresentam maiores áreas de uso, requerem mais recursos e energia para completar seus longos ciclos de vida, possuem baixa densidade populacional e ainda são exploradas através das atividades de caça (CARDILLO et al., 2005; MORRIS et al., 2008). As condições da paisagem são, portanto, determinantes para a persistência destas espécies e responsáveis pelas mudanças na estrutura das comunidades de médios e grandes mamíferos. Existem evidências de que a substituição de espécies em uma comunidade é dirigida pela supressão das espécies de grande porte (BOGONI et al., 2018) como resultado do declínio populacional. Em florestas secas, como a Caatinga, a quantidade de hábitat é fundamental para a manutenção da mastofauna de maior porte e estima-se que o tempo de resposta do grupo às alterações na paisagem seja relativamente curto (< 15 anos) quando comparado aos pequenos mamíferos (ROCHA et al., 2018). Devido a isto podem ser úteis como espécies guarda-chuva em estratégias de conservação ao resguardar outras espécies pouco sensíveis (ROCHA et al., 2018), se caracterizando assim como um modelo adequado para a compreensão da relação entre as características da paisagem e a estrutura das comunidades.

CAPÍTULO I

LANDSCAPE-SCALE PATTERNS AND DRIVERS OF NOVEL MAMMAL COMMUNITIES IN A HUMAN-MODIFIED PROTECTED AREA

Submetido à Landscape Ecology

Landscape-scale patterns and drivers of novel mammal communities in a human-modified protected area

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Abstract

Context Deforestation and livestock raising are disrupting natural ecosystems, but the landscape-scale patterns and drivers of biotic communities in human-modified protected areas are poorly known.

Objectives We assessed how landscape-scale forest cover and isolation from the largest and best-preserved area of the Catimbau National Park (Brazil) affect α- and β-diversity of medium- and large-sized terrestrial mammals. We hypothesized that forest loss and isolation lead to impoverished mammal communities, with limited α-diversity of native species but with higher α-diversity and abundance of free-living exotics, causing a process of biotic homogenization (β-diversity loss) at the regional scale.

Methods Using camera traps, we obtained 823 records of 15 species (8 natives and 7 exotics) in 18 1-km radius landscapes.

Results As expected, forest loss decreased α-diversity of native species and increased the diversity and relative abundance of exotics. However, site isolation from the preserved area showed a weak effect on α-diversity, suggesting that this area does not work regionally as a source of natives neither as an ecological trap for exotics. Supporting the biotic homogenization hypothesis, β-diversity of natives decreased and β-diversity of exotics increased in more deforested landscapes. Yet, species composition was weakly related to forest cover and isolation.

Conclusions Therefore, our findings demonstrate that deforestation jeopardizes native species and favors exotics locally and regionally. Because these novel mammal communities are dominated by herbivores and there is a lack of large carnivores, negative cascading effects on herbivory, predation, and ecosystem functioning are expected, potentially limiting the conservation value of the protected area.

Keywords: Biotic homogenization · Caatinga · Habitat amount · Isolation · Land-use change · Tropical dry forest

Introduction

The increase of human populations has intensified the use of natural ecosystems for human food and energy production (Wassenaar et al. 2007; Ferreira et al. 2012). More than half of Earth's surface has been modified by humans, converting biomes into anthromes (*sensu* Ellis et al. 2010). This poses serious risks to the long-term in situ conservation of native species, especially of those more sensitive to habitat destruction and degradation (Phalan et al. 2011). Yet, exotic species and a few disturbance-loving natives may benefit from the new conditions, changing diversity patterns, community structure and eventually resulting in so-called novel ecosystems (Galetti et al. 2009; Hobbs et al. 2013; Morse et al. 2014; Bogoni et al. 2016). Medium and large terrestrial mammals have considerable sensitivity to these conditions (Bogoni et al. 2016; Keinath et al. 2017), but some exotic species may become human commensals such as free-living domesticated animals (Silva-Junior 2013; Rocha et al. 2018). Therefore, mammals represent a suitable model to understand how deforestation and species exchange may affect biodiversity patterns in human-modified landscapes.

In many deforested regions of Latin America and other tropical countries, including natural protected areas, farmers raise their livestock extensively with no confined techniques (FAO 1996; Monteiro et al. 2017; Zampaligré and Schlecht 2018). Goats, sheep, and cows freely graze on the non-native pastures that replaced the natural ecosystems, but also on the native vegetation that persists in the remaining habitat patches (Schulz et al. 2016). These remnants are also home of native mammals that struggle to maintain their populations under the new suboptimal and threatening conditions, which include dealing with carnivorous exotics such as dogs and cats (Mella-Méndez et al. 2019). Some forest-dependent natives use the landscape matrix to supplement their habitat (Ferreira et al. 2018; Spiesman et al. 2018; Galán-Acedo et al. 2019a), while others benefit from forest conversion to livestock farming and expand their habitats into the agroecosystems that have a structurally complex matrix (Brady et al. 2011; Galán-Acedo et al. 2019a). Although exotic species can be eventually stolen or completely removed from the system due to socioeconomic reasons, farmers take care of their health to avoid mortality and population decline. Conversely, disturbance-sensitive natives are often hunted, captured to supply the illegal market, infected by novel pathogens, run over, or just starve until disappear locally and regionally (Patz et al. 2004; Alves et al. 2016; da Silva Policarpo et al. 2018). These contrasting trends operate simultaneously and are changing mammal communities around the world. Describing these novel communities and their determining factors is urgent, especially in natural protected areas, whose communities are known to be increasingly eroded by changes in the environmental conditions of the surrounding landscapes (Laurance et al. 2012).

Among other important environmental conditions, the presence and proximity of relatively large and well-preserved continuous forests can be particularly critical for the persistence of mammals and other highly vagile organisms in human-modified landscapes (Grass et al. 2019). On the one hand, such large continuous forests can serve as a refuge for forest-dependent natives by providing suitable sites for feeding and reproduction (Ehlers Smith et al. 2018; Watson et al. 2018). Because mammals are highly vagile organisms (Tucker et al. 2018), the largest tracts of well-preserved forests can also act as a source of new individuals to more hostile areas, rescuing populations from extinction in such areas (Dunning et al. 1992; Eriksson et al. 2014; Gilroy et al.

2014). On the other hand, it can function as an ecological trap to exotics by homing predators they have not evolved with, or providing unpalatable, low-quality food resources (Hale and Swearer 2016). If this is true, it is reasonable to expect increased diversity of natives and reduced diversity of exotics in areas located closer to the largest tracts of well-preserved forests. Also, communities of native species should be more dissimilar to each other while communities of exotics should be more similar close to the large tract, as native immigrants are less likely to arrive at distant landscapes and exotics avoid getting close to predators.

Another major driver of biotic communities in human-modified landscapes is landscape-scale forest cover (Fahrig 2013; Morante-Filho et al. 2016; Galán-Acedo et al. 2019b). Forest loss not only limits habitat amount for forest-dwelling species and has negative effects on local (α) diversity of native species, but it can also lead to a process of biotic homogenization (loss of β-diversity) across different spatial scales (Karp et al. 2012; Solar et al. 2015; Gámez-Virués et al. 2015). Such process is caused by the replacement of many disturbance-sensitive species (i.e., ‘loser species’, *sensu* Tabarelli et al. 2012) by a few exotics or disturbance-adapted native species (i.e., ‘winner species’, *sensu* Tabarelli et al. 2012). In this sense, highly deforested landscapes are expected to show a lower α-diversity of natives and higher diversity of exotics. Unless there is no confounding effect of the large best-preserved area, landscapes with similar levels of deforestation should be more similar to each other than landscapes with contrasting forest cover. This should be valid for both groups, natives and exotics, owing to their high capability to disperse across landscapes (Lindstedt et al. 1986; Ofstad et al. 2016).

Here we partitioned the regional (γ) diversity of medium- and large-sized terrestrial mammals from the Catimbau National Park, Northeast Brazil, into independent local (α) and β components. In particular, we assessed whether and how landscape-scale forest cover and isolation from the largest and best-preserved area of the National Park affect α- and β-diversity. We assessed three hypotheses regarding the effect of landscape forest cover and landscape location on mammals in the region. First, we hypothesized that forest loss reduces the α-diversity of native species due to habitat loss and degradation, extirpating most forest-dependent species (losers) and allowing only a few generalist (winner) species to persist in more deforested landscapes. In contrast, forest loss is expected to increase α-diversity of exotics because productive areas in more deforested landscapes provide more resources (e.g. food and shelter) for exotics. Second, pairwise β-diversity of natives should decrease and β-diversity of exotics should increase in more deforested landscapes, although the high vagility of both natives and exotics could result in low regional β-diversity. Finally, the largest tract of relatively well-preserved forest in the Catimbau National Park is expected to act regionally as a source of natives, increasing the α-diversity of this group in sites located nearby. Conversely, it could act as an ecological trap for exotics by homing apex predators such as carnivorous birds and reptiles, decreasing the α-diversity of the group in surrounding landscapes.

Methods

Study region

The study was conducted in the Catimbau National Park, a protect area located in the Pernambuco State, Northeast Brazil (8°29'S, 37°20'W; Fig. 1). The Park was created in December 2002 and covers 62,294 ha. The natural Caatinga vegetation includes distinct tropical dry forest phytophysiognomies, from shrubby vegetation to forests (da Silva et al. 2018). Climate is tropical semiarid, with mean annual temperature of 23ºC and mean precipitation ranging from 480 to 1100 mm (Arnan et al. 2018). The relief has slight and severe ripples and rocky outcrops, with altitude ranging from 600 to 1000 m a.s.l. (Beltrão et al. 2005). Due to outstanding species richness and endemism, this region is considered of high conservation priority (Silva et al. 2003). The best-preserved area (24,597 ha of continuous forest) is located in the western portion of the Park, and is locally known as *Estrada do Gado* (Cattle Road) (Fig. 1). However, different chronic anthropogenic disturbances (e.g. overgrazing and firewood extraction) has been reported as significant drivers of biological impoverishment of the Caatinga vegetation, even within the Catimbau National Park (Ribeiro et al. 2015; da Silva et al. 2018).

Landscape forest cover and location

To assess how landscape forest cover and its isolation from the largest and best-preserved area (*Estrada do Gado*) affect mammal communities in the region, we used recent (2017) images from Landsat 8 satellite to identify two broad land cover types from a supervised classification: (1) forest, defined as tree vegetation cover (following Chazdon et al. 2016); and (2) abandoned field, farming or other areas used for non-confined, traditional livestock farming. After classifying both land use types in the entire Park, we used a stratified random design to establish 18 1-km radius landscapes (i.e. 314 ha each) along two independent gradients: a gradient of forest cover, varying from 20% to 100% of forest cover; and a gradient of distance to the centroid of the *Estrada do Gado*, varying from 4.5 to 22.7 km (Fig. 1). This allowed us to avoid spatial overlap among landscapes and increased the independence in data collection (Eigenbrod et al. 2011). Distances between landscape centroids varied from 2 km to 18.5 km (mean: 8.5 km). We selected this landscape size based on Jackson and Fahrig (2012) who predict that landscape radius should be from 0.3 to 0.5 times the maximum dispersal distance of the species. We are aware that many large mammals may travel more than 1 km a day (Tucker et al. 2018), but the largest and more vagile ones, such as jaguars and tapirs, have been regionally extirpated. In any case, the fact that we found significant responses to forest cover measured at this scale suggests that we are measuring this predictor at its scale of effect (Jackson and Fahrig 2015). Although we could find stronger responses at another scale, this does not limit our conclusions but suggests that our assessment is conservative, as the actual effect of forest cover could be stronger than the one reported here (Jackson and Fahrig 2015). We conducted the supervised classification in QGIS software 2.18.10, and the extraction of spatial variables in ARCGIS 10.3.

Mammals sampling

To quantify the diversity of native and exotic mammals, we installed a camera trap (Bushnell Natureview®) at the centroid of each landscape (Fig. 1). We established the camera traps in sites where we detected signs of mammal activity, such as footprints, feces and shelters. We sampled the 18 landscapes simultaneously and continuously over four months between October 2017 and February 2018, which encompasses the dry season in most parts of the Park. We fixed the camera traps on trees at approximately 20 cm from the ground and monitored them at regular intervals of about 20 days to download the data and replace memory cards and batteries, when necessary. We set the camera traps to capture videos with 30 seconds and 1 minute interval for 24 hours/day, totaling a maximum effort of 2,340 cameras/day. However, due to occasional difficulties in accessing some cameras traps, there was variation in sampling effort between the sampling points (1,282 ± 706 cameras/day, mean ± standard deviation), but this variation did not affect the sampling coverage (see below).

To obtain independent records, we used a temporal criterion to exclude continuous records of the same species during one hour interval after its first record. Usually a mass parameter (>1 kg) is considered to define medium- and large-sized mammals (Chiarello 1999). However, we included all terrestrial and scansorial species that could be identified through camera trap, excluding bats, small rodents and marsupials, since they required specific sampling methods (Hoffmann et al. 2010). All native and exotic mammals recorded during the five months of monitoring were identified and collapsed by sampling unit to characterize the 18 local communities.

Species diversity calculation

We first estimated the completeness of our inventories with the estimator of sample coverage ($\hat{C}_n$) proposed by Chao and Jost (2012), using the iNEXT package for R (Hsieh et al. 2016):

$$\hat{C}_n = 1 - \frac{f_1}{n}\left[\frac{(n-1)f_1}{(n-1)f_1 + 2f_2}\right]$$

where f_1 represents the number of species with one record (singletons), f_2 is the number of species with two records (doubletons), and n is the total number of records in each community. Sample coverage was relatively high in all landscapes, averaging 0.94 (range = 0.80 - 1.00), which ensures reliability to our sampling effort and indicates that our results are not biased by differences in sampling completeness among landscapes (Chao and Jost 2012).

To assess differences in species diversity among landscapes, we used Hill numbers, which express the effective number of species in a given community and satisfy the mathematical replication principle (Jost 2006, 2007). For S species, gamma (γ) diversity was calculated as follows:

$$ {}^{q}D_{\gamma} = \left(\sum_{i=1}^{S} p_i^q \right)^{1/(1-q)} $$

where S is the number of mammal species in the region, p_i is the relative abundance of the ith species and q is a parameter (q order) that determines the sensitivity of the index to species' relative abundance. When q = 0 (${}^{0}D$), the index is not sensitive to species abundances, so it represents the total number of species (species richness). When q = 1 (${}^{1}D$) each species is weighted according to its abundance and expresses the number of 'common' species in the community. When q = 2 (${}^{2}D$) abundances are squared, giving more weight to dominant species, thus representing the number of 'dominant' species in the community (Jost 2007). Mean α-diversity was calculated as:

$$ {}^{q}D_{\alpha} = \left(\frac{1}{N} \sum_{i=1}^{S} p_{i1}^q + \frac{1}{N} \sum_{i=1}^{S} p_{i2}^q + \ldots \right)^{1/(1-q)} $$

where p_i denotes the relative abundance of the ith species in each of the N local communities (Jost 2007). Then, to estimate regional β-diversity we adopted a multiplicative diversity partitioning approach (Jost 2007): ${}^{q}D_{\beta} = {}^{q}D_{\gamma}/{}^{q}D_{\alpha}$. This metric expresses the 'effective number of completely distinct communities', ranging from 1, when all communities are identical to N, when all N communities are completely different (Jost 2007). In our case, we have 18 landscapes, so ${}^{q}D_{\beta}$ can vary between 1 and 18. All analyses were performed using the entropart package (Marcon and Hérault 2015) for R, version 3.5.1 (R Core Team, 2018).

To assess if landscape deforestation leads to the loss of β-diversity (biotic homogenization) of native species, and an increase in β-diversity (differentiation) of exotic species, we calculated the traditional β-Sorensen (β_{SOR}) between pairs of landscapes using the *betapart* package for R (Baselga and Orme 2012). Following

Pardini et al. (2010), we distributed the study landscapes in three categories of deforestation level (6 landscapes per deforestation class): (1) low deforestation (≤ 20% of forest loss), (2) intermediate deforestation (21% to 60%), and (3) high deforestation (>60%). This metric of pairwise β-diversity varies from 1 (total similarity) to 2 (total dissimilarity).

