UNIVERSIDADE ESTADUAL DO MARANHÃO
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OS MAMÍFEROS CORROBORAM O MARANHÃO COMO SENDO UM ESTADO ECÓTONO: COMPOSIÇÃO DAS ESPÉCIES DE MAMÍFEROS NÃO-VOADORES E SUAS ÁREAS PRIORITÁRIAS PARA CONSERVAÇÃO

ODGLEY QUIXABA VIEIRA

SÃO LUÍS
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Tese de Doutorado apresentada ao Programa de Pós-Graduação em Biodiversidade e Biotecnologia da Rede BIONORTE, na Universidade Estadual do Maranhão, como requisito para a obtenção do Título de Doutor em Biodiversidade e Conservação.

Orientador(a): Prof. Dr. TADEU GOMES DE OLIVEIRA

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“But whether there be a God and whatever be His nature; whether we have an immortal soul or not, or whatever may be our state after death, I can have no fear of having to suffer for the study of nature and the search for truth”

Alfred Russel Wallace

RESUMO

VIEIRA, Odgley Quixaba. **Os mamíferos corroboram o Maranhão como sendo um estado ecótono: composição das espécies de mamíferos não-voadores e suas áreas prioritárias para conservação**. 2021. 131 f. Tese (Doutorado em Biodiversidade e Conservação). Programa de Pós-Graduação em Biodiversidade e Biotecnologia da Rede Bionorte, Universidade Estadual do Maranhão, São Luís, 2021.

O Brasil é o país detentor da maior diversidade biológica do planeta. Dentre seus inúmeros biomas, destacam-se a Amazônia e o Cerrado. A denominação de estado ecótono, por estar localizado na região meio-norte do Brasil, entre a Amazônia a Caatinga e o Cerrado, confere ao Maranhão áreas ricas e abundantes em espécies e consequentemente remete a cuidados especiais na sua conservação. Apesar de seu enorme potencial em biodiversidade, o Maranhão ainda possui sua riqueza biológica pouco conhecida, notadamente quanto à sua mastofauna. A metodologia empregada para inventariar a comunidade de pequenos mamíferos não-voadores foi a metodologia padrão de captura-recaptura, utilizando armadilhas do tipo live-traps. Para os mamíferos de médio e grande porte utilizou-se a visualização direta e indireta através da transecção de trilhas pré-estabelecidas assim como entrevistas e uso de armadilhas fotográficas. Para maximizar a busca pelos componentes de mamíferos constituintes já registrados no estado foram também realizadas buscas de literatura através de plataformas digitais confiáveis. Foram registradas 89 espécies de mamíferos não-voadores no Maranhão, onde 23 são consideradas ameaçadas de extinção. A transicionalidade do estado foi comprovada pela semelhança entre o número de espécies associadas aos biomas majoritários presentes no estado, onde 65 destas estão associadas ao Cerrado e 65 à Amazônia, e pela análise de componentes principais, que evidenciou sobreposição entre os agrupamentos de espécies associados a estes biomas. Eventos históricos de expansão-retração das florestas úmidas sobre os espaços ocupados por formações abertas de climas sazonais secos além do efeito da fragmentação nos deslocamentos de muitas espécies permitiu o registro de algumas destas em zonas limítrofes ou até mesmo fora do bioma de origem. As áreas prioritárias para a conservação dos mamíferos não voadores ameaçados no estado do Maranhão, obtidas a partir da média dos modelos de distribuição potencial para cada espécie ameaçada presente no estado, somaram 69 mil km^2. As áreas definidas como prioritárias para conservação por esse estudo estão concentradas no entorno das áreas protegidas da região do Gurupi, do Parque Nacional da Chapada das Mesas, conectando o Parque Estadual do Mirador com as reservas indígenas adjacentes, médio curso do Rio Parnaíba e extremo sul do estado, margeando o Parque Nacional das Nascentes do Rio Parnaíba. Conservar as áreas prioritárias definidas nesse estudo, aumentarão as chances de manutenção de populações viáveis das espécies assim como possibilitarão o deslocamento natural entre áreas que julgarem mais adequadas.

Palavras-chave: mamíferos, transicionalidade, áreas prioritárias, conservação, Maranhão.

ABSTRACT

VIEIRA, Odgley Quixaba. **Mammals corroborate Maranhão as an ecotonous state: composition of non-flying mammal species and their priority areas for conservation**. 2021. 131 f. Tese (Doutorado em Biodiversidade e Conservação). Programa de Pós-Graduação em Biodiversidade e Biotecnologia da Rede Bionorte, Universidade Estadual do Maranhão, São Luís, 2021.

Brazil is the most biodiverse country on Earth, with the Amazon and Cerrado biomes in particular having high levels of species richness. In the state of Maranão, located in the midnorth region of the country, lies an ecotonal zone between the Amazon, Caatinga, and Cerrado biomes. This results in the region having areas with high biodiversity and conservation priority. Despite this, the mammalian fauna of the region is still poorly known. We sampled the nonvolant mammals at several sites in Maranhão state. Small mammals were sampled using live traps, whereas medium and large-sized mammals were surveyed through transect sampling, interviews, and camera traps. We also searched literature extensively through trustable digital platforms. We recorded 89 nonvolant species for Maranhão state, of which 23 are threatened with extinction. The ecotonal nature of the region was supported by the number of species associated to each biome (65 species for the Cerrado and 65 in the Amazon), as well as by a principal component analysis, showing extensive overlap among species of each biome. Historical events such as expansion-retraction of rainforests in open landscapes as well as contemporary habitat loss, resulted in some of the species being detected outside their known distribution limits. Species distribution models showed that an area of 69,000 km^2 within the state is of high conservation priority for threatened mammalian species. These areas are located in the buffer zones of existing protected areas such as the Gurupi region, Chapada das Mesas National Park, Mirador State Park, the middle Parnaíba river, and the Nascentes do Rio Parnaíba National Park. Ensuring the protection of the areas identified in this study, will improve the long-term conservation prospects of threatened species by allowing viable populations and habitat connectivity between existing protected areas.

Key words: mammals, ecotones, conservation priority areas, conservation, Maranhão.

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1. INTRODUÇÃO GERAL

Desde 1992 o Brasil é considerado um país detentor de megadiversidade a partir dos critérios da quantidade de espécies endêmicas e do número de mamíferos, pássaros, répteis e anfíbios existentes (MITTERMEIER et al., 1992). Dada a sua dimensão continental e a grande variação geomorfológica e climática, abriga sete biomas: Amazônia, Cerrado, Pantanal, Mata Atlântica, Caatinga, Campos Sulinos e o bioma Costeiro (ARRUDA, 2001). Esse gigantismo reflete-se também na sua diversidade biológica, detendo, por exemplo, 701 espécies nativas de mamíferos segundo Paglia et al. (2012). Por outro lado, possui conhecimento desequilibrado sobre sua biodiversidade, seja pelas lacunas de informações de muitas áreas, seja pelo maior conhecimento de algumas ordens em relação à outras. Para uma grande variedade de espécies existem poucas informações básicas, como sua simples distribuição geográfica, sendo o conhecimento geralmente restrito ao registro de nomes em listas de espécies (METZGER et al., 2010; REIS et al., 2012).

O estado do Maranhão está localizado na região meio-norte do Brasil e dentro da confluência de 3 grandes biomas: Amazônia, Cerrado e Caatinga (STELLA, 2011) A Amazônia constitui o maior bloco contínuo de floresta tropical no mundo, representando extrema importância ecológica e de serviços ambientais (MMA, 2007). Isso se deve ao fato deste bioma conter uma enorme variedade e complexidade de ecossistemas, o que pode proporcionar aumentos progressivos na sua riqueza de espécies assim como na modificação dos seus padrões de distribuição (PERES, 2005). O Cerrado possui o status da mais diversa savana tropical do mundo, sustentado por uma enorme diversidade de habitats, determinando uma notável alternância de espécies entre diferentes fitofisionomias (KLINK; MACHADO, 2005). Desta forma, por serem igualmente ricos em biodiversidade, merecem atenção especial quanto ao estabelecimento regional de prioridades que conduzam à conservação, à utilização sustentável e à repartição de benefícios desta diversidade biológica com o restante do país.

Assim como muitos estados da federação, o Maranhão é um dos estados brasileiros menos conhecidos quanto à sua diversidade de mamíferos, especialmente em relação aos mamíferos não-voadores, sobre os quais existem informações bastante limitadas. Uma amostra do potencial desta desconhecida riqueza da mastofauna deste estado pode ser constatada na publicação de Oliveira et al. (2007), que fornece informações sobre a expansão da área de distribuição geográfica de muitas espécies de mamíferos no Maranhão. Estes autores relatam evidências sobre ocorrências não usuais de mamíferos, com expansão na área de distribuição de algumas espécies, registros de uso de novos hábitats e registros inéditos de

táxons para o estado. Nessa publicação ficou evidente o caráter transicional deste estado, uma vez que os resultados mostraram que este não possui uma assembleia faunística típica de um único bioma, mas sim uma mistura de ecossistemas, corroborando o que já afirmaram Vivo (1996) e Silva Júnior (1998).

Por fim, o estado, assim como muitos outros do Brasil, passa atualmente por um período de crescimento de áreas cultivadas e urbanas e pelo aumento da densidade populacional, características estas que podem impactar diretamente a fauna local (FEARNSIDE, 2005; GANEM, 2011). Em 2003, um dos três principais ecótonos do país, o Cerrado-Amazônia, que está presente no estado e localizado dentro de uma região Amazônica sob forte pressão antrópica chamada Arco do Desmatamento, já havia perdido 60% de sua cobertura florestal (MMA, 2007). Muitas destas perdas foram dentro de áreas protegidas, criadas com o intuito de manter e proteger diversidade biológica e dos recursos naturais e culturais associados, manejados através de instrumentos legais ou outros instrumentos efetivos (IUCN, 1994). Diante deste quadro ameaças aos recursos naturais e de carência de informações sobre a sua real biodiversidade, são imprescindíveis ações para estimar a composição das espécies de mamíferos do estado, além de ser importantes para avaliar como o grau de perturbação nos remanescentes de naturais tem afetado esta diversidade.

1.1 OBJETIVOS

Esta tese foi desenvolvida em três capítulos com objetivos específicos. Para este estudo foram utilizados dados referentes a buscas bibliográficas e dados primários do Núcleo de Pesquisas em Ecologia e Conservação de Mamíferos da Universidade Estadual do Maranhão/NUPEC-Bio. Os dados foram selecionados em conformidade com o tema abordado em cada capítulo.

Capítulo 1 – Intitulado de "*Non-volant mammalian species richness in the ecotonal Brazilian midnorth: checklist for Maranhão State*", o capítulo é a lista de espécies de mamíferos não-voadores do estado do Maranhão. Fruto de mais de 20 anos de inventários no estado o artigo fecha uma lacuna de conhecimento sobre mamíferos do meio norte do Brasil. Artigo publicado no periódico Biota Neotropica (ISSN 1676-0611, online edition, vol:20, iss:2) .

Capítulo 2 – O capítulo intitulado "*Non-volant mammalian species composition in the Amazon, Cerrado, and Caatinga ecotone of Brazil's midnorth*" traz uma análise taxonômica e biogeográfica da mastofauna justificando similaridades entre as comunidades e por conseguinte evidenciando o caráter ecotonal o estado.

Capítulo 3 – Considerando a elevada riqueza de espécies levantadas assim como os crescentes processos de descaracterização que afligem os biomas pertencentes ao estado, o capítulo intitulado "*Assessing priority areas for mammalian conservation in the Amazon rainforest-savanna-semiarid shrub-woodlands ecotonal area of the Brazilian mid-north*" faz uso de modelos de distribuição espacial de espécies para estabelecer áreas prioritárias para a conservação. Para tal fez uso das espécies ameaçadas registradas ao longo do estado, onde estas atuam de forma mais ampla aumentando as chances de cobrir melhor a biodiversidade regional.

2. REVISÃO DE LITERATURA

2.1 MAMÍFEROS DO MARANHÃO

Historicamente os primeiros estudos sobre mamíferos no Brasil iniciaram com os primeiros exploradores europeus, no início de 1576 (De GÂNDAVO, 2004). Os primeiros trabalhos tinham pouco cunho científico e se limitavam a descrever a exuberância da fauna, tais como diferenças entre as aqui vistas quando comparadas à europeia (MIRANDA, 2004). A descrição formal das espécies só teve início quase dois séculos depois com Linnaeus (1758) através de sua obra *Systema Naturae*, que descrevera 47 espécies nativas. Já no início do séc. 19, com a abertura dos portos brasileiros ao comércio estrangeiro em 1808, muitos naturalistas europeus chegaram ao país em busca de estudar as riquezas de nossas florestas, com destaque para a região Amazônica (ÁVILA-PIRES, 1964; HERSHKOVITZ, 1987). Apenas mais recentemente que Cabrera (1957) publicou uma lista abrangente de espécies de mamíferos sul-americanos, descrevendo, por exemplo, a ocorrência de 48 espécies de pequenos mamíferos não-voadores para o país (MENDES-OLIVEIRA et al., 2015).

No Brasil do século 21 ainda há muitas regiões do país deficientes de inventários de fauna, notadamente nas regiões Norte e Nordeste (REIS et al., 2012). Mesmo o Maranhão abrigando em seu território a maior floresta tropical do mundo, são poucas as pesquisas com mamíferos na região, quando comparado aos seus vizinhos do Norte (LOPES & MENDES-OLIVEIRA, 2015). O estado do Maranhão até recentemente não possuía uma lista única de mamíferos, apenas registros isolados em poucas publicações. Dentre as publicações históricas destacam-se Mamíferos da França Equinocial, Maranhão e Mamíferos descritos na Poranduba Maranhense de Frei Francisco dos Prazeres de Ávila-Pires (1989, 1992). As publicações mais completas são as de Barreto (2007) e Martins & Oliveira (2011), tratando de forma isolada a composição da mastofauna nos biomas Cerrado e Amazônia, respectivamente.

Os mamíferos terrestres não-voadores abrangem tanto os mamíferos de menor porte (<1 kg) como roedores e marsupiais, comumente amostrados em armadilhas de captura, quanto os de médio e grande porte (aqueles com mais de 1 kg de peso), como *Tapirus terrestris*, o maior mamífero terrestre neotropical, com peso entre 150 e 300 kg (SILVA, 1994; PADILLA & DOWLER, 1994). Bastante numerosos e representativos, os pequenos mamíferos possuem papel importante na dinâmica das florestas neotropicais, pois atuam como dispersores de sementes e como predadores de sementes e fungos de forma que mudanças nesses grupos também podem afetar todo o processo de regeneração (JANOS et al., 1995; BREWER & REJMANEK, 1999; RAMBALDI & OLIVEIRA, 2003). Estão intimamente ligados aos

mamíferos de médio e grande porte, principalmente os carnívoros, pois devido a serem presas destes, o efeito do topo para a base da cadeia alimentar (top-down) como consequência da perda de predadores pode afetar toda a sua comunidade (TERBORGH et al., 2001; WANG 2002). Os mamíferos de maior porte são extremamente importantes na preservação dos sistemas biológicos em florestas tropicais, desempenhando um importante papel na estrutura física de habitats, taxas dos processos dos ecossistemas e na diversidade de comunidades (DIRZO & MIRANDA, 1990; JANSON & EMMONS, 1990; TERBORGH, 1992; SINCLAIR, 2003). Portanto os esforços na conservação de mamíferos de médio e grande porte, por exemplo, por necessitarem de grandes áreas para manter populações viáveis, acabam por preservar também as outras espécies da comunidade, notadamente a de pequenos mamíferos.

Embora seja muito mais perceptível a variação na frequência de ocorrência dos médios e grandes mamíferos, a alteração da paisagem também exerce influência na composição da fauna de pequenos mamíferos (PARDINI et al., 2005). Esses problemas são muito comuns em regiões em crescimento populacional ou que busquem desenvolvimento econômico como o estado do Maranhão, muito embora seja forçado a seguir fórmulas de crescimento econômico que marginalizaram os conceitos de desenvolvimento sustentável (FEARNSIDE, 1991). Desta forma torna-se relevante, conhecer a distribuição, avaliar a composição de espécies, abundância e o status de conservação de diversas espécies de mamíferos, sejam elas de pequeno ou grande porte, ameaçadas ou não. Atualmente, a pouca visibilidade do conhecimento da mastofauna do estado assim como os eventuais crescentes processos de descaracterização ambiental deveriam impulsionar o aumento no número de pesquisas relacionadas a esses animais, fundamental para uma melhor caracterização da sua comunidade (BRAZIL, 2015). Assim, é necessário buscar mais informações sobre essas espécies, no intuito de contribuir para a compreensão de problemas taxonômicos e de lacunas referentes à distribuição geográfica, podendo ao final subsidiar estratégias de conservação da biodiversidade no estado.

2.2 TERRITÓRIO MARANHENSE

Localizado no extremo oeste do Nordeste, o Maranhão é o único estado da região que abriga em parte de seu território a floresta Amazônica, a maior área de floresta tropical do mundo, abrangendo nove dos 12 países da América do Sul (JUNK et al., 2011). A porção mais oriental da Amazônia brasileira atinge o estado do Maranhão onde, apesar do bioma cobrir originalmente 111.483 km^2 da sua área (34,8%), apenas 23,82% ainda diz respeito a remanescentes florestais, o que posiciona o estado como o de menor área nessa categoria (SANTOS, 2007; STELLA 2011). O outro principal bioma é o Cerrado, por ocupar também uma grande parcela territorial e desta forma compreender uma longa faixa que se estende da região nordeste ao sul do estado. Ranqueado como o segundo maior bioma sulamericano, o Cerrado ocupa uma área de 22% do território brasileiro e aqui sofre com as mesmas ameaças de desmatamento da Amazônia, haja vista ser o segundo maior bioma do Estado do Maranhão (SANO et al., 2008). Com uma cobertura vegetal original de 212.090 km^2, o Cerrado cobre cerca de 64,1% do território maranhense, apresentando um dos maiores índices de preservação, com 71,9% de cobertura natural/natural não vegetado (STELLA, 2011, BRAZIL, 2015). Apesar de preservado no Maranhão, os recentes dados de monitoramento anual do bioma vêm apontando um crescimento do desmatamento até mesmo superior ao da Amazônia (INPE & FUNCATE, 2017), pois já teria perdido mais de 50% da sua cobertura natural (BRAZIL, 2015). Esta área de transição com paisagens naturais e características fitoclimáticas peculiares torna o estado detentor de uma considerável riqueza biológica e de recursos naturais.

O Maranhão é composto por um mosaico de paisagens ricas em biodiversidade, mas em decorrência de fortes pressões antrópicas sobre os recursos naturais no estado, particularmente nas últimas décadas, grandes áreas da cobertura vegetal foram transformadas pelas atividades agropecuárias e pelo uso madeireiro (MARTINS & OLIVEIRA, 2011). O ecótono Cerrado-Amazônia presente em nosso estado e localizado dentro de uma região Amazônica sob forte pressão antrópica, denominada arco do desmatamento, em 2003 já havia perdido cerca de 60% de sua cobertura florestal. Nesta região encontra-se a maior concentração de matas secas do país, além de ser o habitat de diversas espécies endêmicas (MMA, 2007). Dessa forma, os ecossistemas locais vêm sofrendo profundas mudanças em suas fisionomias, na sua estrutura e na diversidade das espécies da fauna e da flora, representando uma constante e crescente ameaça para a manutenção e preservação dos

ecossistemas, impondo sérios riscos aos princípios da sustentabilidade socioeconômica e ambiental do território maranhense.

Embora 76% do estado sejam considerados como áreas de vegetação, em relação à preservação dos remanescentes, apenas 19% do Estado está protegido por unidades de conservação, e destes, menos de 5% podem ser considerados áreas de proteção integral (De ARAÚJO et al., 2016). O pouco conhecimento sobre o atual status da biodiversidade do estado assim como os eventuais crescentes processos de descaracterização que afligem esses biomas deveriam impulsionar o aumento no número de pesquisas, fundamental para uma melhor caracterização de suas comunidades (BRAZIL, 2015). Caso ações que busquem minimizar esses problemas, esta desconhecida biodiversidade poder ter valor praticamente nulo, fazendo com que a sociedade não percebe a importância da conservação desta e, portanto, não alocando recursos para protegê-la (AGUIAR, 2004; ENRÍQUEZ, 2008).