Statistical analyses

We used generalized linear models with Gaussian error distribution to assess the response of α-diversity metrics (^0D, ^1D, ^2D) of natives and exotics to forest cover and distance to the best-preserved area. We included forest cover, distance to the best-preserved area, species origin (native or exotic) and its interactions with forest cover and distance to the best-preserved area as model predictors in the model. A similar model was built to evaluate the effect of deforestation level (three categories), species origin and their interaction on β_{SOR} values. We checked model residuals for homoscedasticity to evaluate the adequacy of the chosen error distribution following Crawley (2013), using the '*glm*' function in R, and corrected for overdispersion when necessary.

Species composition and its relationship with forest cover and distance to the best-preserved area were examined by an exploratory analysis of direct ordering. To verify if nearest areas or with similar forest cover presented similar composition, we performed Mantel tests in Primer 6. We first constructed a similarity matrix of Bray-Curtis similarity with species abundance data. Prior to analyses, we transformed abundances to square root to reduce the contribution of dominant species and standardized the values by total abundance of the community. Then, we constructed a geographic distance matrix based on the pairwise distance between landscape centroids, and an environmental distance matrix based on the pairwise difference in forest cover between landscapes.

Additionally, to evaluate changes in mammal community structure within each deforestation category, we assessed the dominance of native and exotic species by plotting species rank abundance curves for each category and visually comparing their slopes. The greater the slope with respect to the x-axis, the greater the dominance within the community (Magurran and McGill 2011). This method is widely used to compare differences in community structure (McGill et al. 2007).

Results

Community overview

We obtained 823 independent records of 15 species, 230 records (28%) corresponded to 8 native species and 593 records (72%) to 7 exotic species (Table 1). Native species belonged to six orders: Cingulata, Cetartiodactyla, Carnivora, Didelmorphia, Lagomorpha and Rodentia, being Carnivora the most representative in terms of species richness (Table 1). *Galea spixii* presented the greatest abundance among natives, followed by *Cerdocyon thous*, *Didelphis marsupialis, Sylvilagus brasiliensis*, *Leopardus emiliae*, *Euphractus sexcintus*, *Mazama gouazoubira* and *Conepatus amazonicus*. The exotic species belonged to three orders: Cetartiodactyla, Perissodactyla and Carnivora. The Cetartiodactyla was the most representative order in terms of species richness and abundance, mainly the bovids *Capra hircus*, *Ovis aries* and *Bos taurus* (Table 1).

The abundance of most native species was weakly related to forest cover and landscape location (green bars in Fig. 2). Yet, some exceptions arose: *Mazama gouazoubira* was only present in more forested landscapes, whereas *Sylvilagus* *brasiliensis* was more abundant in more deforested ones (Fig. 2). In contrast to natives, most exotic species were clearly related to forest cover, with relative abundance being higher in more deforested landscapes (Fig. 2). Only *Capra hircus* and *Canis lupus familiaris* were weakly related to forest cover. Regarding the impact of landscape location on exotic species, some species concentrated their abundances near the best-preserved area (*Capra hircus* and *Canis lupus familiaris*), but others were more abundant in more isolated landscapes (*Equus asinus*, *E. caballus*, and *Ovis aries*) (Fig. 2).

Landscapes with different deforestation level were dominated by the same native and exotic species (Fig. 3). Almost 70% of native species dominance was attributed to *Cavia aparea, Cerdocyon thous* and *Didelphis sp*., while *Capra aegagrus hircus* clearly dominated the moderately to high deforested landscapes (>95%, Fig. 3). These rank-abundance patterns decreased the evenness of native mammal communities in more deforested landscapes, whereas exotic communities followed the opposite pattern (Fig. 3).

Alpha diversity patterns

Local α-diversity varied from 1 to 6 species, and was significantly related to forest cover, with native and exotic species showing contrasting responses (see significant interacting effects between forest cover and species origin; Table 2). For natives, all three α-diversity metrics (${}^{0}D_{\alpha}$, ${}^{1}D_{\alpha}$ and ${}^{2}D_{\alpha}$) increased with increasing forest cover, whereas the opposite occurred with exotic species (Fig. 4). Yet, α-diversity of native and exotic species was not related to the distance to the best-preserved area (Table 2).

Beta diversity patterns

The Mantel tests indicated that the geographic distance (Rho = 0.016, *P* = 0.55) and the difference in forest cover (Rho = 0.086, *P* = 0.12) between landscapes were not related to species composition. Regional β-diversity of natives was very low, reaching only three completely different communities out of 18 possible (Fig. 5). Regional β-diversity of exotics was even smaller, especially when considering common and dominant species. When assessing pairwise β-diversity between study landscapes, native species showed a decreasing β-diversity in more deforested landscapes, whereas exotics showed the opposite pattern (Fig. 6).

Discussion

This study assesses the response of α- and β-diversity of medium and large terrestrial mammals to changes in landscape forest cover and isolation in the Catimbau National Park, one of the largest human-modified tropical dry forest reserve from Northeast Brazil. To our knowledge, there is only one previous study of mammals in this National Park, but focused on small mammals (Geise et al. 2010). Among other findings, we found a higher abundance of exotic species and a lower α- and β-diversity of native species in more deforested landscapes. These findings provide new insights into the main drivers of biodiversity patterns in human-modified protected areas, and improve our understanding on the relative role of habitat spatial structure in preserving species diversity in anthropogenic biomes (Ellis et al. 2010).

The regional richness of medium- and large-sized native mammals (8 species) was below expectations for a large protected area (>60,000 ha) with a wide range of natural habitats, such as the Catimbau National Park. A relatively low regional species richness have also been documented in previous studies of mammals in the Caatinga vegetation (Bezerra et al. 2014; de Matos Dias and Bocchiglieri 2016), but some regions can maintain more than 14 species (Delciellos 2016; Guedes et al. 2017; Marinho et al. 2018). We do not believe that relatively low species richness documented here is related to our sample size because sample coverage was very high in all sites. We rather suggest that it is associated with historical livestock farming and hunting activities in the region (Bezerra et al. 2014), which have been old enough to allow extinction debt payment and result in the currently poor, homogenous communities. This is evident by the lack of large-sized native mammals, such as the puma (*Puma concolor*) and tapir (*Tapirus terrestris*), which are known to be among the first mammals to become extirpated by humans in anthropogenic landscapes (Oliveira et al. 2003; Duarte et al. 2012). Other mammals such as gray brocket (*Mazama gouazoubira*) and Northern tiger cat (*Leopardus emiliae*) showed very small populations (Table 1), probably because of hunting pressure (Alves et al. 2016). The presence of these endangered species in the Pernambuco state is restricted to few very well-preserved and inaccessible landscapes (Feijó and Langguth 2013), and here, we found that they are only distributed in landscapes with higher forest cover, thus suggesting forest loss is a major driver of species extinction. Yet, it is important to note that although relatively low, the species richness documented in the present study represent 18% of the species documented for the Caatinga biome (Carmignotto and Astúa 2017), which is a significant figure if we consider that this National Park occupies less than 0.07% of the Caatinga territory. Therefore, the Catimbau National Park has an important role in the preservation of terrestrial mammals of the Caatinga vegetation.

Although important, the role of this and other natural protected areas in biodiversity conservation is clearly threatened by deforestation. Our findings support the hypothesis that landscape deforestation limits α-diversity of native mammal species, but favors the diversity of exotic species in the Catimbau National Park. This is not surprising, as forest cover is positively related to resource availability for forest-dependent species (Watson et al. 2018). Also, this is consistent with the habitat amount hypothesis, which predicts that species density increases with increasing habitat amount, landscape forest cover in this case (Fahrig 2013). Therefore, preventing forest loss and increasing forest cover through restoration activities is critically needed to preserve terrestrial mammals in this irreplaceable protected area.

The negative impact of forest loss on terrestrial mammals is not only associated with the loss of resources, but with increasing hunting pressures in more deforested landscapes. Indigenous and non-indigenous local people are known to use medium and large mammals for many purposes (Specht et al. 2019). Some use mammals for feeding, zootherapy, ornaments, religious practices and as pets (Alves et al. 2016; da Silva Policarpo et al. 2018). Others are hunted because they are considered enemies that can attack their domestic animals (Albuquerque et al. 2012). This can favor the survival of exotic species, contributing to the establishment of a novel mammal community dominated by exotic species (Gawel et al. 2018).

The proliferation of exotic species supports the hypothesis that there is an ongoing process of biotic homogenization in the region. We found a very low β-diversity of both native and exotic species at the regional scale, and a decreasing β-diversity of natives among more deforested landscapes. This phenomenon of biotic homogenization triggered by deforestation and land-use change has been also described elsewhere (Petrozzi et al. 2015; Newbold et al. 2018). In our study region, the decline of forest-dependent native species, the spread of a few habitat generalist natives and the introduction of many domesticated animals that interact with the remaining natives seem to underlying the homogenization. The presence of dogs and cats, for example, threatens native species with predation and pathogen transmission (Loss and Marra

2017; Best 2018). The presence and dominance of goats, cows, horses, dogs and cats in the novel mammal communities of the Caatinga vegetation are likely to exert pressure on functionally similar natives, sharing diseases, competing for resources, and altering the community dynamics. This process deserves special attention because it may suppress ecosystem functions and services (Clavel et al. 2011) and maintain poverty .

The regional biotic homogenization is also supported by the weak effect of landscape isolation from the largest and best-preserved forest, the *Estrada do gado*. In fact, our findings indicate that the *Estrada do gado* neither act regionally as source of native species nor as ecological trap for exotics. Previous human pressure via hunting, livestock farming and other chronic anthropogenic disturbances should have gradually decreased habitat quality for medium and large native mammals in the area (Arnan et al. 2018; Specht et al. 2019). Nonetheless, we acknowledge that our conclusions are based on the distance between each landscape and the centroid of the *Estrada do gado*, which can be a poor measure of the effect of isolation on populations (Bender et al. 2003; Tischendorf et al. 2003). Distance-based isolation metrics can underestimate the effects of isolation because it does not consider the presence of different landscape elements, such as stepping stones, living fences, and other elements in the matrix that can shape inter-patch movements in human modified landscapes (Bender et al. 2003; Tischendorf et al. 2003). Further studies on movement ecology across the 24,597 ha of the *Estrada do gado* and the surrounding landscapes should clarify its role for the regional conservation of mammal diversity.

Overall, our findings indicate that there is a novel mammal community established in the Catimbau National Park, with exotics contributing with half of the species and at least two thirds of the individuals. Because exotic species are predominantly herbivorous, a remarkable impact on plant biomass could be expected, with cascading effects on ecosystem functioning (e.g. Ribeiro et al. 2015). Our findings demonstrate that preventing forest loss is critical to sustain α- and β-diversity of native mammals. Thus, preventing deforestation within the Park is mandatory for conserving the diversity of forest-dependent native mammals. Because protected areas are fundamental to regional biodiversity conservation (Brockington and Wilkie 2015; Guedes et al. 2017), their management strategies are critical to the long-term persistence of native species. Practitioners should be aware that (1) the current mammal communities are dominated by exotics; (2) a few natives benefit from landscape modification; (3) the protection of native vegetation is critically needed, particularly in more forested landscapes that have potential to home more native species; and (4) efforts of reintroduction of natives should be prioritized in the large best-preserved area. The pattern observed in the Catimbau National Park is likely to hold for other seasonally dry tropical forests around the world where hunting, deforestation and poverty coexist.

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Table 1. Exotic and native species of medium and large mammals recorded in the Catimbau National Park, Northeast Brazil. Relative abundance refers to the proportion of independent records per species.

Taxa	**Common name**	**Order**	**Family**	**Origin**	**Relative abundance**
Capra hircus	Goat	Cetartiodactyla	Bovidae	Exotic	0.505
Ovis aries	Sheep	Cetartiodactyla	Bovidae	Exotic	0.084
Bos taurus	Cattle	Cetartiodactyla	Bovidae	Exotic	0.073
Equus asinus	Donkey	Perissodactyla	Equidae	Exotic	0.027
Equus caballus	Horse	Perissodactyla	Equidae	Exotic	0.022
Felis catus	Domestic cat	Carnivora	Felidae	Exotic	0.006
Canis lupus familiaris	Domestic dog	Carnivora	Canidae	Exotic	0.004
Galea spixii	Spix's Yellow-toothed Cavy	Rodentia	Caviidae	Native	0.107
Cerdocyon thous	Crab-eating Fox	Carnivora	Canidae	Native	0.063
Didelphis marsupialis	Common Opossum	Didelphimorphia	Didelphidae	Native	0.046
Leopardus emiliae	Northern Tiger Cat	Carnivora	Felidae	Native	0.019
Sylvilagus brasiliensis	Tapeti	Lagomorpha	Leporidae	Native	0.019
Euphractus sexcinctus	Yellow Armadillo	Cingulata	Dasypodidae	Native	0.013
Mazama gouazoubira	Gray Brocket	Cetartiodactyla	Cervidae	Native	0.007
Conepatus amazonicus	Hog-nosed Skunk	Carnivora	Mephitidae	Native	0.004

Table 2. Results of generalized linear models used to assess the effect of landscape-scale forest cover, distance to the best-preserved area, species origin (native or exotic) and the interaction between these variables on three alpha diversity metrics ($^0D_\alpha$ – species richness, $^1D_\alpha$ – exponential Shannon entropy, $^2D_\alpha$ – inverse Simpson concentration) of medium- and large-sized mammal communities in the Catimbau National Park, Brazil. N = 18 landscapes.

Response variables	**Explanatory variables**	χ^2	***P***
$^0D_\alpha$	forest cover	0.05	0.824
	distance to preserved area	0.15	0.698
	species origin	0.87	0.352
	origin*forest cover	11.56	**<0.001**
	origin*distance	0.98	0.321
$^1D_\alpha$	forest cover	1.12	0.290
	distance to preserved area	0.20	0.656
	species origin	3.70	0.054
	origin*forest cover	10.57	**<0.001**
	origin*distance	0.49	0.483
$^2D_\alpha$	forest cover	1.46	0.226
	distance to preserved area	0.61	0.435
	species origin	4.07	**<0.05**
	origin*forest cover	8.83	**<0.01**
	origin*distance	0.32	0.572

Figure legends

Figure 1. Study region in the Catimbau National Park, Northeast Brazil, indicating the 18 local communities sampled in 1-km radius circular landscapes. Black circles at the centroid of landscapes represent the site were each camera trap was located. The triangle indicates the centroid of the largest and best-preserved area (*Estrada do gado*), from which distances to the centroid of each landscape were measured.

Figure 2. Relative abundance of native and exotic mammal species in forest sites surrounded by increasing forest cover (i.e. percentage of forest within a 1-km radius) and with increasing isolation distance (km) to the best-preserved area of the Catimbau National Park, Brazil. Native species (green): Maz, *Mazama gouazoubira*; Eup, *Euphractus sexcintus*; Did, *Didelphis albiventris*; Con, *Conepatus amazonicus*; Gal, *Galea spixii*; Leo, *Leopardus emiliae*; Cer, *Cerdocyon thous*; Syl, *Sylvilagus brasiliensis*. Exotic species (red): Cap, *Capra aegagrus hircus*; Can, *Canis lupus familiaris*; Fel, *Felis catus*; Bos, *Bos taurus*; Eqa, *Equus asinus*; Eqc, *Equus caballus*; Ovi, *Ovis aries*.

Figure 3. Relative abundance of native and exotic mammal species in landscapes of low (≤20% of forest loss), intermediate (21% to 60% of forest loss) and high deforestation levels (>60% of forest loss) in the Catimbau National Park, Brazil. Native species: Maz, *Mazama gouazoubira*; Eup, *Euphractus sexcintus*; Did, *Didelphis albiventris*; Con, *Conepatus amazonicus*; Gal, *Galea spixii*; Leo, *Leopardus emiliae*; Cer, *Cerdocyon thous*; Syl, *Sylvilagus brasiliensis*. Exotic species: Cap, *Capra aegagrus hircus*; Can, *Canis lupus familiaris*; Fel, *Felis catus*; Bos, *Bos taurus*; Eqa, *Equus asinus*; Eqc, *Equus caballus*; Ovi, *Ovis aries*.