Não só para o Maranhão, mas para o país como um todo, a perda e fragmentação dos hábitats naturais tem acarretado uma série de impactos sobre a biodiversidade (LAURANCE & GASCON, 1997; BIERREGAARD et al., 2001). Isto compromete significativamente a sobrevivência de diversas espécies da fauna e flora, expondo-as precocemente ao risco de extinção. A carência de informações científicas relevantes sobre o *status* de conservação das espécies dificulta a implementação de medidas conservacionistas adequadas, planos de ação prioritários e políticas públicas visando à sobrevivência ao longo prazo das espécies. Nesse contexto estão os programas de levantamento e inventário da biodiversidade, de extrema importância para a quantificação da riqueza ambiental, afim de para permear a adoção de medidas conservacionistas, assegurando resguardar o patrimônio natural em escalas regional e nacional (SILVEIRA et al., 2010).

2.3 ÁREAS PRIORITÁRIAS

Estabelecer "áreas prioritárias para a conservação" constitui um instrumento de política pública para apoiar a tomada de decisão, de forma objetiva e participativa, no planejamento e implementação de ações como criação de unidades de conservação, licenciamento, fiscalização e fomento ao uso sustentável (ROSA, 2003). Entretanto é unanimidade entre os especialistas que os escassos recursos financeiros destinados à conservação da biodiversidade exigem a realização de um exercício de estabelecimento de prioridades (MARGULES & PRESSEY, 2000; SARKAR et al., 2002; WILLIAMS et al., 2002)

A conservação de áreas que permitam a persistência de espécies, de processos ecológicos e de paisagens já é um processo frequente no Brasil. Como exemplos temos as áreas prioritárias para a conservação da Amazônia, realizado em 1990 e da Mata Atlântica do Nordeste, realizado em 1993. Dentre estes merecem destaque os seminários realizados entre os anos 1997 e 2000 que definiram as áreas prioritárias para os biomas no Brasil. O Projeto de Conservação e Utilização Sustentável da Diversidade Biológica Brasileira/PROBIO realizou nestes seminários, de forma inédita, uma ampla consulta envolvendo especialistas, tomadores de decisão e organizações não-governamentais. Através de uma metodologia inovadora, e após sucessivas rodadas de discussões e elaborações de documentos, foram identificadas de 900 áreas e ações prioritárias para a conservação da biodiversidade na Amazônia; Cerrado e Pantanal; Caatinga; Mata Atlântica e Campos Sulinos; e Zona Costeira e Marinha. Em comum a todos estes casos citados está o uso da mesma metodologia, que consiste na seleção dos objetos de conservação, majoritariamente espécies endêmicas e ameaçadas de extinção compilação de dados sobre a distribuição dessas espécies certificação por especialistas, publicação dos resultados e acompanhamento das ações de conservação propostas (MITTERMEIER, et al., 1995; MMA, 2007).

Diversas metodologias já foram propostas para estabelecer prioridades de conservação, algumas focadas em uma única espécie (espécies-bandeira), enquanto que outras focam em várias espécies: “Rule-Based Methods”. Outras defendem sistema de pontuação para posterior ranqueamento, Planejamento Sistemático da Conservação (MARGULES & PRESSEY, 2000) e estratégias de priorização globais: *Hotspots* de Biodiversidade, Global 200 e “Wilderness Areas” (MACE et al., 2007). Entretanto alguns pesquisadores levantam dúvidas quanto ao consenso acerca da escolha do melhor índice, uma vez que, por exemplo, alguns estudos realizados em escala global ou continental sugerem uma forte correlação entre riqueza de espécies e endemismo (p. ex., PEARSON & CARROLL, 1999), ao passo que outros estudos não apoiam tal relação (FLATHER et al., 1997; ORME et al., 2005; LOYOLA et al., 2007). Desta forma, considerar apenas a dimensão taxonômica, considerada importante na identificação de áreas prioritárias, pode não ser a melhor estratégia de conservação, porque riqueza não reflete complementaridade e, portanto, poderia levar a áreas prioritárias com assembleias semelhantes, ao custo de não se conservar assembleias únicas (KUKKAL & MOILANEN, 2013; BROWN et al., 2015; BRUM et al, 2017).

A metodologia utilizada pelo Ministério do Meio Ambiente, órgão estatal responsável pela política nacional de meio ambiente, segue a abordagem do Planejamento Sistemático da Conservação (PSC), conforme Deliberação CONABIO nº 39 de 14/12/2005 (MMA, 2005). O

PSC é, portanto, a metodologia oficial adotada para a elaboração de cenários de conservação que contemplem a proteção da biodiversidade e dos ecossistemas. Várias configurações já foram utilizadas, como grid de quadrículas (BRANDÃO et al., 2004), grid de hexágonos (atualização das Áreas Prioritárias de 2006, MMA, 2007) e bacias hidrográficas (NOGUEIRA et al., 2010). Atualmente a metodologia adotada na 2ª atualização das áreas prioritárias brasileiras continua sendo o PSC (MARGULES & PRESSEY, 2000), da mesma forma como ocorreu no primeiro processo de atualização, em 2006 (MMA, 2007).

O PSC foi originalmente idealizado como um sistema de suporte à decisão e à negociação, tomando como base o princípio da "insubstituibilidade" (DIAS et al., 2006). Busca, desta forma, minimizar os conflitos provocados pela ocupação de um espaço geográfico com atributos naturais únicos, sopesados únicos na manutenção de uma biodiversidade regional (SCARAMUZZA et al., 2011). São princípios do PSC (SCARAMUZZA et al., 2005, p.5-6): representatividade, funcionalidade, eficiência, complementaridade, flexibilidade, insubstituibilidade, vulnerabilidade e defensibilidade. No cenário nacional, pesquisas utilizando o PSC na escolha de zonas a serem protegidas são relativamente recentes (WATTS et al., 2009; KLEIN, 2009). No Brasil a efetividade do planejamento pode ser observada nos trabalhos que analisam suas aplicações e implicações no Pantanal (LOURIVAL, 2008), na escolha de áreas prioritárias para a conservação de anuros do Cerrado (BRANDÃO et al., 2004), compreendendo os gradientes de conhecimento e planejamento de conservação em áreas consideradas "hotspots" de biodiversidade (BINI et al., 2006) e também na seleção de áreas prioritárias para conservação de aves do Cerrado (OLIVEIRA et al., 2007; PINTO et al., 2007, 2008). Associado ao PSC está o programa Marxan, tido como a ferramenta mais eficiente na seleção de áreas protegidas (WATTS et al., 2009) haja vista este, além de ter sido criado sob os conceitos do PSC, busca nos seus desenhos cenários de conservação solucionar o "problema do conjunto mínimo", almejando uma representação mínima de determinadas características de biodiversidade com o menor custo possível (McDONNELL et al., 2002). Ao final, após serem definidos os alvos e metas de conservação, é realizada uma análise de lacunas para identificar quais áreas contribuem para atingir os objetivos de conservação pré-determinados.

No estado 75% de sua área é composta por remanescentes de vegetação, e considerando que a integridade da paisagem é um indicador de biodiversidade, a presença de unidades de conservação no estado é de fundamental importância para a proteção destes recursos naturais (SEOANE et al., 2010). O território maranhense possui 34 Unidades de Conservação (UC's), incluindo as federais, as estaduais e as privadas. Na esfera federal, sob a

administração do IBAMA, existem 10 UC's, sendo 04 de Proteção integral e 06 de Uso Sustentável. No âmbito estadual existem 13 UC's: 05 de Proteção Integral, 07 de Uso Sustentável e 01 de Manejo Provisório, totalizando aproximadamente 13mil ha de áreas prioritárias para conservação da biodiversidade. Quanto ao grau de importância destas áreas, 4,8% foram classificadas na categoria de importância alta, enquanto que 17,2% e 16,6% referentes às categorias de importância muito alta e extremamente alta, respectivamente. As áreas prioritárias de importância extremamente alta estão distribuídas principalmente ao nordeste e sudoeste do Estado, e possuem menos de 1% de sua área total em unidades de conservação de proteção integral, situação semelhante para as demais categorias de importância. Estas áreas apresentam forte correlação com as unidades de conservação, o que não é estranho, haja vista a necessidade de regular a pressão antrópica sobre essas áreas que, em alguns casos, já apresentam um alto processo de fragmentação florestal. Entre as ações prioritárias para conservação estão a criação e/ou ampliação de unidades de conservação e a criação de mosaicos de áreas protegidas e corredores ecológicos. No caso do Maranhão, para as áreas prioritárias de importância extremamente alta, e alta, essas são as ações recomendadas, o que poderia fortalecer a conservação da biodiversidade do Estado (BRASIL, 2007; de ARAÚJO et al., 2016).

Como dito anteriormente, a extensão territorial do Maranhão associada à ocorrência de três biomas diferentes contribuem para uma ampla diversificação da flora e da fauna. E considerando que a vegetação é um dos componentes mais importantes da biota, alterações em habitats naturais como sua diminuição em extensão e integridade podem indicar um declínio dessa biodiversidade (BRASIL, 2010). Desta forma, estabelecer áreas prioritárias para conservação é importante não só para criação de eventuais novas unidades de conservação, mas também para minimizar os efeitos da pressão antrópica sobre estas áreas, seja através da expansão das mesmas ou através do estabelecimento de corredores que minimizem o processo de fragmentação.

A decisão sobre a conservação de uma área depende de sua representatividade biológica, considerando os mais variados níveis de organização, sejam estes ecossistemas, comunidades, populações e espécies (MARGULES & PRESSEY, 2000). Essa representatividade garante uma amostra da biodiversidade local, sempre buscando atestar se as populações são viáveis à longo prazo (GASTON et al., 2002). Uma das formas de avaliar consiste em confrontar o registro das espécies com a presença das mesmas nas Unidades de Conservação a partir de um sistema de informação geográfica (SIG). A presença de organismo registrados fora das áreas já protegidas, pode identificar regiões importantes para a

conservação para estas espécies, tendo em vista o padrão espacial de distribuição (MARGULES & PRESSEY, 2000). Cabe ressaltar que somente áreas protegidas não são suficientes para assegurar a sobrevivência da maioria das espécies (JENKINS & JOPPA, 2009).

Atualmente são diversos os métodos utilizados na tentativa de preencher lacunas de conhecimento com fins conservacionistas. Nesse campo, a modelagem preditiva de distribuição geográfica tem ocupado destaque, por ser um método reconhecido de distribuição da biodiversidade (ELITH, et al., 2006; ZHANG et al., 2012). A modelagem preditiva é considerada mais uma poderosa ferramenta da identificação de áreas importantes para a conservação da biodiversidade atual, pois possui baixo custo e vem crescendo juntamente com a maior disponibilidade de bancos de dados (ZIMMERMANN et al., 2010; GIANNINI et al., 2012). Modelos de distribuição espacial são ferramentas importantíssimas que permitem a projeção no espaço geográfico de padrões de ocorrência de espécies. Este tipo de abordagem tem sido muito utilizado para mamíferos terrestres, haja vista esse tipo de modelagem de distribuição de espécies ameaçadas pode contribuir na determinação de áreas prioritárias para conservação. A modelagem da potencial distribuição geográfica de uma dada espécie é realizada através das características ambientais de pontos de ocorrência já conhecidos, onde o modelo resultante representa uma aproximação da potencial distribuição assim como locais adequados à sobrevivência da espécie, de acordo com as variáveis escolhidas (GIOVANELLI et al., 2010; AUSTIN, 2002).