Figure 4. Effect of landscape forest cover and distance to the best-preserved area of the Catimbau National Park, Brazil, on the species richness (${}^0D_\alpha$), number of common species (${}^1D_\alpha$) and number of dominant species (${}^2D_\alpha$) of medium and large terrestrial mammals, separately assessing native (dashed line) and exotic (continuous line) species.

Figure 5. Beta diversity of all (${}^0D_\beta$, q=0), common (${}^1D_\beta$, q=1) and dominant (${}^2D_\beta$, q=2) species of medium and large mammals in 18 landscapes from the Catimbau National Park, Brazil.

Figure 6. Beta diversity (β_{SOR}) of native and exotic mammal assemblages between pairs of landscapes with different deforestation levels in the Catimbau National Park, Brazil: low deforestation (≤20% of forest loss), intermediate deforestation (21% to 60% of forest loss) and high deforestation (>60% of forest loss). The box plots show the median, 1st and 3rd quartiles and range.

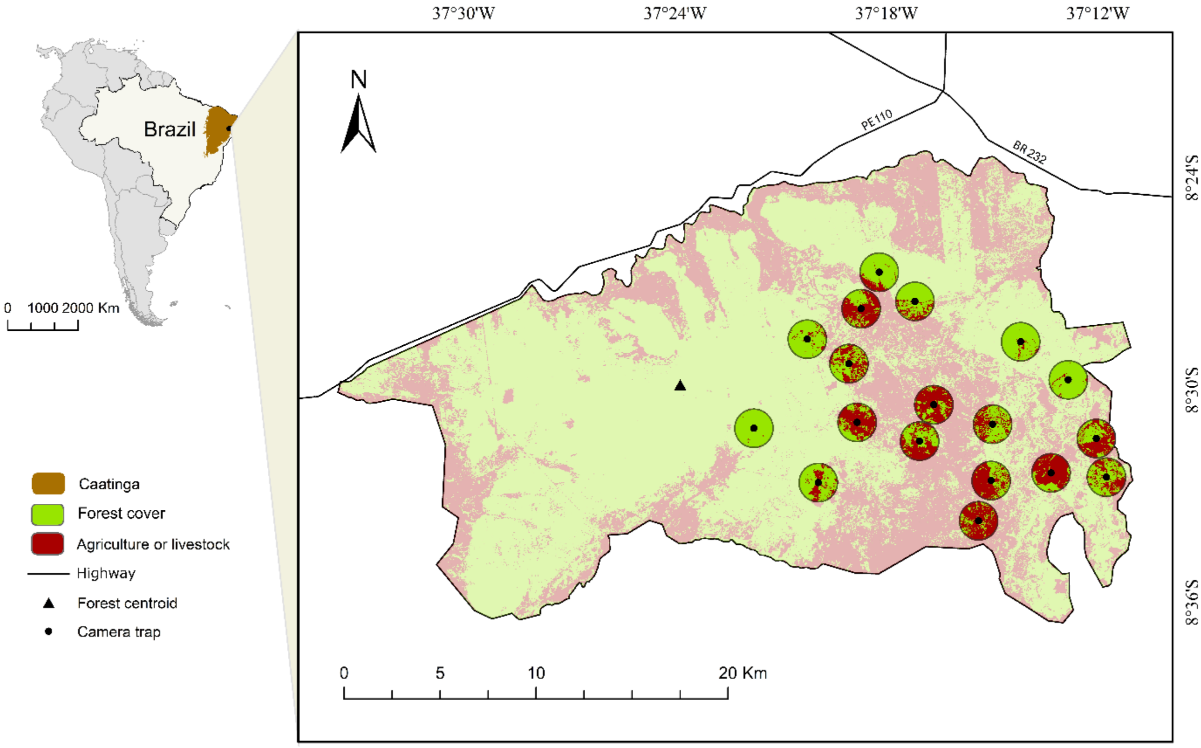
37°30'W
37°24'W
37°18'W
37°12'W
8°24'S
8°30'S
8°36'S
N
PE110
BR 232
Brazil
0 1000 2000 Km
Caatinga
Forest cover
Agriculture or livestock
Highway
Forest centroid
Camera trap
0
5
10
20 Km

Figure 1.

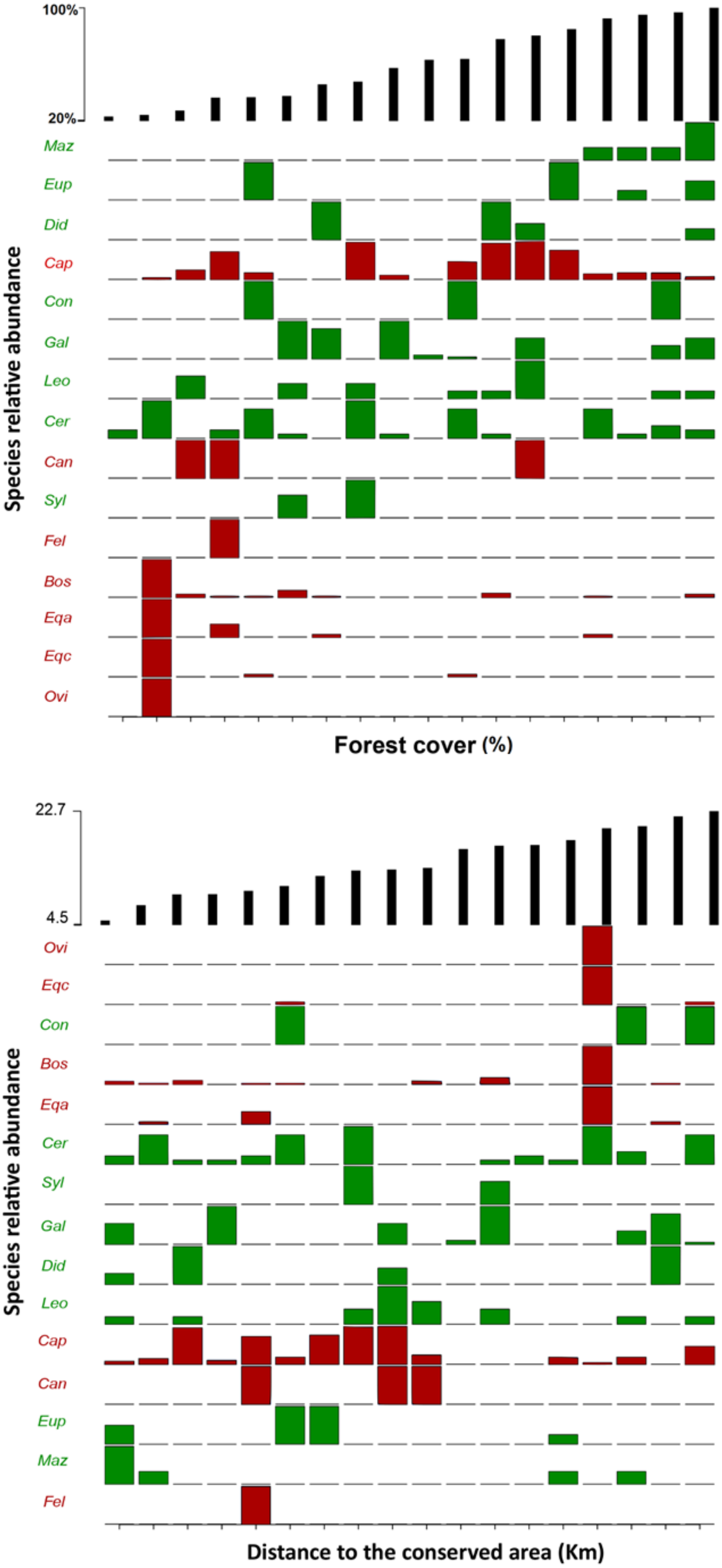
100%
20%
Species relative abundance
Maz
Eup
Did
Cap
Con
Gal
Leo
Cer
Can
Syl
Fel
Bos
Eqa
Eqc
Ovi
Forest cover (%)
22.7
4.5
Species relative abundance
Ovi
Eqc
Con
Bos
Eqa
Cer
Syl
Gal
Did
Leo
Cap
Can
Eup
Maz
Fel
Distance to the conserved area (Km)

Figure 2

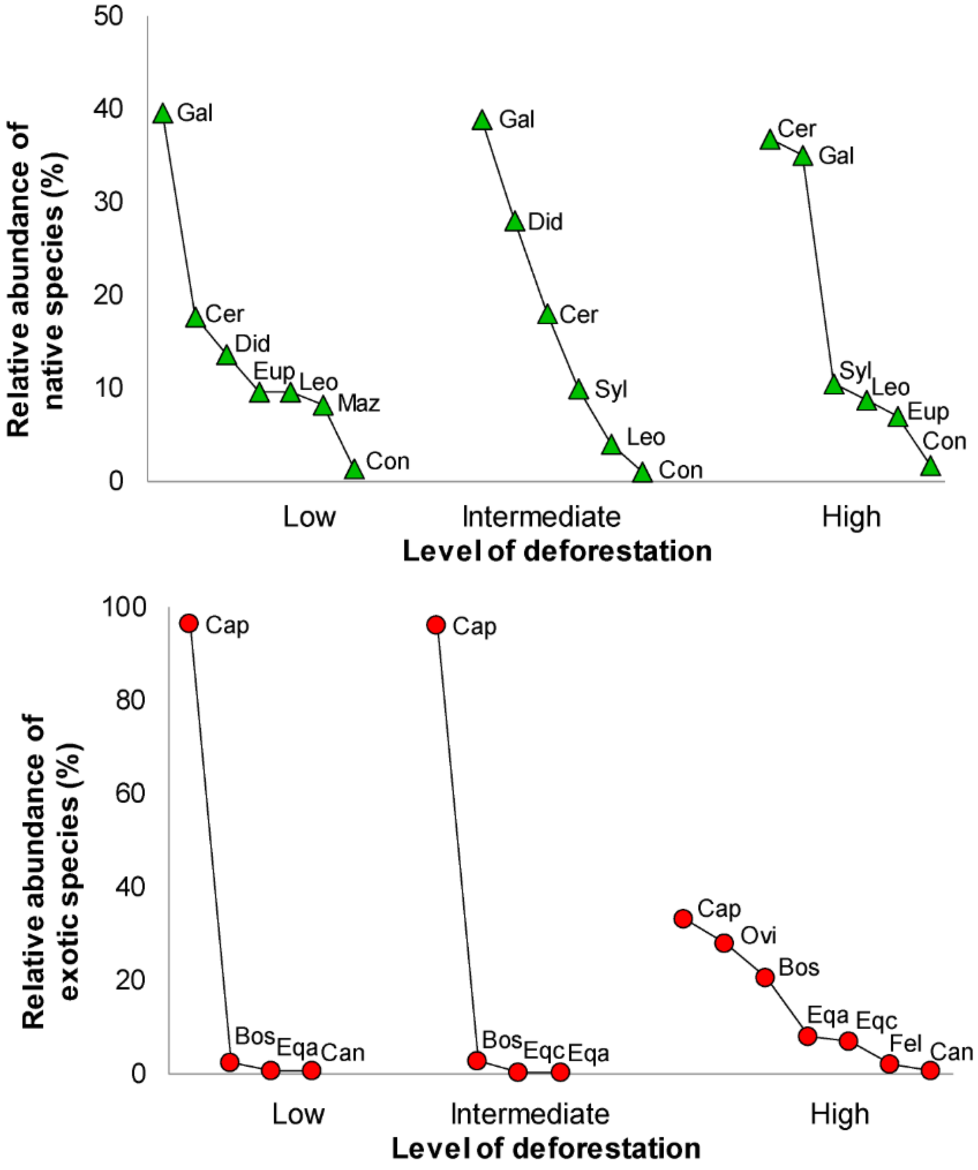
50
40
30
20
10
0
Relative abundance of native species (%)
Gal
Cer
Did
Eup
Leo
Maz
Con
Gal
Did
Cer
Syl
Leo
Con
Cer
Gal
Syl
Leo
Eup
Con
Low
Intermediate
High
Level of deforestation
100
80
60
40
20
0
Relative abundance of exotic species (%)
Cap
Bos
Eqa
Can
Cap
Bos
Eqc
Eqa
Cap
Ovi
Bos
Eqa
Eqc
Fel
Can
Low
Intermediate
High
Level of deforestation

Figure 3

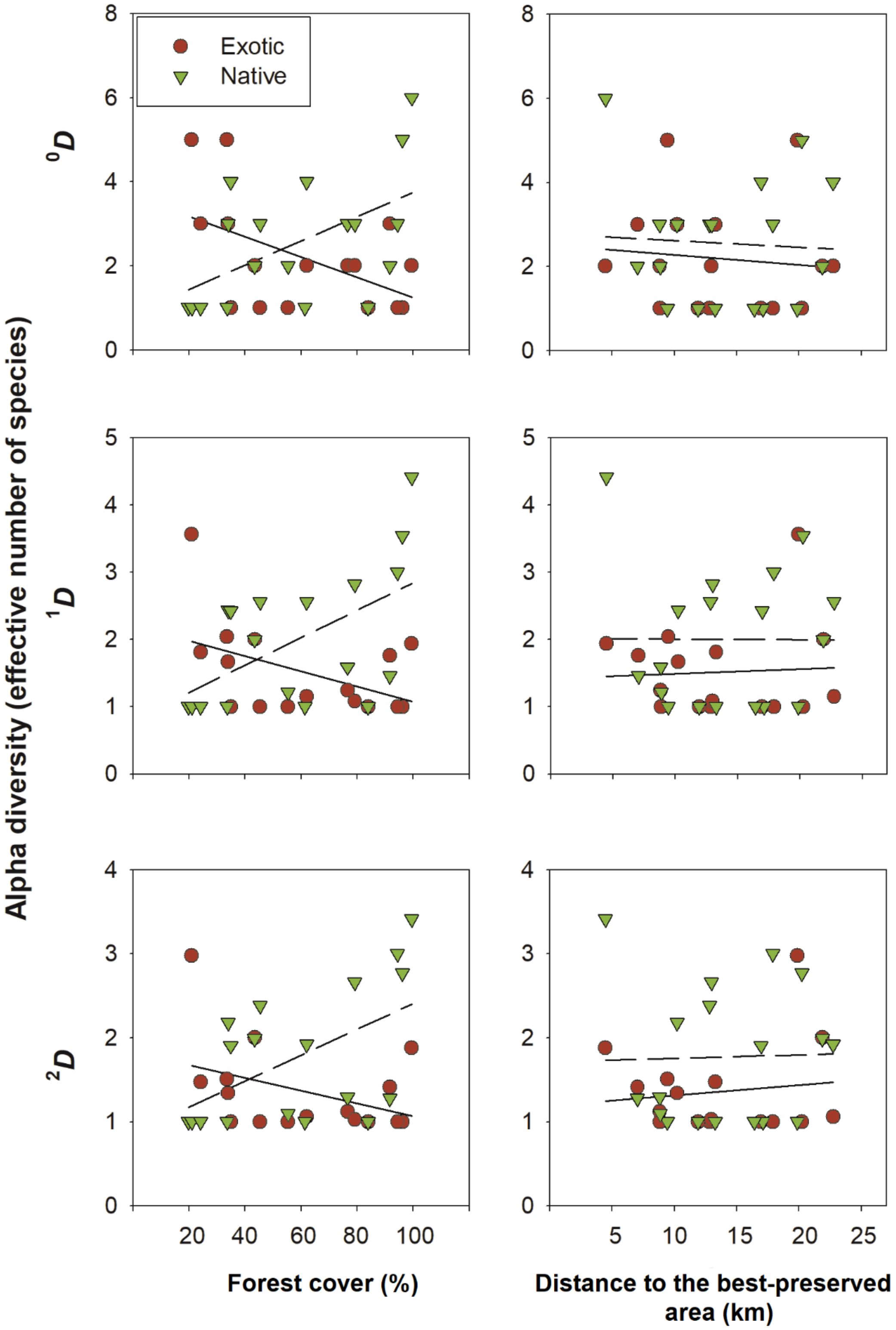
Exotic
Native
^0D
^1D
^2D
Alpha diversity (effective number of species)
8
6
4
2
0
5
3
1
20
40
60
80
100
5
10
15
20
25
Forest cover (%)
Distance to the best-preserved area (km)