Considerando o cenário crescente de degradação e o baixo conhecimento da distribuição das espécies ameaçadas de mamíferos terrestres para o estado, o uso da modelagem de distribuição geográfica pode fornecer informações importantes para o delineamento de estratégias de conservação o grupo. Desta forma, usando modelos de distribuição espacial a partir da seleção dos registros de espécies ameaçadas, é possível (i) estabelecer áreas prioritárias à conservação para os mamíferos terrestres não voadores do Maranhão a partir de espécies focais, (ii) identificar as áreas com maior riqueza de espécies e importância biológica, a partir da sobreposição dos mapas confeccionados e (iii) determinar locais que funcionem como pontos de conexão entre áreas com alta riqueza de espécies.

O Brasil, como país signatário da Convenção sobre Diversidade Biológica (CDB), realizou entre os anos de 1998 e 2000 a “Avaliação e Identificação das Áreas e Ações Prioritárias para a Conservação dos Biomas Brasileiros”. Ao final do evento foi instituída uma portaria que determinou a criação de 900 áreas prioritárias, devendo estas serem revistas periodicamente em um prazo não superior a dez anos, em virtude dos avanços do

conhecimento e das condições ambientais (MMA, 2007). Dentro deste contexto, estudos de biodiversidade como este devem não apenas coletar dados técnico-científicos, mas subsidiar com dados programas que busquem conservação, uso sustentável e recuperação/restauração da biodiversidade brasileira, aqui, com enfoque nos recursos naturais no Maranhão. Assim, diante da alta pressão antrópica, assim como pela sua potencial biodiversidade, o estado reúne requisitos minimamente necessários para a identificação de áreas prioritárias, frente aos escassos recursos financeiros destinados à conservação da biodiversidade

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Capítulo 1

Non-volant mammalian species richness in the ecotonal Brazilian midnorth: checklist for Maranhão State

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Introduction

Maranhão is among the least known states of Brazil in terms of its biodiversity, either due to the classic veil line proposed by Preston (1948) or the geographical bias in funding allocated to support biological inventory studies (MAGNUSSON et al., 2016). Nevertheless, its extensive area presents many attributes that allow for high levels of biodiversity, diverse vegetation in particular. Roughly 64.1% of the territory of Maranhão occurs within the Cerrado biome, 34.8% within the Amazon biome and 1.1% is classified as part of the Caatinga biome (STELLA, 2011).

A total of 138 municipalities in Maranhão occur within the Cerrado biome, 110 within the Amazon biome and 15 within the Caatinga biome. The Amazon represents the largest continuous area of rainforest in the world and is recognized for its extreme ecological importance and essential environmental services (MMA, 2007). Such recognition is supported by the large variety and complexity of ecosystems presented by the biome, which affords progressive increases in species richness (PERES, 2005). The Cerrado biome is considered to be the most diverse tropical savanna in the world, also presenting a large variety of habitats and remarkable alternation of species between different phytophysiognomies (MEDEIROS et al., 2011).

Despite the natural richness of these biomes, Maranhão is currently experiencing a period of increasing agriculture, urban expansion and a growing population density, all of which can have direct impacts on local fauna (STEHMANN & SOBRAL, 2017). Although it covers about 64.1% of the state territory and presents one of the highest rates of preservation, with 71.9% of its natural vegetation remaining, the Cerrado biome in Maranhão is also considered highly threatened (STELLA, 2011; BRAZIL, 2015). For example, the MATOPIBA region (an acronym designated by using the initials for the states of Maranhão, Tocantins, Piauí and Bahia) represents a large portion of the Cerrado biome in which the average devoted to cotton, corn and soybean production has grown by 400% between 1990 and 2010 (LORENSINI et al., 2015). Historically covering 34.8% of the state territory, the Amazon biome portion of Maranhão is also highly threatened, having been reduced to remnants representing just 23.82% of its original area due to the drastic transformations of forest and non-forest ecosystems, this is the lowest percentage of remaining vegetation among the nine Brazilian Amazon States (SANTOS, 2007; STELLA, 2011; IMESC, 2019).

Mammals occurring in the state of Maranhão are closely linked to the vegetation of the environment and strongly related to the quality and size of habitat remnants (CHIARELLO,

1999; PERES, 2000). Despite the extensive literature regarding mammal species composition of the Amazon and Cerrado biomes in general, there is little knowledge about mammalian distributions in Maranhão (i.e. Wallacean Shortfall). Mammal species can influence the entire dynamic of the ecosystems in which they occur, having important ecological roles in the dispersal of seeds, spores and plant propagules, as well as regulating natural prey populations. A proper biological inventory of mammal species for Maranhão is necessary to achieve a better understanding regarding the conservation status of habitat remnants in the state.

Therefore, given that the biodiversity of Maranhão is so rich and equally threatened by trends in socio-economic development, the state deserves special attention setting priorities for the region that result in positive outcomes for conservation, sustainable use and the benefits derived of this biological diversity for the rest of the country. Part of the conservation concerns for Maranhão are due to a systematic lack of knowledge regarding its fauna, notably that of non-volant terrestrial mammals, including information gaps for many geographic areas and greater degrees of knowledge for certain mammalian orders relative to others.

Currently there is no single checklist for the species of mammals occurring in the state of Maranhão, our comprehensive knowledge is limited to isolated records in a few publications and mostly addressing species composition of the Cerrado and Amazon biomes independently (ÁVILA-PIRES, 1989, 1992; OLIVEIRA et al., 2007, 2011). Basic information on the geographic occurrence and abundance of mammal species at various locations, as well as actions seeking to estimate the actual species richness of this region, are needed. Therefore, the main objective of the current study is to present a comprehensive checklist for non- volant mammal species known to occur in the state of Maranhão.

Materials and Methods

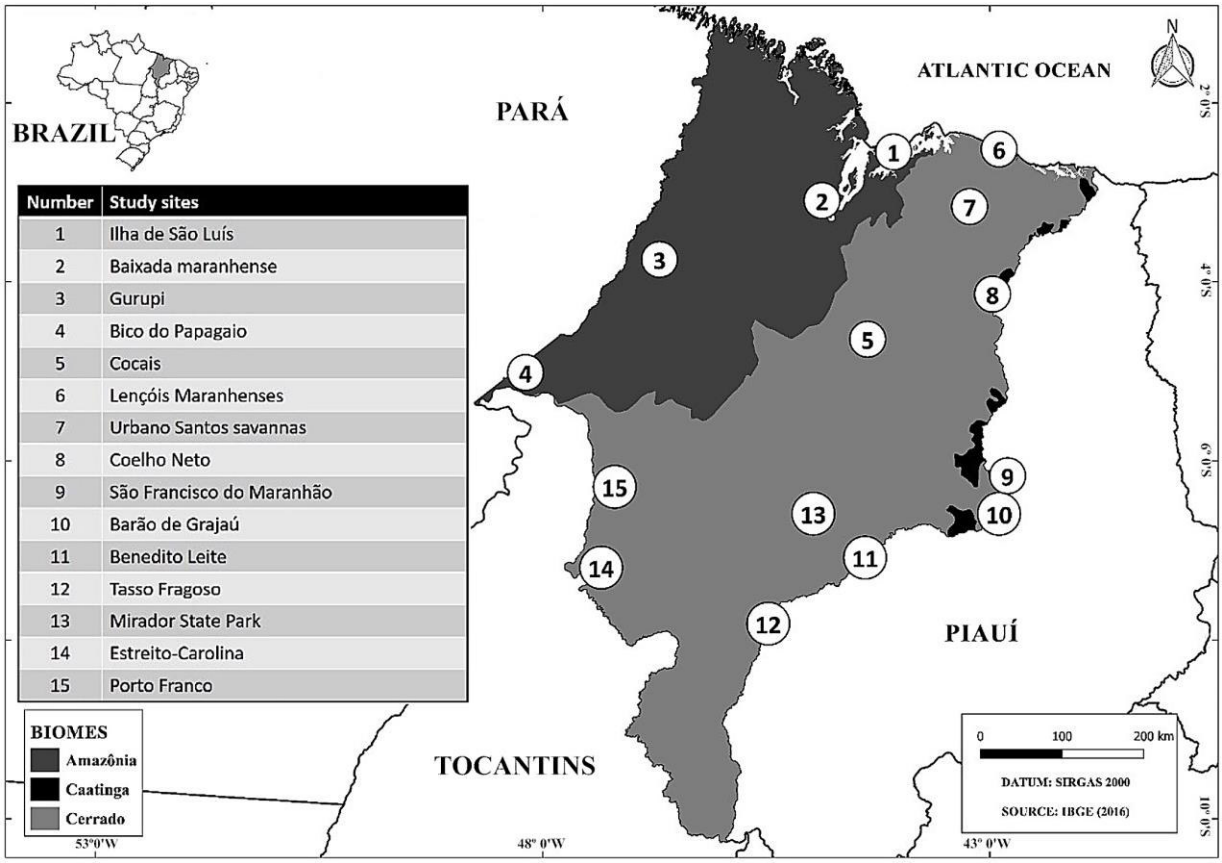
1. Study area

The study corresponds to the Brazilian state of Maranhão, with roughly 331,983 km2. The state has transitional conditions between the super humid climate of the Brazil's northern region and the semi-arid climate of the northeast region of the country, with a predominance of forest vegetation, open fields and Cerrado habitats, and a large variety of ecosystems including mangroves, sand dunes, estuaries, extensive beaches and lake basins (KÖPPEN, 1948; MARANHÃO, 2002). Additionally, the Mata dos Cocais area, a babassu palm formation that is classified by IBGE (1992) as an Open Ombrophilous Forest, stands out for its uniqueness and is considered a characteristic landscape of Maranhão (RIOS, 2001). The

average annual temperature for the whole area is 26ºC, with a large temperature range between the northern and southern portions of the state, a rainfall regime that is highly correlated with the geographic occurrence of the different biomes, annual precipitation of around 1,100 mm in the southwestern region where the Cerrado biome is dominant and often exceeding 2,000 mm annually in Amazon biome areas (PINTO et al., 2011; BRASIL, 2013).