Figure 4

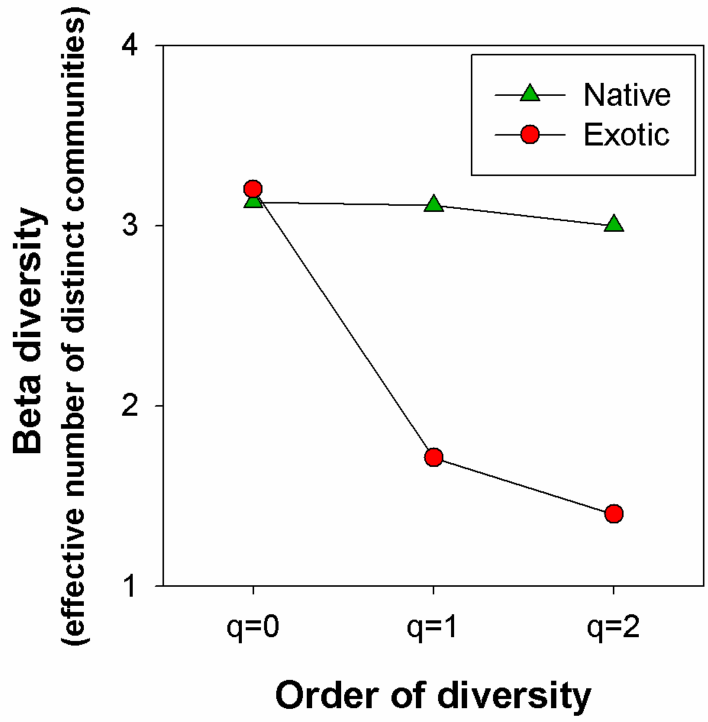
Beta diversity
(effective number of distinct communities)
4
3
2
1
q=0
q=1
q=2
Order of diversity
Native
Exotic

Figure 5

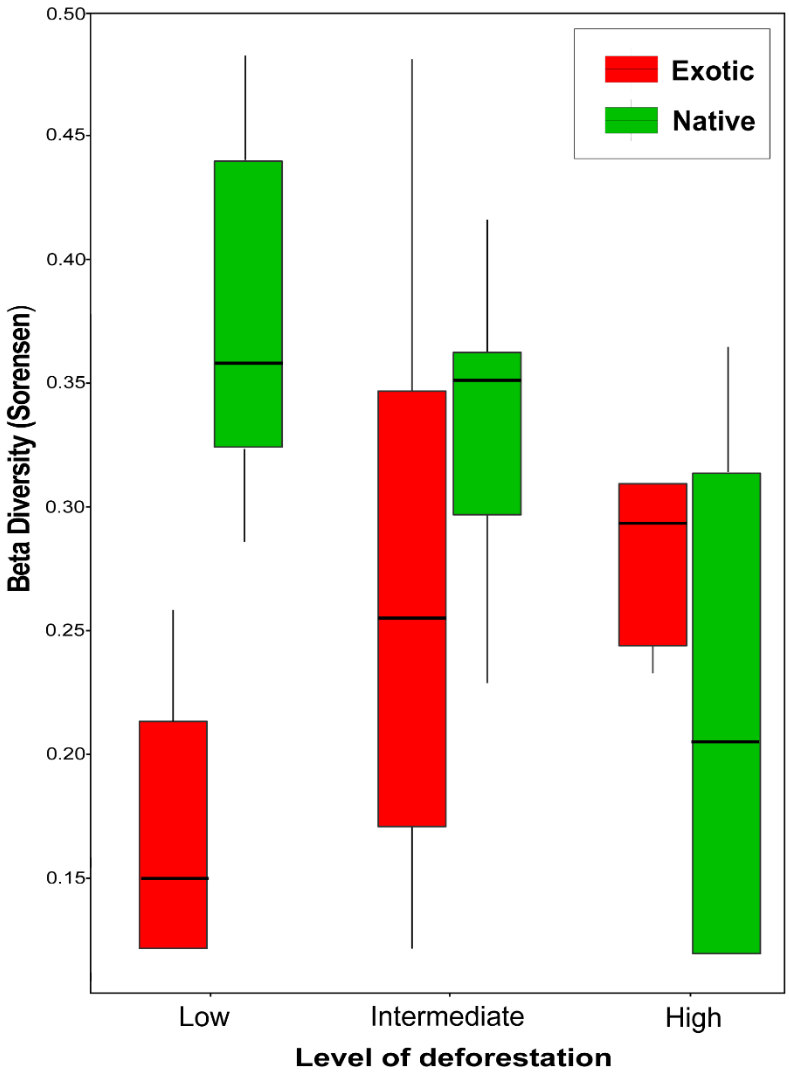
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
Beta Diversity (Sorensen)
Exotic
Native
Low
Intermediate
High
Level of deforestation

Figure 6

CAPÍTULO II

FOXES AND GOATS: IS THAT THE FUTURE OF THE CAATINGA?

A ser submetido ao Journal of Applied Ecology

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Foxes and goats: is that the future of the Caatinga?

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Abstract

1. Novel ecosystems are a product of land-use change, species introduction, and regeneration following human disturbance. Although they have become increasingly common in the Anthropocene covering more than 35% of global terrestrial surface, their compositional and diversity patterns are poorly known. Human-modified landscapes where cattle, goats and sheep have free access to the remaining original vegetation and interact with native mammals are suitable to assess the organization of novel ecosystems and communities.
2. Using camera traps, we sampled native and exotic species of medium and large mammals in four 16-km^2 landscapes of the Brazilian Caatinga. We installed four camera traps in each landscape and monitored the mammals for nine months to describe species composition, dominance, and alpha and beta diversity patterns along the gradient of landscape disturbance. We expected contrasting responses of natives and exotics, with a trend for impoverishment and homogenization of natives in more disturbed landscapes and the opposite for exotics.
3. We obtained 2808 independent records of 17 species, 754 records (27%) corresponded to 10 native species and 2054 (73%) to seven exotic species. Native *Cerdocyon thous* (fox) and introduced *Capra hircus* (goat) accounted for 49% of the records and dominated the most disturbed landscapes. Alpha diversity patterns followed expectations, but nonlinearly. Lower levels of disturbance sustained greater alpha diversity of natives, which reduced logistically in most disturbed landscapes. Alpha diversity of exotics were lower in the most conserved landscape as expected, but also in the most disturbed, suggesting a negative quadratic response.

4. Regional beta diversity was not affected by landscape disturbance, but at smaller spatial scale, pairwise beta diversity within landscapes indicated that intermediate levels of disturbance homogenize the communities of both natives and exotics, while higher levels of disturbance make them more heterogeneous.
5. *Synthesis and applications*. A novel community of medium and large mammals full of exotic individuals has established in the Caatinga. As landscape disturbance increases, the community converges to foxes and goats only. We recommend forest restoration, protection from illegal hunting and market, reintroduction of locally extirpated native species and adoption of sustainable livestock farming to revert the biodiversity erosion.

Introduction

Over the past centuries, human activities have resulted in climate change, deforestation, habitat fragmentation and biological invasion (Blackburn et al., 2011; Johnson et al., 2017; Pecl et al., 2017). Pristine ecosystems have been modified anywhere in the globe, some have been completely replaced by urban settlements and agricultural fields, while others have been degraded and then abandoned (Ellis, Goldewijk, Siebert, Lightman, & Ramankutty, 2010). The conservation value of these ‘abandoned ecosystems’ was underappreciated for many years, but the assumption that pristine is good and anything else is bad has been changed with the non-judgmental term ‘novel ecosystems’ (Marris, 2009). Defined as ‘systems of abiotic, biotic and social components (and their interactions) that, by virtue of human influence, differ from those that prevailed historically, having a tendency to self-organize and manifest novel qualities without intensive human management’ (Hobbs et al., 2013), the novel ecosystems cover more than 35% of the global surface (Ellis et al., 2010; Marris, 2009).

Although they are unlikely to deliver the same ecosystem services that pristine ecosystems do, they may help to protect biodiversity and ecosystem services in regions where wilderness areas have been vanished. However, this possibility still lacks empirical support as compositional and diversity patterns of novel ecosystems remain poorly known, especially in domains with high climatic vulnerability such as the Brazilian Caatinga.

A common aspect in the origin of novel ecosystems is the introduction of exotic species. The exotic species, which may or not become invasive, usually occupies the space left by disturbance-intolerant native species and start to co-occur with disturbance-loving natives. The biological properties of the mix of natives and exotics will depend on which species dominate the local communities, how they use the space and if they are able to connect the local communities and drive the metacommunity to biotic homogenization. In the case of novel ecosystems embedded in livestock landscapes, farming activities protect the populations of exotics (i.e. the livestock itself such as cows, goats, sheep), favoring growth, reproduction and preventing death of individuals. At the same time the exotics compete for limiting resources with the natives, hunting and illegal market may reduce the populations of game natives in the remaining original ecosystems (Albuquerque et al., 2012; Barboza, Lopes, Souto, Fernandes-Ferreira, & Alves, 2016). Moreover, workers often use horses in their daily activities and raise cat and dogs in their homes, which are recognized to negatively interact with native fauna (Mella-Méndez, Flores-Peredo, Bolívar-Cimé, & Vázquez-Domínguez, 2019). In this sense, the study of terrestrial mammals in livestock landscapes with varying levels of disturbance become a great opportunity to assess the extent of novel ecosystems.

Natives and exotics are expected to show contrasting responses to landscape disturbance (Morse et al., 2014), which can be estimated on the basis of spatial characteristics (e.g. forest cover, level of fragmentation) and previous disturbance regime (e.g. time since forest conversion, use of slash-and-burn techniques). The responses of mammal communities to landscape modification can be measured by analyzing the species composition along an anthropogenic disturbance gradient, as well as by partitioning the gamma diversity into alpha (local) and beta components (between sites) along the gradient (Jost, 2007). As disturbance increases, it is expected that alpha and beta diversity of natives decline, resulting in homogeneous communities with small number of species; in contrast, alpha and beta diversity of exotics should increase in more disturbed landscapes, as more areas are devoted to production and different exotic are introduced. Nonetheless, the intensity of hunting, illegal market, commercial aspirations of landowners and other spatially unrelated factors may confound these expectations.

The Caatinga is a seasonally dry tropical forest that originally covers 912,529 km^2 (Silva & Barbosa, 2017), but is currently reduced to half of their territory and widely fragmented (Antongiovanni, Venticinque, & Fonseca, 2018). About 28 million people live within their limits and most depend directly on forest resources for food and energy (Silva & Barbosa, 2017). Recent surveys indicate that there are more than 180 native mammals species in the Caatinga, with 10 endemics and 17 threatened (Carmignotto & Astúa, 2018; Gutiérrez & Marinho-Filho, 2017; ICMBio, 2016). About 17 million exotic mammals, especially goats, sheep and cows, are raised without confinement with free access to forest remnants (EMBRAPA, 2018). Likewise, dogs and cats also have access to the remaining vegetation (Hughes & Macdonald, 2013;

Lessa, Guimarães, de Godoy Bergallo, Cunha, & Vieira, 2016). These biotic and social aspects make the Caatinga a good scenario for the study of novel ecosystems.

In this study, we assessed how compositional and diversity patterns of native and exotic mammal species vary over a gradient of landscape disturbance in the Cariri region, Paraíba state, Northeast Brazil. Using cameras traps, we documented native and exotic species in four landscapes of 16 km^2 with different levels of disturbance and estimated their alpha, beta and gamma diversity. We expected contrasting responses of natives and exotics, with a trend for impoverishment and homogenization of natives in more disturbed landscapes and the opposite for exotics. As a preamble, we compared species composition and dominance along the disturbance gradient.

Methods

Study region

The study was conducted in the Cariri region located in the Paraíba State, Northeast Brazil, the driest region of Brazil with average annual rainfall about 400 mm (from 246 mm to 600 mm). Climate is hot semiarid (BSh) according to the Köppen classification (Alvares, Stape, Sentelhas, De Moraes Gonçalves, & Sparovek, 2013), with a mean annual temperature of 26 ºC. The vegetation types ranges from seasonally dry forests to shrubby vegetation (Barbosa et al., 2007). Although relatively close to the Atlantic rain forest, this region is at the plateau of the Borborema highlands about 580 m a.s.l. and does not receive orographic precipitation.

Besides climatic vulnerable and threatened with desertification, the Cariri has been facing land-use change since the 19th century. In early 20th century, forest was converted to large-scale cotton fields through slash-and-burn practices, but successive pests and diseases broke the cotton industry and many fields were abandoned. Extensive cattle farming was then imported from other Brazilian regions but also failed due to low productivity of the herbaceous stratum, being now restricted to small herds. Goat and sheep farming increased more recently, but confinement is rarely adopted because most producers are too poor to cover the high costs of fences and animal food. However, this land-use history was not homogeneous over the entire Cariri, creating a mosaic of landscapes with contrasting levels of disturbance (Velloso, Sampaio, & Pareyn, 2002). We selected four of them based on logistical access and security for equipment and researchers: Private Natural Heritage Reserve (RPPN) Fazenda Almas (07°28’15”S and 36°52’51”W); Fazenda São Paulo dos Dantas (7°38'57"S and 37°4'51"W); Fazenda Salambaia (7º22’7”S and 36º16’49”W); and São João do Cariri Experimental Station (7º22’28”S and 36º31’40”W). These four landscapes compose a clear anthropogenic disturbance gradient that is summarized in Table 1 and Figure 1.

Mammals sampling

To quantify the biodiversity of native and exotic mammals, we installed four camera traps (Bushnell Natureview®) at each landscape. We established the camera traps in sites where we detected signs of mammal activity, such as footprints, feces and shelters. We sampled the sites simultaneously and continuously over nine months between October 2018 and July 2019, which encompasses the dry and rain seasons in the Cariri (Nascimento & Alves, 2008). We fixed the camera traps on trees at approximately 20 cm from the ground and monitored them at regular intervals of about 20 days to download the data and replace memory cards and batteries, when necessary. We set the camera traps to capture two images with 1 minute interval for 24 hours/day, totaling a maximum effort of 4,416 cameras/day.

To obtain independent records, we used a temporal criterion to exclude continuous records of the same species during one hour interval after its first record. Usually a mass parameter (>1 kg) is considered to define medium- and large-sized mammals (Chiarello, 1999). However, we included all terrestrial and scansorial species that could be identified through camera trap, excluding bats, small rodents and marsupials, since they required specific sampling methods (Hoffmann et al., 2010). All native and exotic mammals recorded during the nine months of monitoring were identified to characterize the 16 local communities (four by landscape). The potential dependence of the camera traps within the same landscape was controlled statically with mixed models (see Statistical Analyses).

Species diversity calculation

We first estimated the completeness of our inventories with the estimator of sample coverage ($\hat{C}_n$) proposed by Chao and Jost (2012), using the iNEXT package for R (Hsieh et al. 2016):

$$\hat{C}_n = 1 - \frac{f_1}{n}\left[\frac{(n-1)f_1}{(n-1)f_1 + 2f_2}\right]$$

where f_1 represents the number of species with one record (singletons), f_2 is the number of species with two records (doubletons), and n is the total number of records in each community. Sample coverage was very high in all landscapes, averaging 0.97 (range = 0.90 - 1.00), which ensures reliability to our sampling effort and indicates that our results are not biased by differences in sampling completeness among landscapes (Chao & Jost, 2012).

To assess differences in species diversity among landscapes, we used Hill numbers, which express the effective number of species in a given community and satisfy the mathematical replication principle (Jost, 2006, 2007). For *S* species, gamma (γ) diversity was calculated as follows:

$$^{q}D_{\gamma} = \left(\sum_{i=1}^{S} p_i^q \right)^{1/(1-q)}$$

where *S* is the number of mammal species in the region, p_i is the relative abundance of the *i* the species and *q* is a parameter (q order) which determines the sensitivity of the index to species' relative abundance. When q = 0 (^{0}D), the index is not sensitive to species abundances, so it represents the total number of species (species richness). When q = 1 (^{1}D) each species is weighted according to its abundance and expresses the number of 'common' species in the community. When q = 2 (^{2}D) abundances are squared, giving more weight to dominant species, thus representing the number of 'dominant' species in the community (Jost, 2007). Mean α-diversity was calculated as:

$$^{q}D_{\alpha} = \left(\frac{1}{N} \sum_{i=1}^{S} p_{i1}^q + \frac{1}{N} \sum_{i=1}^{S} p_{i2}^q + \ \ldots \right)^{1/(1-q)}$$

where p_i denotes the relative abundance of the *i*th species in each of the *N* local communities (Jost, 2007).

Then, to estimate regional β-diversity we adopted a multiplicative diversity partitioning approach (Jost, 2007): $^{q}D_{\beta} = {}^{q}D_{\gamma}/{}^{q}D_{\alpha}$. This metric expresses the 'effective number of completely distinct communities', ranging from 1, when all communities are identical to *N*, when all *N* communities are completely different (Jost, 2007). In our case, we have four local communities in each landscape, so $^{q}D_{\beta}$ can vary between 1 and 4. All analyses were performed using the entropart package (Marcon & Hérault, 2015) for R, version 3.5.1 (R Core Team, 2018).

Additionally, to assess if landscape disturbance leads the loss of β-diversity (as a measure of biotic homogenization sensu de Castro Solar et al. 2015) of native species, and an increase in β-diversity (differentiation) of exotic species, we calculated the β-Sorensen (β_{SOR}) between pairs of landscapes using the *betapart* package for R (Baselga & Orme, 2012). This metric of pairwise β-diversity varies from 0 (total similarity) to 1 (total dissimilarity).

Statistical analyses

To compare the compositional patterns among landscapes, we conducted non-metric multidimensional scalings (NMDS) using the Bray-Curtis index as a measure of taxonomic similarity and the function metaMSD of the R package Vegan (Oksanen et al. 2018). We complemented this analysis by conducting an analysis of similarities (ANOSIM) to test for the existence of statistically differences in species composition among the landscapes. To this end, we used the function anosim of the R package Vegan.

To evaluate changes in mammal community structure within each landscape, we assessed the dominance of native and exotic species by plotting species rank abundance curves for each category of species origin and visually comparing their slopes. The greater the slope with respect to the x-axis, the greater the dominance within the community (Magurran and McGill 2011). This method is widely used to compare differences in community structure (McGill et al. 2007).

We used generalized linear mixed models to assess the response of alpha diversity metrics (${}^0D$, ${}^1D$, ${}^2D$) to landscape disturbance, species origin and their interaction. We assumed Gaussian error distributions for ${}^1D$ and ${}^2D$ and Poisson error distributions for ${}^0D$ (Crawley, 2013). The camera trap ID was set as random effect to account for the potential dependence of cameras within the same landscape. We ran the mixed models with lm4 and nlme functions of R. A generalized linear model was built using the glm function of R to evaluate the effect of landscape disturbance, species origin and their interaction on β_{SOR}. We checked model residuals to satisfy model assumptions following Crawley (2013).

Results

Metacommunity overview

We obtained 2808 independent records of 17 species, 754 records (27%) corresponded to 10 native species and 2054 records (73%) to 7 exotic species (Table 2). Native species belonged to six orders: Cingulata, Primates, Pilosa, Carnivora, Didelmorphia and Rodentia, being Carnivora the most representative in terms of species richness (Table 2). *Cerdocyon thous* (fox) presented the greatest abundance among native species (42% all native records), followed by *Conepatus amazonicus*, *Didelphis albiventris, Callithrix jacchus, Euphractus sexcintus, Galea spixii*, *Procyon cancrivorus*, *Herpailurus yagouaroundi*, *Leopardus emiliae* and *Tamandua tetradactyla*. The exotic species belonged to three orders: Cetartiodactyla, Perissodactyla and Carnivora. The Cetartiodactyla was the most representative order in terms of species richness and abundance, mainly the bovids *Capra hircus*, *Bos taurus* and *Ovis aries* (Table 2). *Capra hircus* (goat) was by far the most abundant exotic (52% of exotic records).

Landscapes with high (SAL) and very high disturbance levels (SJC) were dominated by the same native and exotic species: foxes and goats (Fig. 2). Landscapes with low and very low disturbance levels were more equitable for exotic and native species, though ALM had proportionally more *Bos Taurus* than *Capra hircus*. The rank-abundance curves also revealed that the evenness among natives species decreased as expected from ALM to SJC (green curves in Fig. 2). On the other hand, the evenness among the exotic species did not vary consistently with landscape disturbance (red curves in Fig. 2); the more equitable was the low disturbed FSP.

The ordinations indicated that there was no clear taxonomic segregation among the landscapes, as local communities were similar to others that were subjected to different disturbance level (Fig. 3). In fact, species composition of both natives and exotics varied regardless landscape disturbance. This compositional pattern were also supported by the anosim analyses, which do not indicate significant effect of disturbance on the composition of exotics (R = 0.012; P>0.05) and natives (R = 0.034; P>0.05).

Alpha diversity patterns

The effective number of species varied from 1 to 8 species (${}^{0}D_{\alpha}$), but was not significantly related to landscape disturbance level due to high variation among local communities (Table 3; Fig. 4). The same trend was observed for ${}^{1}D_{\alpha}$ and ${}^{2}D_{\alpha}$ (Table 3; Fig. 4). Except for ${}^{1}D_{\alpha}$, alpha diversity of natives was not different from alpha diversity of exotics, indicating species introductions numerically equaled natural origin in terms of species numbers (Table 3; Fig. 4). In the landscape with high deforestation level (SAL) α-diversity of exotics tended to be greater than that of natives for the three α-diversity metrics.

Although the interaction term of the alpha diversity models was not significant – this term would support the expected contrasting responses of natives and exotics to landscape disturbance (Table 3), the red box plots of Figure 4 suggested a nonlinear response of exotics to disturbance. More specifically, they suggested a negative quadratic function in which the most conserved and the most disturbed landscapes (SJC and ALM, respectively) had low diversity values and the intermediate levels of disturbance (SAL and FSP) had the highest diversity values. Similarly, the green box plots of Figure 4 also suggested non-linear response of natives to disturbance. In this case a logistic function along the disturbance gradient is suggested, characterized by higher values of diversity in more conserved landscapes (ALM and FSP) followed by an abrupt drop in the most disturbed landscapes (SAL and SJC).

Beta diversity patterns

Regional β-diversity of natives and exotics was relatively low in all landscapes, reaching only two completely different communities out of four possible, and did not vary consistently over the disturbance gradient (i.e. curves overlapped; Fig. 5). When assessing the pairwise β-diversity between the local communities of the same landscape (β_{SOR}), native and exotic species did not respond linearly and oppositely to landscape disturbance (Fig. 6; Table S1). Instead, the box plots of Figure 6 suggested a positive quadratic function in which local communities are less similar to each other in the most disturbed and most conserved landscapes (SJC and ALM, respectively) and more similar at intermediate levels of disturbance (SAL and FSP).

Discussion

Our results demonstrate that exotic species numerically dominate the metacommunity of medium and large mammals of the driest region of Brazil, as only one every four mammals sampled in Caatinga remnants is native. Compositional patterns do not arise from differences in landscape disturbance, but the hyperdominance of foxes and goats in the most disturbed landscapes is outstanding. Diversity patterns indicate that the increase in landscape disturbance do not impoverish and homogenize the local communities linearly as expected; the responses are nonlinear instead. Accordingly, regarding alpha diversity, very high levels of disturbance are bad even for exotics and lower levels of disturbance are good for natives. In terms of beta diversity, intermediate levels of disturbance homogenize the communities of both native and exotics, but higher levels of disturbance increase the beta diversity. Overall, our findings reveal that novel mammal communities have established in the Cariri region, but regardless their differences from pristine ecosystems, they are sensitive to landscape disturbance.

A conclusion from our analyses is that landscape disturbance modifies species dominance dramatically. The increase in landscape disturbance reduces the evenness of native species, favoring the dominance of foxes (*Cerdocyon thous*), an extremely generalist canid capable of easily colonize new environments, maintaining viable populations even in urban centers and threaten local populations (Courtenay & Maffei, 2004; Somsen & Trouwborst, 2019). The effect of change in landscape on the evenness of exotic species is less evident and seems to depend on local factors linked to commercial desires of farm owners, which directly influence the size of exotic populations. For example, the low disturbed FSP, the landscape with greatest evenness of exotic species, has a diversified production system based on smaller herds with relatively similar sizes. On the other hand, at the highly disturbed SAL, the goat herd is much larger than cattle herd because the owners are not interested in cattle production. This is reflected in the abundance rank curves – more even in FSP than SAL – and is likely to result in pervasive changes in trophic structure and ecosystem function (Brady, Mcalpine, Possingham, Miller, & Baxter, 2011; Magioli et al., 2019). Goat grazing has been recognized as a risk for ecosystem stability because they can cause biodiversity loss and alter plant community composition (Salgado-Luarte et al., 2019), but their ecological role in the novel mammal communities of the Caatinga remain to be assessed (Melo, 2018).

Landscape disturbance is known to modify diversity patterns and ecosystem functions in many ecosystems around the world (e.g Carrara et al., 2015; Sousa, Longo, & Santos, 2019). Our findings support this global phenomenon but highlight that the response to disturbance is not necessarily linearly. Nonlinear responses have been reported for several native vertebrates groups (Morante-Filho, Faria, Mariano-Neto, & Rhodes, 2015; Pardini, de Bueno, Gardner, Prado, & Metzger, 2010), with deforestation thresholds ranging between 94% and 15% of the landscape. Although we had not employed nonlinear adjustment to our data, the analyses suggest that 70% of deforestation (the level of SAL deforestation) is too much to maintain alpha diversity of natives. Therefore, avoiding deforestation is mandatory to conserve the diversity of native mammals. Nonlinear responses of exotic diversity to landscape disturbance are rarer in the literature, but the negative quadratic function suggested by our box plots indicates that even the exotic species do not benefit from very high levels of disturbance. In this sense, desertification must be avoided for the sake of biodiversity (native or not), and sustainable livestock production should become the rule in the Caatinga to avoid excessive deforestation.

Landscape disturbance plays a role on beta diversity patterns as well (Arroyo-Rodríguez et al., 2013), but our results suggest that they are stronger at smaller spatial scale (i.e. within the landscape). At the regional scale, the differences in landscape disturbance were not able to segregate taxonomic groups or to promote the reduction of the number of completely distinct communities in the most disturbed landscapes. Most of the species actually occured in all landscapes, suggesting that the mammal metacommunity of the Cariri is structured by mass effects. Contrary to the classic niche view, in which species are selected by environmental conditions, mass effects assume that species reproduce in excess under optimal conditions and, through dispersion events, export individuals to less suitable sites (Leibold et al., 2004). This mechanism, known as rescue effect in the metapopulation literature, can be scaled to the metacommunity level (Leibold et al., 2004), generating the regional pattern of biotic homogenization.

Within each landscape, at smaller spatial scale, the beta diversity response to landscape modification is clearer. Our results indicate that the extremes of the landscape disturbance gradient are characterized by greater differentiation between local communities than the intermediate points. This nonlinear response is consistent for both native and exotic species and indicates that the difference between the local communities inside each landscape decreases as landscape disturbance increases, but increases again in most disturbed landscape until reaching levels similar to those of most conserved landscape. The explanation for this positive quadratic response seems to be linked to habitat supplementation at intermediate disturbance levels (Tscharntke et al., 2012). In these cases, species have more elements of landscape matrix to explore (Magioli et al., 2019) and are more likely to connect local communities, reducing the pairwise beta diversity of the landscape. Under very high levels of disturbance, these elements are scarce and species appear to exhibit more fidelity to microsites (e.g. rock locations in SJC), increasing the pairwise beta diversity of the landscape. Whatever the mechanism involved, it is quite evident the novel mammal communities of the Cariri region are sensitive to changes in landscape attributes.

Implications for management and conservation

There are important implications for management and conservation of the Caatinga: (1) It is important to note that even the most degraded landscape (SJC) presented exclusive species (Southern Tamandua), therefore it also contributes to conservation at the regional level. It is essential that SJC, as well as the other three desertification nuclei of the Caatinga, be prioritized in the national forest restoration agenda (BRASIL, 2017). (2) A major conservation effort must be undertaken to increase the regional diversity (gamma) of native species. It is known that the causes of the low regional species richness (gamma) are due to historical climatic factors, such as extremely prolonged droughts during the pleistocene glacier peaks (decades or centuries) and to contemporary factors, such as droughts in the El niño years. In addition, pressure for hunting, illegal trade, indiscriminate use of fire in slash-and-burn agriculture and deforestation must have contributed to the low number of native species in the Cariri region. The reintroduction of regionally extinct carnivores such as the large felines should be implemented. (3) A new model of livestock production needs to be developed for the Cariri and other regions of Caatinga to avoid an even greater mischaracterization of native mastofauna. We recommend that the system used in the FSP be replicated throughout the Caatinga, as it conciliates production with conservation. (4) The introduction of exotic species should be conducted more carefully in the Caatinga, otherwise the current mammal communities will become increasingly dominated by species that did not evolve within the Caatinga. There is an extensive literature on how exotic species may modify ecosystem functions and services (Walther et al., 2009). This knowledge may guide further (if any) exotic introductions. (5) The hunting and illegal trade of mammals must be combated strongly to prevent that conserved landscapes such as ALM face defaunation. (6) Finally, our data indicate that the remaining Caatinga of the Brazil’s driest region is dominated by foxes and goats, a mix of native and exotic species. Further researches should assess the extent to which these species are able to maintain the system's functionality and couple with climate and land-use changes.

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Table 1. Description of the four landscapes used in this study, including their location in the state of Paraíba, Northeast Brazil. Landscapes are sorted by their level of disturbance, from the least to the most disturbed.

Landscape	**Abbreviation used in the figures**	**City**	**Forest cover in 16 km^2 (%)**	**Main human activities**	**Illegal hunting**	**Level of disturbance**	**Source**
Private Natural Heritage Reserve Fazenda Almas	ALM	São José dos Cordeiros and Sumé	95%	Nature conservation, research and education	yes	very low	Barbosa et al., 2007
Fazenda São Paulo dos Dantas	FSP	Prata	70%	Sustainable livestock and plant farming	yes	low	Dantas et al., 2019
Fazenda Salambaia	SAL	Cabaceiras and Boa Vista	30%	Ecotourism, research, education and livestock farming (mainly goats and sheep)	yes	high	Souza, 2019
São João do Cariri Experimental Station	SJC	São João do Cariri	5%	Livestock and plant farming for scientific and educational ends	yes	very high	Barbosa et al., 2007

Table 2. Exotic and native species of medium and large mammals recorded in the Cariri region, Northeast Brazil. Relative abundance refers to the proportion of independent records per species.