2. Data collection

Inventories were realized at 15 study sites throughout the state of Maranhão, selected to include portions of the Amazon and Cerrado regions, as well as transitional areas between the two biomes in the most diverse plant formations (Figure 1). Because the percentage of Caatinga cover in the state is negligible (ca. 1.1%), we decided to only sample sites within the Amazon and Cerrado biomes of the state. Live-traps appropriate for small mammals and camera traps were installed at sampling locations along predetermined transects of varying sizes within each of the study sites. The total sampling effort resulted in 71,082 nights/live-trapping, 1,283 transect km/traveled and 9,639 nights/camera-trapping (Table 1). The data presented here have been collected since 1994, but with greater consistency from 2004-2018. Additional information regarding biological inventories from different parts of Maranhão acquired from the bibliographic survey was also included.



Number	Study sites
1	Ilha de São Luís
2	Baixada maranhense
3	Gurupi
4	Bico do Papagaio
5	Cocais
6	Lençóis Maranhenses
7	Urbano Santos savannas
8	Coelho Neto
9	São Francisco do Maranhão
10	Barão de Grajaú
11	Benedito Leite
12	Tasso Fragoso
13	Mirador State Park
14	Estreito-Carolina
15	Porto Franco

Figure 1. Location of study sites where non-volant mammal species were sampled in the state of Maranhão, Brazil.

3. Small mammals

The current small mammal survey was performed using the standard methodology of installing live-traps in capture lines along the selected sampling locations at each of the study sites. A capture station consisting of Sherman (8 x 8 x 23 cm) and Tomahawk (14 x 14 x 40 cm) live-traps was established every 20 m, the first type being deployed at each capture station and the second type at alternating stations. In closed-canopy habitats, Sherman live-traps were installed at a height of 1.5–2.5 m above ground at alternate stations to Tomahawk live-traps located on the ground. Peanut butter mixed with banana and/or other fruits was used to bait the live-traps, which were actively deployed for seven consecutive nights (AURICCHIO & SALOMÃO, 2002; LAMBERT et al., 2006; UMETSU & PARDINI, 2007). The sampling protocol for small mammals is outlined in Table 1. All marsupial and small rodent species identifications were based on published systematic studies, as well as other important compilations regarding the taxonomy and geographic distribution of these groups (PAGLIA et al. 2012; BRANDÃO et al., 2015; GARDNER, 2008; MIRANDA & DA SILVA

2015; PATTON et al., 2015; PERCEQUILLO et al., 2015; QUINTELA et al. [in press]). Species identifications were later confirmed by specialists. Voucher specimens were also collected for reference, comparison and confirmation of certain species identifications with other scientific materials and under the appropriate federal government collecting permits including: IBAMA 38/2010, IBAMA 45398-3, IBAMA 113/2004, IBAMA 2001.009125/2008-67, IBAMA 08/2010, IBAMA 035/2009/CGFAP, IBAMA 036/2009/CGFAP, IBAMA 037/2009/CGFAP, IBAMA 038/2009/CGFAP, IBAMA 39/2009/ CGFAP, SEMA/MA 05/2017). Voucher specimens collected during the current study have been deposited in the vertebrate natural history collections of the Universidade Estadual do Maranhão and the Museu Paraense Emílio Goeldi (Supplementary material).

Table 1. Geographic locations and sampling efforts for the study sites included in elaborating the current non-volant mammal species checklist for the state of Maranhão, Brazil.

Sampling locations		Sampling Periods	Central geographic coordinates	Sampling effort		
				Live-traps (nights/trapping)	Walking transects (km)	Camera-traps (nights/ trapping)
1	Ilha de São Luís	2010-2015	2°38'43.69" S / 44° 8'55.42" O	21.568	211	5.548
2	Baixada Maranhense	2017-2018	3°11'18.98" S / 44°56'52.29" O	2.520	15	-
3	Região do Gurupi	2003-2014	3°50'50.20" S / 46°45'52.37" O	10.080	98	25
4	Região do Bico do Papagaio e adjacências	1994/ 2008-2010	5° 6'40.00" S / 48°15'46.26" O	14.173	398	560
5	Região dos Cocais	2012-2013	4°44'19.71"S / 44°26'16.19" O	2.520	17	70
6	Região dos Lençóis Maranhenses	1994	2°36'46.53" S / 42°58'4.05" O	-	30	-
7	Cerrados de Urbano Santos	2005	3°15'21.21" S / 43°17'49.94" O	1.536	15	70
8	Região de Coelho Neto/MA	2008	4°14'5.25" S / 43° 2'27.73" O	2.520	17	70
9	Região de São Francisco do Maranhão	2009	6°15'54.25" S / 42°52'23.11" O	1.688	78	395
10	Região de Barão de Grajaú/MA	2009	6°41'24.58" S / 43° 2'29.19"O	2.110	82	410
11	Região de Benedito Leite/MA	2009	7°10'47.26" S / 44°32'23.00" O	1.960	66	355
12	Região de Tasso Fragoso/MA	2009	7°55'3.55" S / 45°37'18.59" O	1.822	85	420
13	Parque Estadual do Mirador	2013-2018	6°41'17.43" S / 45° 7'5.13" O	3.936	30	1.616
14	Região de Estreito-Carolina/MA	2002	7°17'29.34" S / 47°29'22.82" O	2.651	117	-
15	Região de Porto Franco/MA	2009	6°23'15.13" S / 47°20'17.73" O	1.978	25	100
	Total Effort			**71.062**	**1.283**	**9.639**

4. Medium and large-sized mammals

A variety of non-invasive sampling methods were used in the current study to identify medium and large-sized mammal species, including evidence from bones, skin, tracks, carcasses, vocalizations and photographs. To this end, camera-traps were deployed along several walking transects, while additional trails were also surveyed on foot and at different times of the day during the entire data collection period realized at each of the sampling areas, a standard methodology for this type of study (OLIVEIRA et al. 1988; OLIVEIRA & CASSARO, 2005; WILSON & DELAHAY, 2001). Whenever necessary, species identifications were supported by consulting several field guide references (EMMONS & FEER, 1997; OLIVEIRA & CASSARO, 2005; BONVICINO et al., 2008).

The mammal species detected here were also classified by their appropriate threat categories according to criteria of the International Union for Conservation of Nature - IUCN (Version 13 - IUCN, 2017), these same criteria were also used in the most recent evaluation of the conservation status for threatened fauna in Brazil (ICMBio, 2018).

Results

A total of 89 non-volant, wild mammal species were confirmed as occurring within the state boundaries of Maranhão (Table 2, Figures 2 and 3). Considering mammal species occurrences by biome, a total of 66 species were found to be associated with the Cerrado biome, and 65 species with the Amazon, 5 of which were recorded exclusively in the Amazonian region of the state.

Considering only non-volant mammals that are known to occur in Brazil, species richness in Maranhão represents 12.70% of the total richness proposed by Paglia et al. (2012) and 11.2% of that proposed by Quintela et al. (in press). (Table 3). The mammal species diversity of Maranhão is representative of 27 families and 9 orders. The three most diverse non-volant mammal orders in Brazil are the Rodentia, Primates and Didelphimorphia, although many taxonomic aspects of the first and last of these groupings are still poorly defined. Regarding the mammalian fauna of Maranhão according to the current results, the order Rodentia is the most representative (24 species), followed by Carnivora (20 species) and relegating Didelphimorphia (13 species) to the rank of third most diverse mammal order for the state.

A total of 23 of the 89 species recorded here, or 25.84%, are included in the Brazilian Red List of threatened and endangered animals (ICMBio, 2018). Of these 23 species, the

order Carnivora is the most highly represented (10 species), followed by Primates (5 species) and Cetartiodactyla (3 species). Regarding IUCN threat of extinction categories, mammal species classified as being Vulnerable (VU) were the most highly represented (18 species).

Table 2. Checklist of non-volant mammal species registered as occuring in the state of Maranhão, Brazil. *(to be continued)*

TAXON	THREAT CATEGORY	COMMON NAME	BIOME	TYPE OF RECORD	SAMPLING LOCATION
DIDELPHIMORPHIA					
Didelphidae					
Caluromys philander (Linnaeus, 1758)		Mucuri / Bare-tailed Woolly Opossum	Am, MA, Ce, Pt	C, V, Io	L3,L5,L6,1,2,3,4,5,7,9,11,14
Chironectes minimus (Zimmermann, 1780)		Mucura-d'água / Water Opossum	Am, MA, Ce, Pt, Pp	Io, I	L4,L6,3,4
Didelphis albiventris Lund, 1840		Mucura / Guaiba Dwarf Mouse Opossum	Ce, Ca, Pt, Pp	C, V, Io	L3,L5,L6,4,5,6,7,8,9,10,11,12,13,14
Didelphis marsupialis Linnaeus, 1758		Mucura / Common Opossum	Am	C, V, Io	L3,L5,L6,1,2,3,4,5,7,9,10,11,12,14,15
Gracilinanus agilis(Burmeister, 1854)		Mucuri / Agile Gracile Opossum	Ce, Ca, Pt	C	L3,L4,L5,L6,1,3,4,5,7,9,10,11,12,13,14,15
Marmosa murina (Linnaeus, 1758)		Mucuri / Linnaeus's Mouse Opossum	Am, MA, Ce, Pt	C	L3,L5,L6,1,3,4,5,7,8,9,10,12,13,14,15
Marmosops (Sciophanes) cf. *parvidens* (Tate, 1931)		Mucuri / Slender Opossum	Am	C	L6,3,4
Metachirus nudicaudatus (É. Geoffroy, 1803)		Mucura / Guianan Brown Four-eyed Opossum	Am, MA, Ce, Pt	C	L4,L6,3,4
Marmosa (Micoureus) demerarae		Mucuri / Woolly Mouse Opossum	Am, MA, Ce, Ca	C	L6,2,3,4,5,9,11,12,13
Monodelphis americana (Müller, 1776)		Mucuri / Northern Three-striped Opossum	MA, Ce	C	L6,3,4
Monodelphis domestica (Wagner, 1842)		Mucuri / Gray Short-tailed Opossum	MA, Ce, Ca, Pt	C	L3,L6,1,3,4,5,7,8,9,10,11,12,14,15
Philander opossum (Linnaeus, 1758)		Mucura-de-quatro-olhos / Gray Four-Eyed Opossum	Am, Ce, Pt	C	L3,L6,3,4,14
Thylamys karimii (Petter, 1968)		Mucuri / Karimi's Fat-tailed Mouse Opossum	Ce, Ca	C	L3,4,10,11,12,13,14,15
PILOSA					
Bradypodidae					
Bradypus variegatus Schinz, 1825		Preguiça / Brown-throated Sloth	Am, MA	V, Io, I	L2,L3,L5,L6,1,3,4,5,6,7,9,13,14,15