Taxa	**Common name**	**Order**	**Family**	**Origin**	**Relative abundance**
Capra hircus	Goat	Cetartiodactyla	Bovidae	Exotic	0.381
Bos taurus	Cattle	Cetartiodactyla	Bovidae	Exotic	0.162
Ovis aries	Sheep	Cetartiodactyla	Bovidae	Exotic	0.108
Equus caballus	Horse	Perissodactyla	Equidae	Exotic	0.049
Equus asinus	Donkey	Perissodactyla	Equidae	Exotic	0.016
Canis lupus familiaris	Domestic dog	Carnivora	Canidae	Exotic	0.010
Felis catus	Domestic cat	Carnivora	Felidae	Exotic	0.005
Cerdocyon thous	Crab-eating Fox	Carnivora	Canidae	Native	0.112
Conepatus amazonicus	Hog-nosed Skunk	Carnivora	Mephitidae	Native	0.042
Didelphis albiventris	Common Opossum	Didelphimorphia	Didelphidae	Native	0.040
Callithrix jacchus	Common Marmoset	Primates	Callitrichidae	Native	0.023
Euphractus sexcinctus	Yellow Armadillo	Cingulata	Dasypodidae	Native	0.017
Galea spixii	Spix's Yellow-toothed Cavy	Rodentia	Caviidae	Native	0.010
Procyon cancrivorus	Crab-eating Raccoon	Carnivora	Procyonidae	Native	0.010
Herpailurus yagouaroundi	Jaguarundi	Carnivora	Felidae	Native	0.008
Leopardus emiliae	Northern Tiger Cat	Carnivora	Felidae	Native	0.005
Tamandua tetradactyla	Southern Tamandua	Pilosa	**Myrmecophagidae**	Native	0.002

Table 3. Results of generalized mixed linear models used to assess the effect of landscape disturbance, species origin (native or exotic) and their interaction on three alpha diversity metrics ($^{0}D_{\alpha}$ – species richness, $^{1}D_{\alpha}$ – exponential Shannon entropy, $^{2}D_{\alpha}$ – inverse Simpson concentration) of medium- and large-sized mammal communities in the Cariri, Paraíba State, Brazil. Camera trap ID was set as random effect (see Methods).

Response variables	**Explanatory variables**	**df**	**F-value**	***P*-value**
$^{0}D_{\alpha}$	Landscape disturbance	3,12	1.59	0.242
	Species origin	1,12	3.46	0.087
	Disturbance × origin	3,12	1.82	0.196
$^{1}D_{\alpha}$	Landscape disturbance	3,12	0.82	0.505
	Species origin	1,12	5.12	0.043
	Disturbance × origin	3,12	2.28	0.131
$^{2}D_{\alpha}$	Landscape disturbance	3,12	0.56	0.646
	Species origin	1,12	4.28	0.061
	Disturbance × origin	3,12	2.14	0.147

Figure legends

Figure 1. Study region in the Cariri region, Paraíba State, Northeast Brazil, indicating the location of the four landscapes of 1,600 ha, their proportion of disturbance (red) and forest cover (green). SJC (São João do Cariri Experimental Station); SAL (Fazenda Salambaia); FSP (Fazenda São Paulo dos Dantas) and ALM (Private Natural Heritage Reserve Fazenda Almas).

Figure 2. Relative abundance of native and exotic mammal species in landscapes with very high (SJC), high (SAL), low (FSP) and very low disturbance levels (ALM) in the Cariri region, Paraíba State, Northeast Brazil. Native species: Cer, *Cerdocyon thous*; Con, *Conepatus amazonicus*; Tam, *Tamandua tetradactyla*; Eup, *Euphractus sexcintus*; Did, *Didelphis albiventris*; Gal, *Galea spixii*; Pro, *Procyon cancrivorus*; Leo, *Leopardus emiliae*; Cal, *Callithrix jacchus*; Her, *Herpailurus yagouaroundi*. Exotic species: Cap, *Capra aegagrus hircus*; Bos, *Bos taurus*; Fel, *Felis catus*; Ovi, *Ovis aries*; Eqc, *Equus caballus*; Eqa, *Equus asinus*; Can, *Canis lupus familiaris*.

Figure 3. Ordination of 16 local communities sampled in four landscapes with contrasting level of disturbance in the Cariri region, Paraíba State, Northeast Brazil. São João do Cariri Experimental Station (rhombus); Fazenda Salambaia (square); Fazenda São Paulo dos Dantas (inverted triangle) and Private Natural Heritage Reserve Fazenda Almas (circle). Refer to Table 1 to details on landscape disturbance.

Figure 4. Effect of landscape disturbance level and species origin on alpha diversity metrics (${}^{0}D_{\alpha}$, ${}^{1}D_{\alpha}$ and ${}^{2}D_{\alpha}$) of medium and large terrestrial mammals, separately

assessing native (green) and exotic (red) species. The median (thin line), 1th and 3th quartiles (boundaries of boxes) and 95% interval confiance (vertical line) are indicated for each landscape. SJC (São João do Cariri Experimental Station); SAL (Fazenda Salambaia); FSP (Fazenda São Paulo dos Dantas) and ALM (Private Natural Heritage Reserve Fazenda Almas). Refer to Table 1 to details on landscape disturbance.

Figure 5. Regional beta diversity of medium and large mammals in four landscapes with contrasting level of disturbance in the Cariri region, Paraíba State, Northeast Brazil. SJC (São João do Cariri Experimental Station); SAL (Fazenda Salambaia); FSP (Fazenda São Paulo dos Dantas) and ALM (Private Natural Heritage Reserve Fazenda Almas). Refer to Table 1 to details on landscape disturbance.

Figure 6. Pairwise beta diversity of native and exotic mammal communities in four landscapes with contrasting level of disturbance in the Cariri region, Paraíba State, Northeast Brazil. SJC (São João do Cariri Experimental Station); SAL (Fazenda Salambaia); FSP (Fazenda São Paulo dos Dantas) and ALM (Private Natural Heritage Reserve Fazenda Almas). Refer to Table 1 to details on landscape disturbance. The median (thin line), 1th and 3th quartiles (boundaries of boxes) and 95% interval confiance (vertical line) are indicated for each of landscapes: SJC, SAL, FSP and ALM.

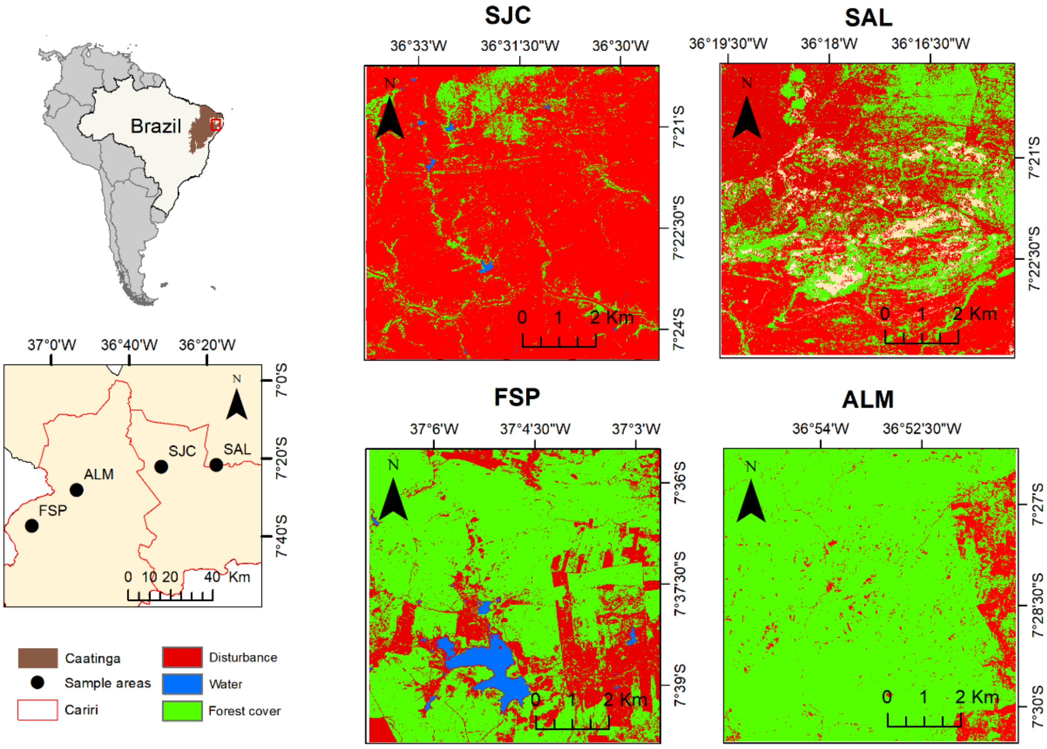
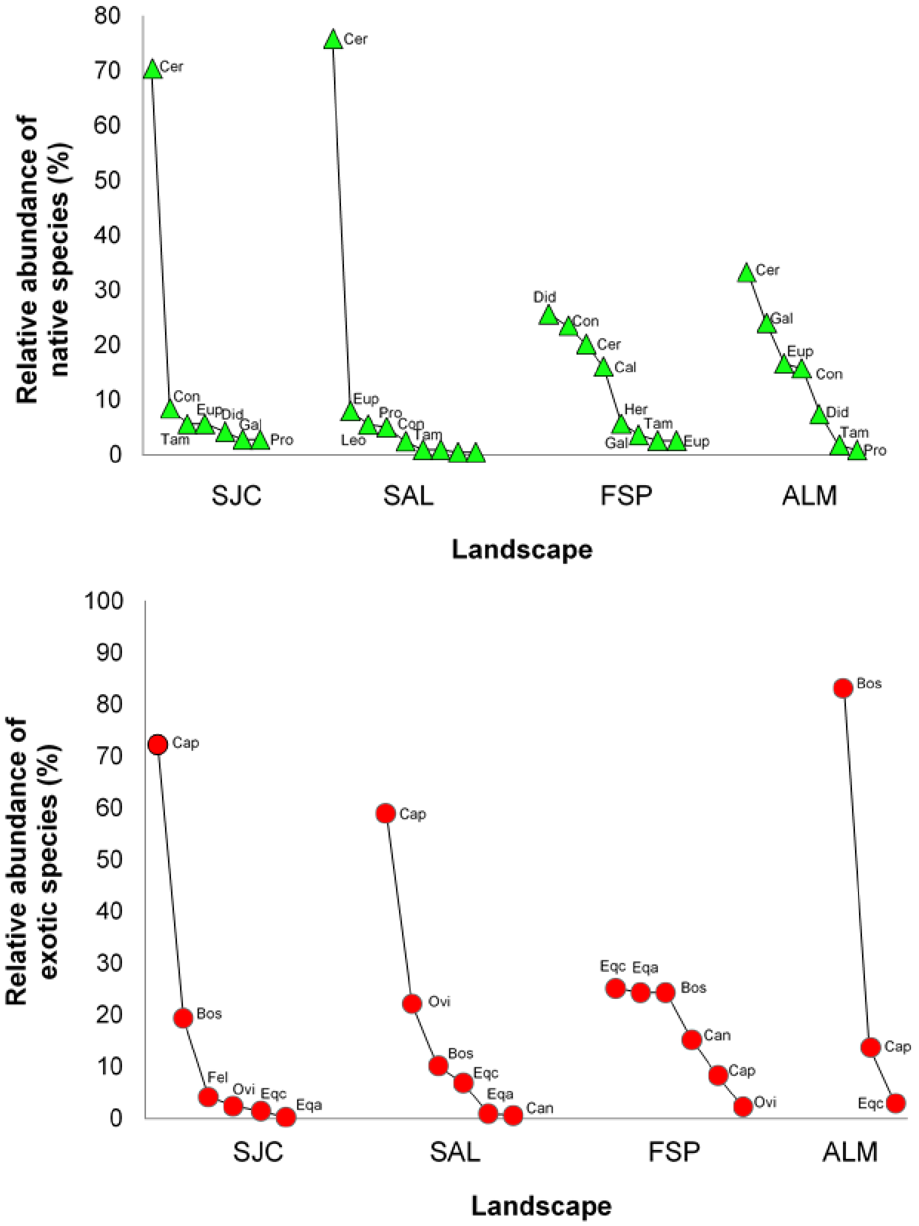

Brazil
37°0'W
36°40'W
36°20'W
7°0'S
7°20'S
7°40'S
SJC
SAL
ALM
FSP
0 10 20 40 Km
N
Caatinga
Sample areas
Cariri
Disturbance
Water
Forest cover
SJC
36°33'W
36°31'30"W
36°30'W
7°21'S
7°22'30"S
7°24'S
0 1 2 Km
SAL
36°19'30"W
36°18'W
36°16'30"W
7°21'S
7°22'30"S
0 1 2 Km
FSP
37°6'W
37°4'30"W
37°3'W
7°36'S
7°37'30"S
7°39'S
0 1 2 Km
ALM
36°54'W
36°52'30"W
7°27'S
7°28'30"S
7°30'S
0 1 2 Km

Figure 1.


Relative abundance of native species (%)
80
70
60
50
40
30
20
10
0
Cer
Con
Eup
Did
Gal
Tam
Pro
Cer
Eup
Pro
Con
Tam
Leo
Did
Con
Cer
Cal
Her
Tam
Gal
Eup
Cer
Gal
Eup
Con
Did
Tam
Pro
SJC
SAL
FSP
ALM
Landscape
Relative abundance of exotic species (%)
100
90
80
70
60
50
40
30
20
10
0
Cap
Bos
Fel
Ovi
Eqc
Eqa
Cap
Ovi
Bos
Eqc
Eqa
Can
Eqc
Eqa
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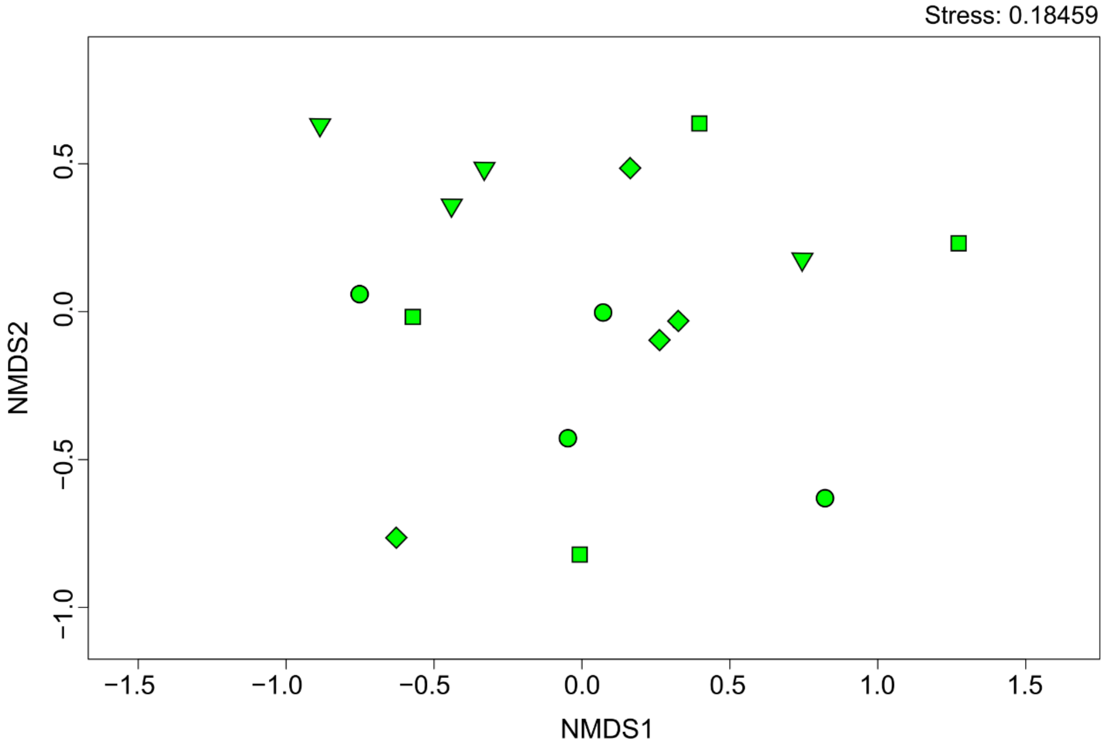
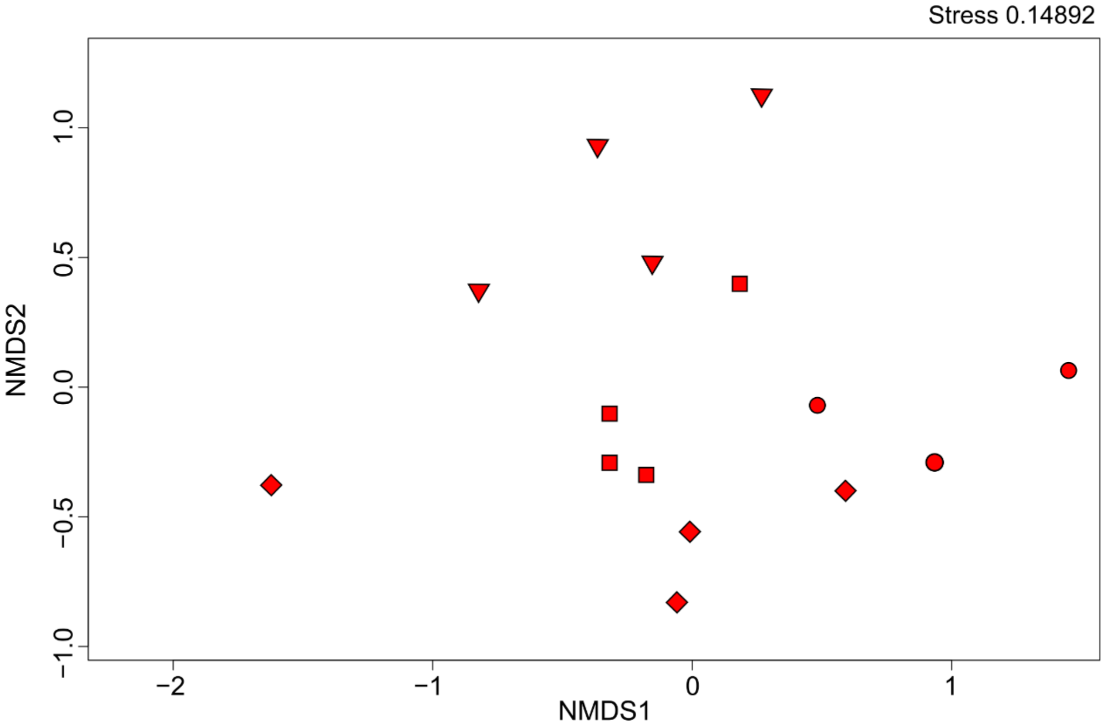
SJC
SAL
FSP
ALM
Landscape