Table 2. Checklist of non-volant mammal species registered as occuring in the state of Maranhão, Brazil. *(to be continued)*

TAXON	THREAT CATEGORY	COMMON NAME	BIOME	TYPE OF RECORD	SAMPLING LOCATION
Cyclopedidae					
Cyclopes didactylus (Linnaeus, 1758)		Tamanduaí / Silky Anteater	Am, MA, Ce	V, I	L2,L5,L6,1,3,4,6
Megalonychidae					
Choloepus didactylus (Linnaeus, 1758)		Preguiça-real / Linnaeus's Two-toed Sloth	Am	V, I	L5,L6,3,4
Myrmecophagidae					
Myrmecophaga tridactyla Linnaeus, 1758	VU	Tamanduá-bandeira / Giant Anteater	Am, MA, Ce, Ca, Pt, Pp	V, Io, I	L3,L5,L6,3,4,5,9,12,13,14,15
Tamandua tetradactyla (Linnaeus, 1758)		Mambira / Tamandua	Am, MA, Ce, Ca, Pt, Pp	V, Io, I	L2,L3,L6,1,2,3,4,5,6,7,8,10,12,13,14,15
CINGULATA					
Dasypodidae					
Cabassous unicinctus (Linnaeus, 1758)		Tatu-rabo-de-couro / Southern Naked-tailed Armadillo	Am, MA, Ce, Ca, Pt	Io, I	L3,L5,L6,3,4,5,7,9,13,14,15
Dasypus kappleri[1] Krauss, 1862		Tatu-quinze-quilos / Greater Long-nosed Armadillo	Am	Io, I	L4,L6,3,4
Dasypus novemcinctus Linnaeus, 1758		Tatu-comum / Nine-banded Armadillo	Am, MA, Ce, Ca, Pt, Pp	V, Io, I	L2,L3,L5,L6,1,3,4,5,6,7,8,9,12,13,14,15
Dasypus septemcinctus Linnaeus, 1758		Tatu-xina / Seven-banded Armadillo	Am, MA, Ce, Ca, Pt, Pp	V, Io, I	L3,L5,4,5,7,12,13,14,15
Euphractus sexcinctus (Linnaeus, 1758)		Tatu-peba / Six-banded Armadillo	Am, MA, Ce, Ca, Pt, Pp	V, Io, I	L2,L3,L5,L6,1,3,4,5,6,7,8,9,11,12,13,14,15
Priodontes maximus (Kerr, 1792)	VU	Tatu-canastra / Giant Armadillo	Am, MA, Ce, Pt	Io, I	L3,L5,L6,3,4,11,12,13
Tolypeutes tricinctus (Linnaeus, 1758)	EN	Tatu-bola-da-caatinga / Brazilian Three-banded Armadillo	Ce, Ca	Io, I	L3,L4,L5,7,13
PRIMATES					
Aotidae					

Table 2. Checklist of non-volant mammal species registered as occuring in the state of Maranhão, Brazil. *(to be continued)*

TAXON	THREAT CATEGORY	COMMON NAME	BIOME	TYPE OF RECORD	SAMPLING LOCATION
Aotus azarae infulatus (Kuhl, 1820)		Quatro-olhos / Feline Night Monkey	Am	V, Io, I	L3,L6,3,4,5,7,11,13,14,15
Atelidae					
Alouatta ululata Elliot, 1912	EN	Capelão / Maranhão Red-handed Howler Monkey	Am, Ca	V, Io, I	L2,L3,3
Alouatta belzebul (Linnaeus, 1766)	VU	Capelão / Red-handed Howler Monkey	Am, MA	V, Io, I	L3,L6,3,4,5,6,12,13,14,15
Alouatta caraya (Humboldt, 1812)		Capelão / Black-and-Gold Howler Monkey	MA, Ce, Ca, Pt, Pp	V, Io, I	L6,14
Callitrichidae					
Callithrix jacchus (Linnaeus, 1758)		Soim / Common Marmoset	MA	V	L2,L3,5,6,7,8,9,10,11,12,13
Saguinus niger (É. Geoffroy, 1803)	VU	Soim / Black-handed Tamarin	Am	V	L6,3,4,15
Cebidae					
Cebus kaapori Queiroz, 1992	CR	Cairara / Ka'apor Capuchin	Am	V, Io, I	L6,3
Sapajus apella (Linnaeus, 1758)		Macaco-prego / Guianan Brown Tufted Capuchin	Am	V, Io, I	L2,L3,L6,1,3,4,6,7,8,14,15
Sapajus libidinosus (Spix, 1823)		Macaco-prego / Bearded Capuchin	MA, Ce, Ca	V, Io, I	5,12,13
Saimiri sciureus (Linnaeus, 1758)		Mão-de-ouro / Common Squirrel Monkey	Am	V, Io, I	L3,L6,1,3,4,14,15
Pitheciidae					
Chiropotes satanas (Hoffmannsegg, 1807)	CR	Cuxiú-preto / Black Saki	Am	V, Io, I	L6,3,4
CARNIVORA					
Canidae					
Cerdocyon thous (Linnaeus, 1766)		Raposa / Crab-eating Fox	MA, Ce, Ca, Pt, Pp	V, Io, I	L2,L3,L6,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15
Chrysocyon brachyurus (Illiger, 1815)	VU	Lobo-guará / Maned Wolf	Ce, Pt, Pp	Io, I	L3,4,12,13,14,15
Lycalopex vetulus (Lund, 1842)	VU	Raposa / Hoary Fox	Ce, Pt	V, Io, I	L3,5,7,9,10,11,12,13,14,15
Speothos venaticus (Lund, 1842)	VU	Cachorro-do-mato / Bush Dog	Am, MA, Ce, Pt	V, I	L3,L6,3,4,7,12,13,14,15

Table 2. Checklist of non-volant mammal species registered as occuring in the state of Maranhão, Brazil. *(to be continued)*

TAXON	THREAT CATEGORY	COMMON NAME	BIOME	TYPE OF RECORD	SAMPLING LOCATION
Procyonidae					
Nasua nasua (Linnaeus, 1766)		Quati / South American Coati	Am, MA, Ce, Ca, Pt, Pp	V, Io, I	L2,L3,L6,1,2,3,4,5,6,7,8,12,13,14,15
Potos flavus (Schreber, 1774)		Macaco-da-meia-noite / Kinkajou	Am, MA, Ce	I	L6,3,4
Procyon cancrivorus (G. Cuvier, 1798)		Guaxinim / Crab-eating Raccoon	Am, MA, Ce, Ca, Pt, Pp	V, Io, I	L2,L3,L6,1,3,4,5,6,7,9,11,12,13,14,15
Mustelidae					
Eira barbara (Linnaeus, 1758)		Papa–mel / Tayra	Am, MA, Ce, Ca, Pt	V, I	L3,L6,3,4,5,7,12,13,14,15
Galictis cuja (Molina, 1782)		Furão / Lesser Grison	MA, Ce, Ca, Pp	C, V, Io, I	L3,L6,3,4,5,7,12,13,15
Galictis vittata (Schreber, 1776)		Furão / Greater Grison	Am, MA, Ce, Ca, Pt	V, Io, I	L6,3,14
Lontra longicaudis (Olfers, 1818)		Lontra / Neotropical Otter	Am, Ma, Ce, Pt, Pp	V, I	L2,L3,L6,L7,3,4,5,6,7,9,11,12,13,14,15
Pteronura brasiliensis (Gmelin, 1788)	VU	Ariranha / Giant Otter	Am, MA, Ce, Pt	V, Io, I	L6,L9,3,4,7
Mephitidae					
Conepatus semistriatus[2] (Boddaert, 1785)		Gambá / Striped Hog-nosed Skunk	Am, MA, Ce, Ca, Pt	C, V, I	L3,L4,L6,3,5,9,12,13,14
Felidae					
Leopardus pardalis (Linnaeus, 1758)		Maracajá-verdadeiro / Ocelot	Am, MA, Ce, Ca, Pt, Pp	V, Io, I	L2,L3,L6,1,2,3,4,5,6,7,8,10,12,13,14,15
Leopardus tigrinus (Schreber, 1775)	EN	Maracajá-í / Oncilla	Am, MA, Ce, Ca, Pt, Pp	V, Io, I	L2,L3,L6,3,4,5,6,7,9,10,12,13,14,15
Leopardus wiedii (Schinz, 1821)	VU	Maracajá-peludo / Margay	Am, MA, Ce, Ca, Pt, Pp	C, V, Io, I	L3,L6,3,4,5,7,10,13,14,15
Leopardus colocolo (Molina, 1782)	VU	Gato-palheiro	Ce, Pt, Pp	V, I	L3,5,10,11,12,13,14,15
Panthera onca (Linnaeus, 1758)	VU	Onça-pintada/preta / Jaguar	Am, MA, Ce, Ca, Pt, Pp	Io, I	L3,L6,3,4,5,7,9,11,12,13,14,15
Puma concolor (Linnaeus, 1771)	VU	Onça-vermelha / Cougar	Am, MA, Ce, Ca, Pt, Pp	V, Io, I	L3,L6,3,4,5,7,12,13,14,15

Table 2. Checklist of non-volant mammal species registered as occuring in the state of Maranhão, Brazil. *(to be continued)*