Figure 2


Stress: 0.18459
NMDS2
0.5
0.0
−0.5
−1.0
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
NMDS1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NMDS2
1.0
0.5
0.0
−0.5
−1.0
−2
−1
0
1
NMDS1

Figure 3

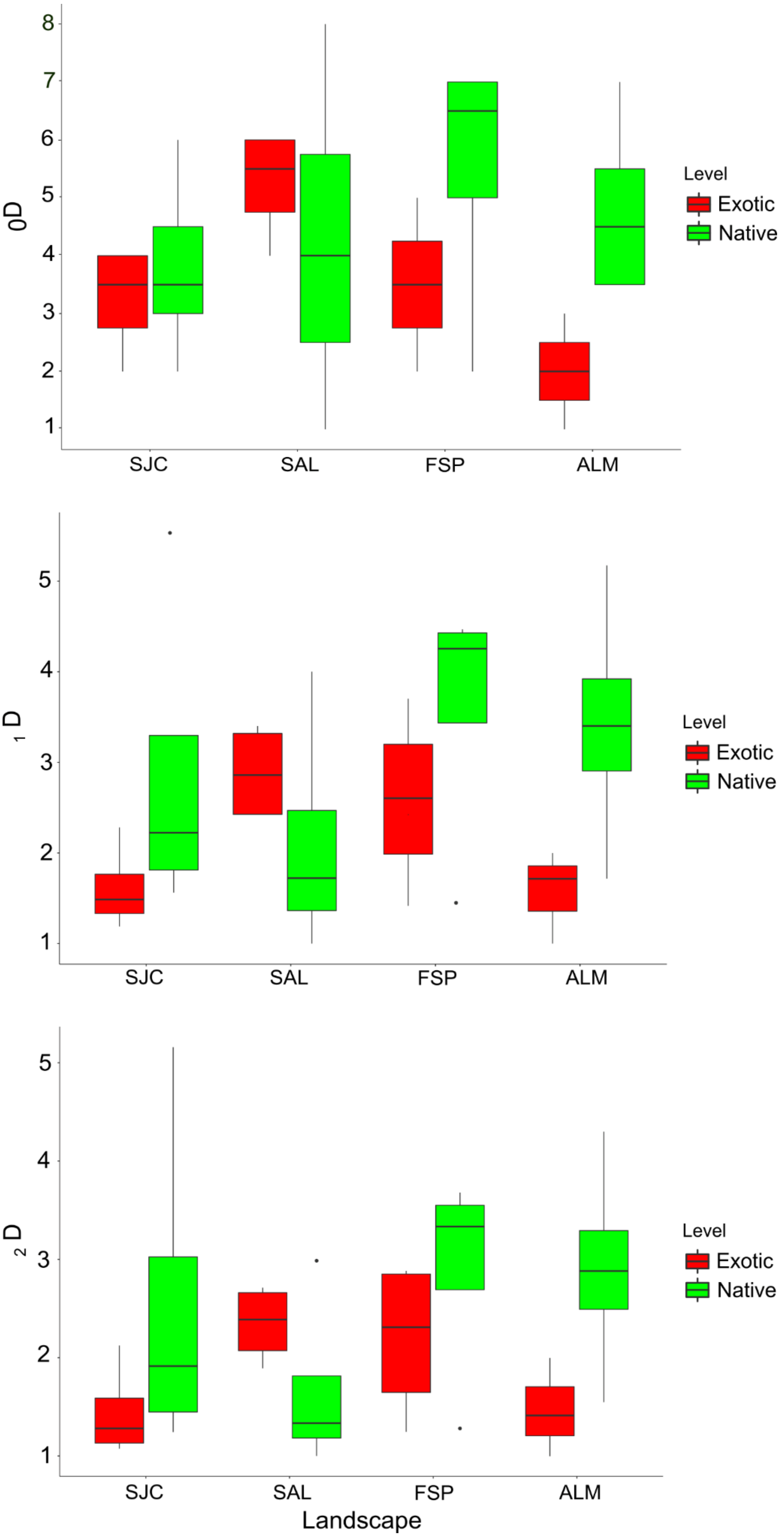
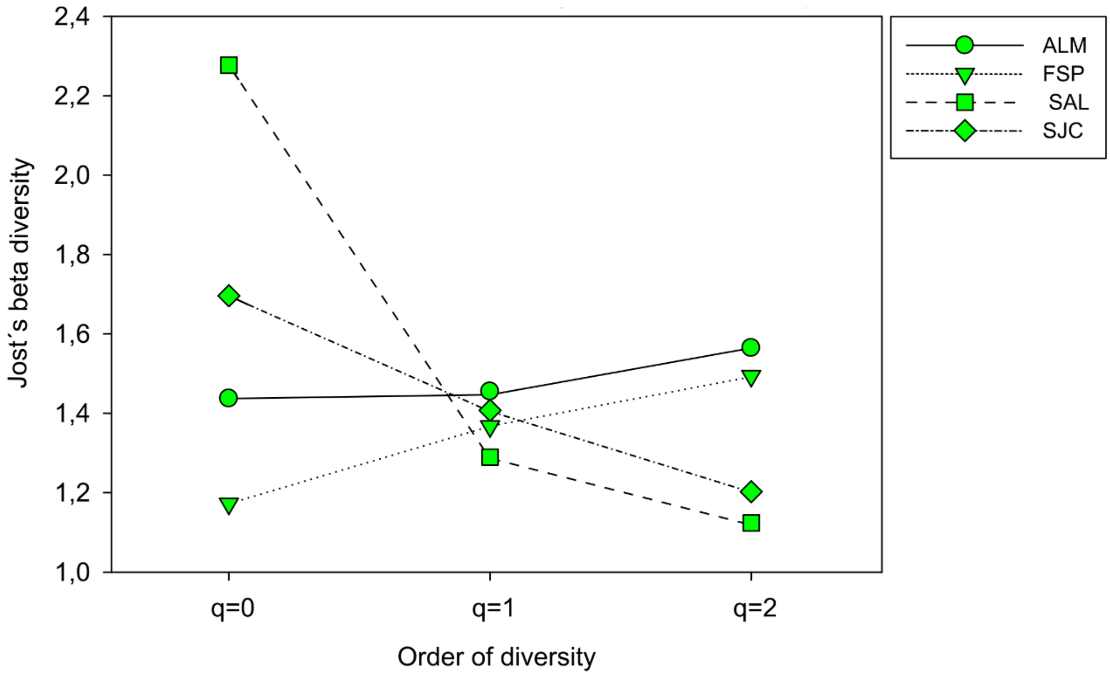

0D
8
7
6
5
4
3
2
1
SJC
SAL
FSP
ALM
Level
Exotic
Native
1 D
5
4
3
2
1
SJC
SAL
FSP
ALM
Level
Exotic
Native
2 D
5
4
3
2
1
SJC
SAL
FSP
ALM
Landscape
Level
Exotic
Native

Figure 4


2,4
2,2
2,0
1,8
1,6
1,4
1,2
1,0
Jost´s beta diversity
q=0
q=1
q=2
Order of diversity
ALM
FSP
SAL
SJC

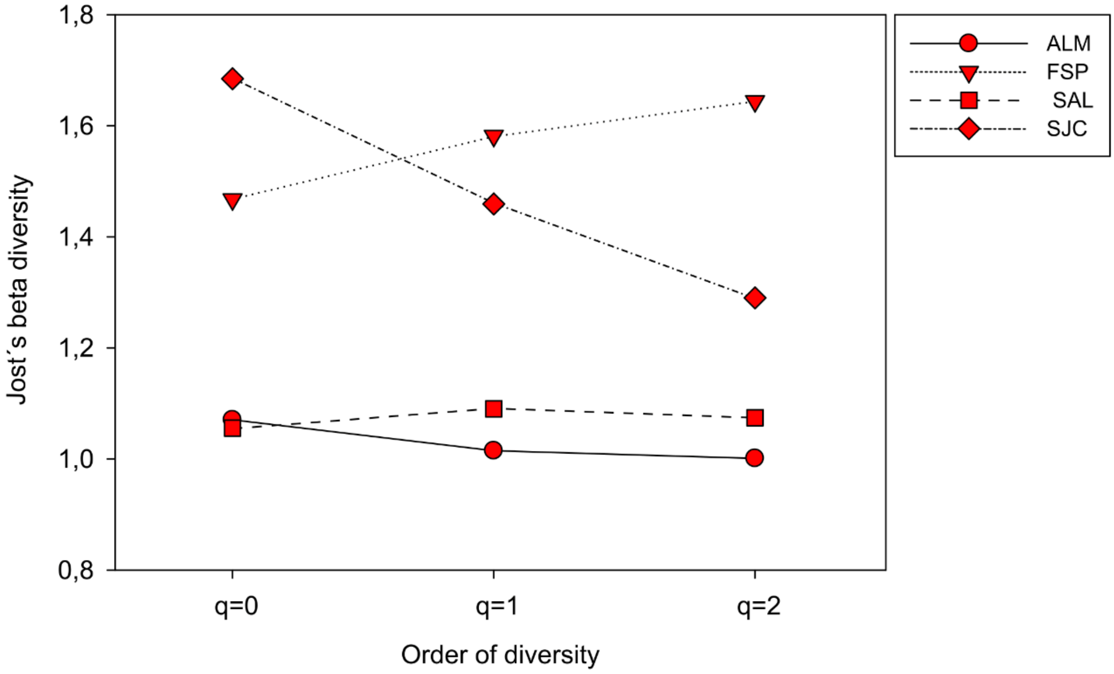

1,8
1,6
1,4
1,2
1,0
0,8
Jost´s beta diversity
q=0
q=1
q=2
Order of diversity
ALM
FSP
SAL
SJC

Figure 5

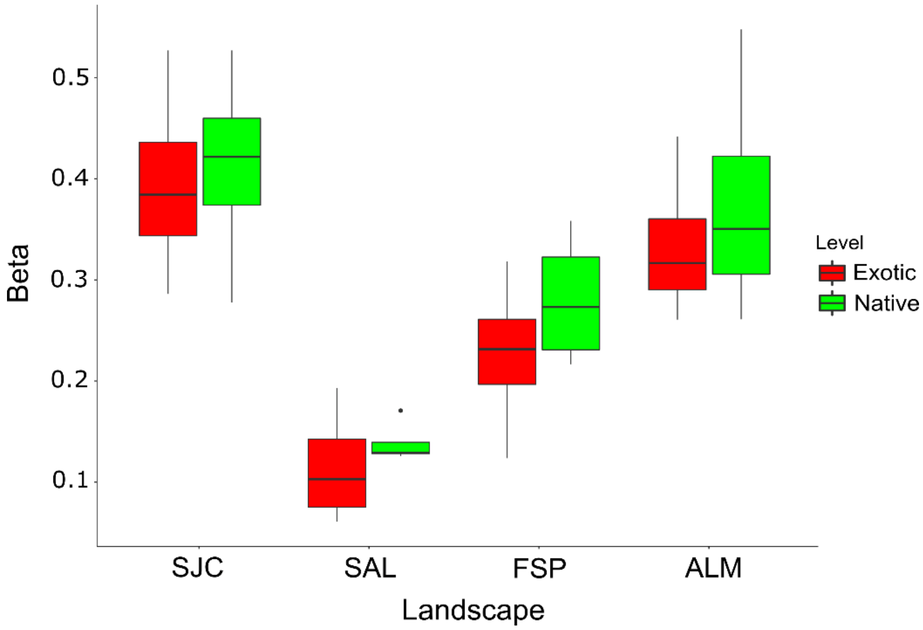

0.5
0.4
0.3
0.2
0.1
Beta
SJC
SAL
FSP
ALM
Landscape
Level
Exotic
Native

Figure 6

3. CONSIDERAÇÕES FINAIS

As comunidades de médios e grandes mamíferos nativos da Caatinga estão sujeitas a um processo de perda de espécies e homogeneização biótica, mediado sobretudo pela redução da cobertura florestal e introdução de espécies exóticas. As espécies nativas que se mantém são aquelas beneficiadas pela modificação na paisagem, em função de seus hábitos generalistas e da ampla capacidade de dispersão. Por outro lado, a persistência das espécies de hábitos mais restritos e dependentes da floresta está ameaçada.

Este é um cenário comum também às áreas protegidas e deve ser mitigado com o controle do desmatamento e estratégias de fiscalização da caça e comércio ilegais. Embora a degradação ambiental extrema seja ruim até para as espécies exóticas, é importante destacar que as paisagens mais degradadas também possuem valor para a conservação, pois podem abrigar espécies nativas exclusivas nos remanescentes de vegetação. Além disso, deve ser conduzido um esforço para aumentar a diversidade regional, principalmente através da reintrodução de espécies e por meio do combate à caça e ao comércio ilegal de mamíferos nativos.

As "novas comunidades" aqui descritas demonstram claramente que estamos diante de uma Caatinga repleta de mamíferos que não evoluíram em seus domínios. Os dados indicam que as paisagens mais degradadas da região mais seca do Brasil – o Cariri paraibano – e de uma das maiores unidades de conservação da Caatinga – o Parque Nacional do Catimbau – são dominadas por cachorros-do-mato e cabras. Pesquisas futuras devem avaliar até que ponto essas espécies são capazes de manter a funcionalidade do sistema.

Ademais, é urgente o estabelecimento de um novo modelo de pecuária sustentável para Caatinga, como o desenvolvido na Fazenda São Paulo dos Dantas no município do Prata, PB, para evitar uma descaracterização ainda maior da mastofauna de médio e grande porte. Este modelo deve ser combinado com ações efetivas de reflorestamento, prioritariamente em paisagens muito desmatadas, para aumentar a disponibilidade de habitat para as espécies nativas e conciliar produção com conservação.