TAXON	THREAT CATEGORY	COMMON NAME	BIOME	TYPE OF RECORD	SAMPLING LOCATION
Herpailurus yagouaroundi (É. Geoffroy, 1803)	VU	Gato-mourisco / Jaguarundi	Am, MA, Ce, Ca, Pt, Pp	V, I	L2,L3,L6,2,3,4,5,6,7,11,12,13,14,15
PERISSODACTYLA					
Tapiridae					
Tapirus terrestris (Linnaeus, 1758)	VU	Anta / South American Tapir	Am, MA, Ce, Ca, Pt	V, Io, I	L3,L6,3,4,12,13,14,15
CETARTIODACTYLA					
Tayassuidae					
Tayassu pecari (Link, 1795)	VU	Queixada / White-lipped Peccary	Am, MA, Ce, Ca, Pt, Pp	V, Io, I	L3,L6,3,4,12,13,14,15
Pecari tajacu (Linnaeus, 1758)		Caititu / Collared Peccary	Am, MA, Ce, Ca, Pt, Pp	V, Io, I	L2,L3,L6,3,4,5,6,7,12,14,15
Cervidae					
Blastocerus dichotomus (Illiger, 1815)	VU	Suçuapara / Marsh Deer	Ce, Pt	Io, I	L3,13,14
Mazama americana (Erxleben, 1777)		Veado-mateiro / South American Red Brocket	Am, MA, Ce, Pt	V, I	L3,L6,3,4,5,7,12,13,14,15
Mazama gouazoubira (G. Fischer, 1814)		Veado-catingueiro / South American Brow Brocket	Am, MA, Ce, Ca, Pt, Pp	V, I	L2,L3,L6,3,4,5,6,7,12,13,14,15
Mazama nemorivaga (F. Cuvier, 1817)		Veado-foboca / Amazonian Brown Brocket Deer	Am	V, I	4
Ozotoceros bezoarticus (Linnaeus, 1758)	VU	Veado-galheiro / Pampas Deer	Ce, Pt, Pp	Io, I	L3,4,12,13,14
RODENTIA					
Sciuridae					
Sciurus aestuans Linnaeus, 1766		Quatipuru / Brazilian Squirrel	Am	C	L3,L6,L8,3,4,5,7,14,15
Cricetidae					
Calomys expulsus[3] (Lund, 1841)		Rato-do-chão / Caatinga Laucha	Ce, Ca	C	L3,4,7,9,10,11,12,13,14,15
Cerradomys scotti (Langguth & Bonvicino, 2002)		Rato-do-mato / Lindbergh's Rice Rat	Ce, Pt	C	L3,5,9,10,11,13,14,15

Table 2. Checklist of non-volant mammal species registered as occuring in the state of Maranhão, Brazil. *(to be continued)*

TAXON	THREAT CATEGORY	COMMON NAME	BIOME	TYPE OF RECORD	SAMPLING LOCATION
Hylaeamys megacephalus (G. Fischer, 1814)		Rato-do-mato / Azara's Broad-headed Rice Rat	Am, MA, Ce, Pt	C	L8,5,9,12
Holochilus sciureus Wagner, 1842		Rato-d'água / Amazonian Marsh Rat	Am, Ce, Ca	C	L6,1,2,3,11
Necromys lasiurus (Lund, 1841)		Rato-do-mato / Hairy-tailed Akodont	Am, MA, Ce, Ca, Pt, Pp	C	L3,L6,1,3,4,7,8,11,12,13,14
Nectomys rattus (Pelzeln, 1883)		Rato-d'água / Amazonian Water Rat	Am, Ce, Ca, Pt	C	L3,L6,L8,3,4
Oecomys cf. *bicolor* (Tomes, 1860)		Rato-da-árvore / White-bellied Arboreal Rice Rat	Am, Ce, Pt	C	L3,L6,3,4,5,9,11,12,13
Oligoryzomys cf. *nigripes* (Olfers, 1818)		Rato-do-mato / Black-footed Colilargo	MA, Ce, Ca, Pt, Pp	C	L6,L8,1,3,4,5,9,10,11,12,14
Rhipidomys emiliae (J. A. Allen, 1916)		Rato-da-árvore / Eastern Amazon Climbing Mouse	Am	C	L3,L6,L8,3,4,9,13
Rhipidomys cf. *macrurus* (Gervais, 1855)		Rato-da-árvore / Long-tailed Climbing Mouse	Ce, Ca	C	5,10,14
Thalpomys cf. *lasiotis* (Thomas, 1916)		Rato-do-chão / Hairy-eared Mouse	Ce	C	13
Wiedomys pyrrhorhinos (Wied-Neuwied, 1821)		Rato-de-fava / Red-nosed Mouse	Ca	C	9,10,11
Caviidae					
Galea spixii (Wagler, 1831)		Preá / Spix's Yellow-toothed Cavy	Am, MA, Ce, Ca, Pt	V, I	L3,L6,1,3,4,5,6,7,13,14,15
Hydrochaeris hydrochaeris (Linnaeus, 1766)		Capivara / Capybara	Am, MA, Ce, Ca, Pt, Pp	V, Io, I	L3,L6,L8,2,3,4,5,12,13,14,15
Kerodon rupestris (Wied-Neuwied, 1820)	VU	Mocó / Rock Cavy	Ca	V, I	L3,L4,9,11,12,13,14
Cuniculidae					
Cuniculus paca (Linnaeus, 1766)		Paca / Spotted Paca	Am, MA, Ce, Ca, Pt, Pp	V, Io, I	L2,L3,L6,1,2,3,4,5,6,7,9,11,12,13,14,15
Dasyproctidae					
Dasyprocta prymnolopha Wagler, 1831		Cutia / Black-rumped Agouti	Am, MA, Ce, Ca	V, Io, I	L2,L3,L6,L8,1,2,3,4,5,6,7,8,9,11,12,13,14,15

Table 2. Checklist of non-volant mammal species registered as occuring in the state of Maranhão, Brazil. *(conclusion)*

TAXON	THREAT CATEGORY	COMMON NAME	BIOME	TYPE OF RECORD	SAMPLING LOCATION
Erethizontidae					
Coendou prehensilis (Linnaeus, 1758)		Ouriço, porco-espinho / Brazilian Porcupine	Am, MA, Ce, Ca, Pt	V, Io, I	L3,L4,L6,3,4,5,7,9,10,11,12,13,14,15
Echimyidae					
Dactylomys cf. *dactylinus* (Desmarest, 1817)		Toró, rato-do-bambu / Amazon Bamboo Rat	Am	C, V, I	L4,L6,L8,3,4,15
Echimys chrysurus (Zimmermann, 1780)		Rato-da-árvore / White-faced Spiny Tree-rat	Am	C, V	L1,L3,L4,L6,L8,3,4,7
Makalata cf. *didelphoides*		Rato-coró / Red-nosed Armored Tree-rat	Am	C, I	L3,L6,L8,1,3,4,5,9,13,15
Proechimys roberti Thomas, 1901		Rato-de-espinho / Robert's Spiny-rat	Am, Ce	C, I	L3,L6,L8,1,2,3,4,5,7,9,12,13,14,15
Thrichomys laurentius (Thomas, 1904)		Punaré, rabudo / São Lourenço's Punaré	MA, Ca	C, I	L3,5,7,8,10,11,12,13,14
LAGOMORPHA					
Leporidae					
Sylvilagus brasiliensis (Linnaeus, 1758)		Coelho, tapeti / Tapeti	Am, MA, Ce, Ca, Pt, Pp	V, Io, I	L3,L6,3,4,5,7,9,11,12,13,14,15

Legend: Species under taxonomic revision: [1] = *Dasypus beniensis* (FEIJO & CORDEIRO-ESTRELA, 2016); [2] = *Conepatus amazonicus* (FEIJÓ & LANGGUTH, 2013); [3] = *Calomys mattevii* (GURGEL-FILHO et al., 2015); Threat category (ICMBio, 2018): CR = Critically Endangered, EN = Endangered, VU = vulnerable; Biome: Am = Amazon, MA = Mata Atlântica/Atlantic Forest, Ce = Cerrado, Ca = Caatinga, Pt = Pantanal, Pp = Pampas; End BR = Endemic to Brazil; Type of Record: C = capture, V = direct observation/camera-trap, Io = indirect observation/tracks or remains, I = Interview; Sampling locations: L1 = OLIVEIRA & MESQUITA (1998), L2 = OLIVEIRA & BOGÉA (2004), L3 = OLIVEIRA et al. (2007a), L4 = OLIVEIRA et al. (2007b), L5 = GARDNER et al. (2008), L6 = OLIVEIRA et al. (2011), L7 = MESQUITA & MENESES (2015), L8 = PATTON et al. (2015), L9 = PRIST et al. (2017), 1 = Ilha de São Luís, 2 = Baixada Maranhense, 3 = Região do Gurupi, 4 = Região do Bico do Papagaio e adjacências, 5 = Região dos cocais, 6 = Região dos Lençóis Maranhenses, 7 = Cerrados de Urbano Santos/MA, 8 = Região de Coelho Neto/MA, 9 = Região de São Francisco do Maranhão, 10 = Região de Barão de Grajaú/MA, 11 = Região de Benedito Leite/MA, 12 = Região de Tasso Fragoso/MA, 13 = Parque Estadual do Mirador, 14 = Região de Estreito-Carolina/MA, 15 = Região de Porto Franco/MA.