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ANEXOS

Ministério do Meio Ambiente - MMA
Instituto Chico Mendes de Conservação da Biodiversidade - ICMBio
Sistema de Autorização e Informação em Biodiversidade - SISBIO

Autorização para atividades com finalidade científica

Número: 56032-1	Data da Emissão: 25/07/2017 16:28	Data para Revalidação*: 24/08/2018

* De acordo com o art. 28 da IN 03/2014, esta autorização tem prazo de validade equivalente ao previsto no cronograma de atividades do projeto, mas deverá ser revalidada anualmente mediante a apresentação do relatório de atividades a ser enviado por meio do Sisbio no prazo de até 30 dias a contar da data do aniversário de sua emissão.

Dados do titular

Nome: TAINÁ SHERLAKYANN ALVES PESSOA	CPF: 073.880.504-18
Título do Projeto: CONSERVAÇÃO DE MAMÍFEROS DE MÉDIO E GRANDE PORTE EM SISTEMAS AGROPECUÁRIOS DA CAATINGA	
Nome da Instituição : UFPB - UNIVERSIDADE FEDERAL DA PARAÍBA	CNPJ: 24.098.477/0001-10

Cronograma de atividades

#	Descrição da atividade	Início (mês/ano)	Fim (mês/ano)
1	Instalação e manutenção de armadilhas fotográficas	09/2017	09/2018
2	Instalação, manutenção e verificação de plots de pegadas	09/2017	09/2018
3	Execução de entrevistas	09/2017	08/2019
4	Elaboração de relatórios	09/2017	08/2019

Observações e ressalvas

1	As atividades de campo exercidas por pessoa natural ou jurídica estrangeira, em todo o território nacional, que impliquem o deslocamento de recursos humanos e materiais, tendo por objeto coletar dados, materiais, espécimes biológicos e minerais, peças integrantes da cultura nativa e cultura popular, presente e passada, obtidos por meio de recursos e técnicas que se destinem ao estudo, à difusão ou à pesquisa, estão sujeitas a autorização do Ministério de Ciência e Tecnologia.
2	Esta autorização NÃO exime o pesquisador titular e os membros de sua equipe da necessidade de obter as anuências previstas em outros instrumentos legais, bem como do consentimento do responsável pela área, pública ou privada, onde será realizada a atividade, inclusive do órgão gestor de terra indígena (FUNAI), da unidade de conservação estadual, distrital ou municipal, ou do proprietário, arrendatário, posseiro ou morador de área dentro dos limites de unidade de conservação federal cujo processo de regularização fundiária encontra-se em curso.
3	Este documento somente poderá ser utilizado para os fins previstos na Instrução Normativa ICMBio n° 03/2014 ou na Instrução Normativa ICMBio n° 10/2010, no que especifica esta Autorização, não podendo ser utilizado para fins comerciais, industriais ou esportivos. O material biológico coletado deverá ser utilizado para atividades científicas ou didáticas no âmbito do ensino superior.
4	O titular de licença ou autorização e os membros da sua equipe deverão optar por métodos de coleta e instrumentos de captura direcionados, sempre que possível, ao grupo taxonômico de interesse, evitando a morte ou dano significativo a outros grupos; e empregar esforço de coleta ou captura que não comprometa a viabilidade de populações do grupo taxonômico de interesse em condição in situ.
5	O titular de autorização ou de licença permanente, assim como os membros de sua equipe, quando da violação da legislação vigente, ou quando da inadequação, omissão ou falsa descrição de informações relevantes que subsidiaram a expedição do ato, poderá, mediante decisão motivada, ter a autorização ou licença suspensa ou revogada pelo ICMBio, nos termos da legislação brasileira em vigor.
6	Este documento não dispensa o cumprimento da legislação que dispõe sobre acesso a componente do patrimônio genético existente no território nacional, na plataforma continental e na zona econômica exclusiva, ou ao conhecimento tradicional associado ao patrimônio genético, para fins de pesquisa científica, bioprospecção e desenvolvimento tecnológico. Veja maiores informações em www.mma.gov.br/cgen.
7	Em caso de pesquisa em UNIDADE DE CONSERVAÇÃO, o pesquisador titular desta autorização deverá contactar a administração da unidade a fim de CONFIRMAR AS DATAS das expedições, as condições para realização das coletas e de uso da infra-estrutura da unidade.

Outras ressalvas

1	O pesquisador deve agendar as atividades de campo através do e-mail pncatimbau.pe@icmbio.gov.br. Qualquer publicação decorrente deverá ter cópia em arquivo remetida a este mesmo e-mail. Poderá haver solicitação de acesso aos dados brutos, pela equipe do ICMBio, com o compromisso de sigilo, se assim for necessário às questões de manejo da UC.

Locais onde as atividades de campo serão executadas

#	Município	UF	Descrição do local	Tipo
1		PE	PARQUE NACIONAL DO CATIMBAU	UC Federal

Atividades X Táxons

#	Atividade	Táxons

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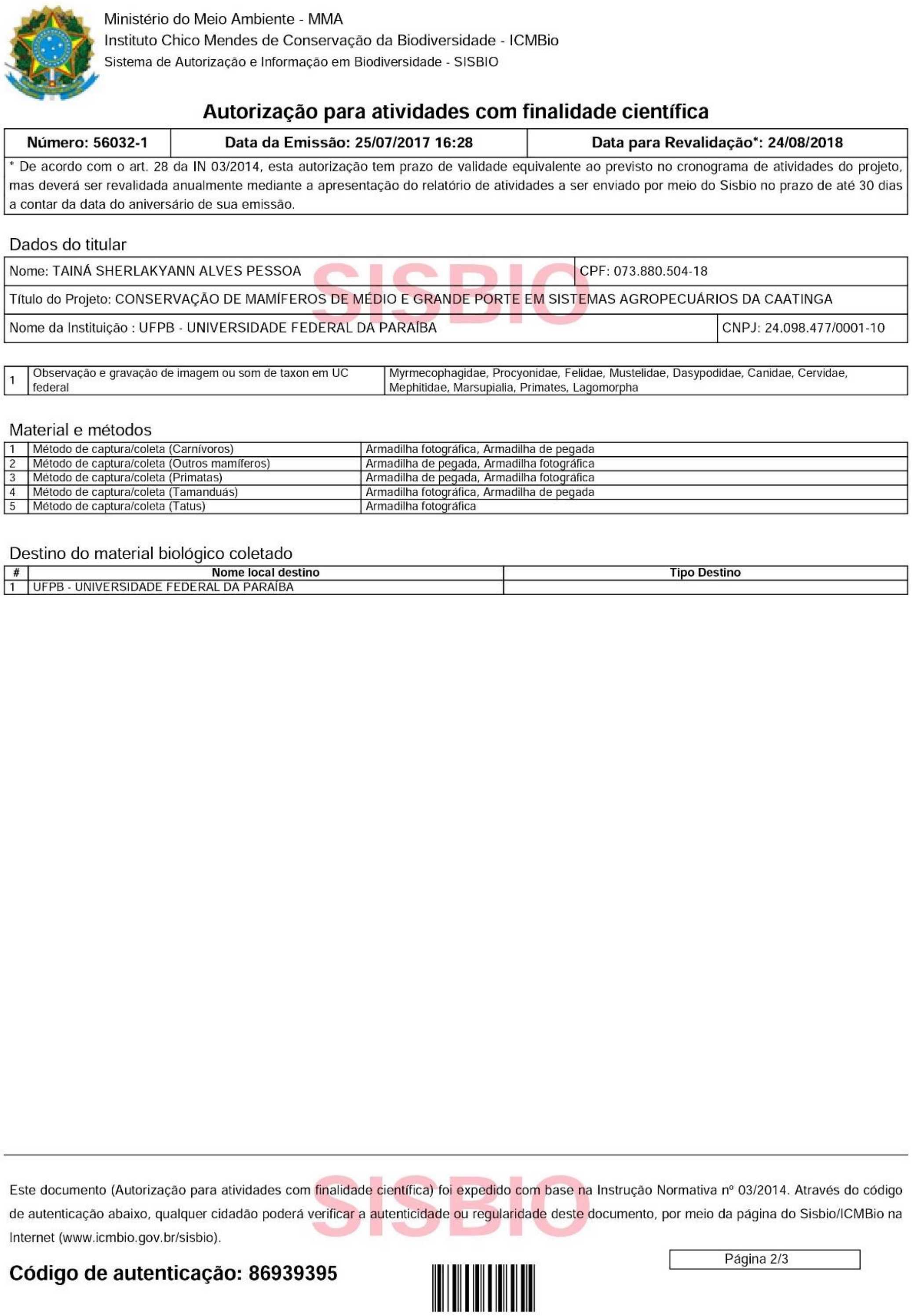
Página 1/3



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CNPJ: 24.098.477/0001-10

1	Observação e gravação de imagem ou som de taxon em UC federal	Myrmecophagidae, Procyonidae, Felidae, Mustelidae, Dasypodidae, Canidae, Cervidae, Mephitidae, Marsupialia, Primates, Lagomorpha

Material e métodos

1	Método de captura/coleta (Carnívoros)	Armadilha fotográfica, Armadilha de pegada
2	Método de captura/coleta (Outros mamíferos)	Armadilha de pegada, Armadilha fotográfica
3	Método de captura/coleta (Primatas)	Armadilha de pegada, Armadilha fotográfica
4	Método de captura/coleta (Tamanduás)	Armadilha fotográfica, Armadilha de pegada
5	Método de captura/coleta (Tatus)	Armadilha fotográfica

Destino do material biológico coletado

#	Nome local destino	Tipo Destino
1	UFPB - UNIVERSIDADE FEDERAL DA PARAÍBA	

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Registro de coleta imprevista de material biológico

De acordo com a Instrução Normativa nº 03/2014, a coleta imprevista de material biológico ou de substrato não contemplado na autorização ou na licença permanente deverá ser anotada na mesma, em campo específico, por ocasião da coleta, devendo esta coleta imprevista ser comunicada por meio do relatório de atividades. O transporte do material biológico ou do substrato deverá ser acompanhado da autorização ou da licença permanente com a devida anotação. O material biológico coletado de forma imprevista, deverá ser destinado à instituição científica e, depositado, preferencialmente, em coleção biológica científica registrada no Cadastro Nacional de Coleções Biológicas (CCBIO).

Táxon*	Qtde.	Tipo de amostra	Qtde.	Data

* Identificar o espécime no nível taxonômico possível.

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The Rufford Foundation
www.rufford.org

17th October 2016

Taina Sherlakyann Alves Pessoa
66 Vidal de Negreiros AVE
Jacaraú, PB 58278-000
Brazil

Our ref: 20547-2

Dear Taina

I am pleased to advise you that the trustees of The Rufford Foundation have approved a 2nd RSG grant of £5000. The grant is being made towards your project – CONSERVATION OF LARGE AND MEDIUM SIZE MAMMALS IN BIODIVERSTIY-FRIENDLY AGRICULTURAL SYSTEMS OF THE BRAZILIAN CAATINGA.

You agree that you will only use the grant for the purposes of that project and will provide to the trustees a full formal report in twelve months' time to detail how the grant has been used (using the Rufford Foundation Final Report template sent with this letter). The report will include an account of all relevant expenditure in the period covered by the report. If you use the grant for purposes other than the above project, or do not supply us with a report that we consider to be satisfactory, then you agree to reimburse the grant to us in full. You will also provide us, by email, with ongoing reports and photographs from the project to be used on the Rufford Foundation website (refer to email attachment entitled Submissions for the Rufford Foundation website).

By accepting the grant you warrant to us that you, Taina Sherlakyann Alves Pessoa, will comply with the terms of the grant as set out in this letter.

Attached is your Banking Information Form – please ensure you read and understand this form as it is critical that the information you provide us is correct. It is always recommended that you contact your bank and confirm the information you provide is correct.

We should be grateful if you would sign a copy of this letter to accept the terms of this grant and send by email to **jane@rufford.org** together with your completed banking information form. **As soon as the funds are received, please acknowledge safe receipt by email to jane@rufford.org.**

Yours sincerely
Josh Cole
Grants Director

I have read and understood the terms of this letter:

Signed Tainá Sherlakyann Alves Pessoa

Print Name Tainá Sherlakyann Alves Pessoa

THE RUFFORD FOUNDATION
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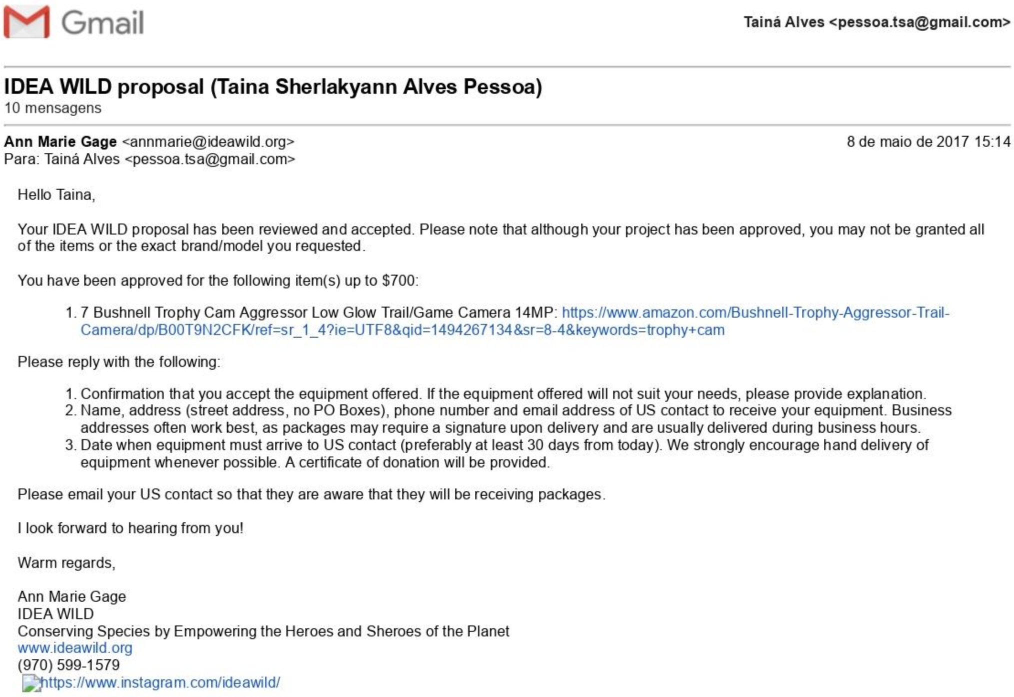

Gmail

Tainá Alves <pessoa.tsa@gmail.com>

IDEA WILD proposal (Taina Sherlakyann Alves Pessoa)

10 mensagens

Ann Marie Gage <annmarie@ideawild.org> 8 de maio de 2017 15:14
Para: Tainá Alves <pessoa.tsa@gmail.com>

Hello Taina,

Your IDEA WILD proposal has been reviewed and accepted. Please note that although your project has been approved, you may not be granted all of the items or the exact brand/model you requested.

You have been approved for the following item(s) up to $700:

1. 7 Bushnell Trophy Cam Aggressor Low Glow Trail/Game Camera 14MP: https://www.amazon.com/Bushnell-Trophy-Aggressor-Trail-Camera/dp/B00T9N2CFK/ref=sr_1_4?ie=UTF8&qid=1494267134&sr=8-4&keywords=trophy+cam

Please reply with the following:

1. Confirmation that you accept the equipment offered. If the equipment offered will not suit your needs, please provide explanation.
2. Name, address (street address, no PO Boxes), phone number and email address of US contact to receive your equipment. Business addresses often work best, as packages may require a signature upon delivery and are usually delivered during business hours.
3. Date when equipment must arrive to US contact (preferably at least 30 days from today). We strongly encourage hand delivery of equipment whenever possible. A certificate of donation will be provided.

Please email your US contact so that they are aware that they will be receiving packages.

I look forward to hearing from you!

Warm regards,

Ann Marie Gage
IDEA WILD
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