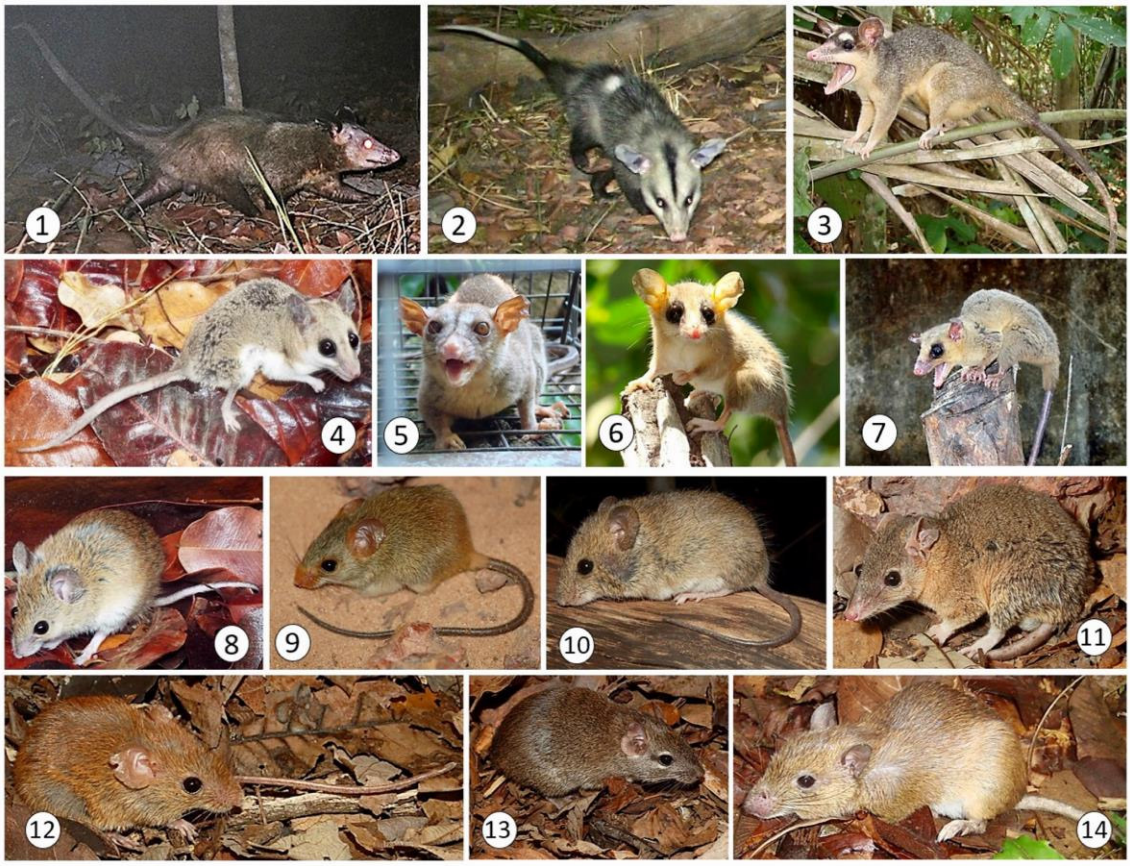


Figure 2. Records of small non-volant mammalian species in Maranhão state, Brazil. 1 = *Didelphis marsupialis*, 2 = *Didelphis albiventris*, 3 = *Phylander opossum*, 4 = *Thylamis karimii*, 5 = *Caluromys philander*, 6 = *Gracilinanus agilis*, 7 = *Marmosa (Micoureus) demerarae*, 8 = *Thalpomys cf. lasiotis*, 9 = *Wiedomys pyrrhorhinos,* 10 = *Calomys expulsus*, 11 = *Monodelphis domestica,* 12 = *Cerradomys scotti,* 13 = *Thrichomys laurentius,* 14 = *Proechimys roberti*

Figure 3. Records of medium and large non-volant mammalian species in Maranhão state, Brazil. 1 = *Tamandua tetradactyla,* 2 = *Myrmecophaga tridactyla,* 3 = *Priodontes maximus,* 4 = *Dasypus novemcinctus,* 5 = *Cyclops didactylus,* 6 = *Eira barbara,* 7 = *Lycalopex vetulus,* 8 = *Cerdocyon thous,* 9 = *Speothos venaticus,* 10 = *Nasua nasua,* 11 = *Procyon cancrivorus,* 12 = *Conepatus semistriatus,* 13 = *Galictis cuja,* 14 = *Galictis vitatta,* 15 = *Lontra longicaudis,* 16 = *Leopardus colocola,* 17 = *Herpailurus yagouaroundi,* 18 = *Puma concolor,* 19 = *Leopardus wiedii,* 20 = *Leopardus tigrinus,* 21 = *Leopardus pardalis,* 22 = *Panthera onca,* 23 = *Sapajus apella,* 24 = *Aotus azarae infulatus,* 25 = *Chiropotes satanas,* 26 = *Cebus kaapori,* 27 = *Alouatta caraya,* 28 = *Callithrix jacchus,* 29 = *Saguinus niger,* 30 = *Ozotoceros bezoarticus* , 31 = *Mazama americana,* 32 = *Mazama gouazoubira,* 33 = *Tayassu pecari,* 34 = *Pecari tajacu,* 35 = *Tapirus terrestris,* 36 = *Dasyprocta prymnolopha,* 37 = *Cuniculus paca,* 38 = *Coendou prehensilis,* 39 = *Hydrochaeris hydrochaeris.*

Table 3. Comparison of non-volant mammal species richness for recent in Brazil and the states of Maranhão (MA), Mato Grosso do Sul (MS), Mato Grosso (MT), São Paulo (SP), Rio de Janeiro (RJ) and Santa Catarina (SC).

ORDER	Brazil		States					
	Paglia et al. 2012	Quintela et al. (in press)	MA	MS	MT	SP	RJ	SC
Didelphimorphia	55	59	13	17	31	24	14	17
Pilosa	8	12	5	2	5	3	4	4
Cingulata	11	12	7	7	9	5	5	5
Primates	118	125	11	6	26	10	9	3
Carnivora	33	35	20	20	21	17	17	26
Perissodactyla	1	2	1	1	1	1	1	1
Cetartiodactyla	10	10	7	6	7	8	4	7
Rodentia	234	255	24	33	67	58	49	54
Lagomorpha	1	2	1	1	1	1	1	1
Total	**471**	**512**	**89**	**93**	**168**	**127**	**104**	**118**

MA = this paper; MS = TOMAS et al. (2017); MT = BRANDÃO et al. (2019); SP = VIVO et al. (2011); RJ = ROCHA et al. (2004); SC = CHEREM et al. (2004);

Discussion

Systematic biological inventories are essential for assessing the conservation status of a region's biodiversity and help in providing guidelines to select priority areas for environmental protections (DINIZ-FILHO et al. 2004; JENKINS et al., 2015). The current study employed different approaches to collecting information regarding mammal species occurrence in Maranhão in order to create the most comprehensive state checklist possible. Nonetheless, and despite all of the evidence considered in elaborating the resulting checklist, it is likely that the actual species richness of non-volant mammals for the state of Maranhão is somewhat greater than what is reported here.

Compared to previously published information, the checklist based on the current assessment adds 4 unique records for the state of Maranhão. Oliveira et al. (2007a, 2011) listed 82 species as occurring in Maranhão, while Lima (2009) added one important record of Tolypeutes tricinctus, species present in the Nascentes do Rio Parnaíba National Park, the area of which is mostly located within the state boundary of Piauí state and extends into just a small part of Maranhão. Although less representative quantitatively, Oliveira & Mesquita (1998), Oliveira & Bogéa (2004), Oliveira et al. (2007b), Gardner (2008), Mesquita & Meneses (2015), Prist et al. (2017) and Patton et al. (2015) were also consulted, corroborating the occurrence of

the species already described for some of the study locations. The last two of these publications represent complete taxonomic revisions and result from international collaborations to most accurately define the identification, distribution and taxonomy of South American mammal species as a whole.

Non-volant mammal species richness in Maranhão in the Amazon (N = 65) and Cerrado (N = 66) regions of Maranhão is similar. This represents 16.3% and 26.3% respectively, of the total species diversity for this group at the national level. Nineteen species were recorded at more than 10 of the study sites, corroborating their characterization as generalists occurring in all of dominant landscapes of Maranhão. Among the 16 that Paglia et al. (2012) listed as being exclusive to the Amazon (Table 2), only *Choloepus didactylus*, *Cebus kaapori*, *Chiropotes satanas*, *Mazama nemorivaga* and *Marmosops* cf. *parvidens* were recorded exclusively in the Amazonian portion of the state. *Didelphis marsupialis*, *Sapajus apella*, *Aotus azarae infulatus*, and *Sciurus aestuans* were recorded outside the Amazon domain, thus confirming their expected presence in forested areas beyond the Amazon-Cerrado ecotone (FEIJÓ & LANGGUTH, 2013; PINTO & ROBERTO, 2016; LIMA et al., 2017; PATTON et al., 2015). *Rhipidomys emiliae*, *Dactylomys* cf. *dactylinus* and *Makalata* cf. *didelphoides* complete the list of Amazonian species recorded in forested areas within savanna landscapes, thus highlighting the role of these forests as corridors that allow the expansion of small Amazonian mammals into the Cerrado (REDFORD & FONSECA, 1986; COSTA, 2003, CARMIGNOTTO, 2005). *Echimys chrysurus* is the last Amazonian species to reach the forest formations in the Cerrado biome, between the municipalities of Urbano Santos and Vargem Grande, clearly because of the deciduous forests in that region (OLIVEIRA & MESQUITA, 1998).

Maranhão state houses 20 species endemic to Brazil (Table 2). It is worth noting the case of Primates, with four out of five species being associated to the Amazonian portion of the state, which currently faces a critical conservation outlook (OLIVEIRA et al., 2011). *Cebus kaapori* and *Chiropotes satanas* were recorded in areas of primary and disturbed forests, besides this they are both rare and highly threatened throughout their range (ALMEIDA & VIEIRA, 2010). *Saguinus niger* has a range similar to *C. kaapori* and *C. satanas* within the state, nevertheless the species was recorded more often in disturbed habitats, and this species tends to be common in anthropic environments (MENDES-OLIVEIRA, 1996). *Thylamys karimii*, has been reported on the western portion of Maranhão state in the Bico do Papagaio region, yet its single record was in a marginal

portion of that region, in open areas of Cerrado savanna as expected (CARMIGNOTTO & MONFORT, 2006; GARDNER, 2008). *Lycalopex vetulus* and *Thalomys lasiotis* were recorded only in the Cerrado portion of the state; both species are typically associated to the central Cerrado further south, however *L. vetulus* has been expanding its range towards the north and northeast regions of the country, and the same seems likely for *Thalomys lasiotis* (MARINHO-FILHO et al., 2002; DALPONTE 2009; LEMOS et al., 2013). Three species were recorded marginally outside their typical biomes, *Wiedomys pyrrhorhinos*, *Kerodon rupestris* and *Callithrix jacchus*, the first two outside the Caatinga (OLIVEIRA et al., 2003; GONÇALVES et al., 2005; OLIVEIRA & BONVICINO, 2011), while the last one outside the Atlantic Forest. *C. jacchus* is an introduced species (DA ROSA et al., 2017) that has reached the central part of the Maranhão Babaçú Forest ecoregion, this area has witnessed major habitat destruction particularly in the Itapecuru river basin (SILVA JR., 1999).

Certain species that are most often associated with open habitats in the state, such as *Cerdocyon thous* (recorded at all sampling points), *Lycalopex vetulus* and *Galictis cuja*, showed that their actual distributions can extend beyond the proposed limits of savanna or grassland type environments. Nonetheless, these unusual occurrences may be best explained by the effects of expanding agro-pastoral environments on the displacement of both generalists and highly specialized species, which show some tendencies to disperse from disturbed areas through open habitat formations (MICHALSKI & PERES, 2005; UMETSU & PARDINI, 2007; OLIVEIRA, 2009).

Among the rare species for Maranhão, *Blastocerus dichotomus* stands out with its distribution reaching the southern limits of the state where there are well-preserved areas of Cerrado near Chapada das Mesas and Nascentes do Parnaíba National Parks. *Tolypeutes tricinctus*, a threatened species that is relatively sensitive to anthropogenic disturbances, was documented by means of personal interviews in the region of Urbano Santos and Mirador State Park, though in the latter, it has apparently not been seen for 20 years. *Alouatta ululata* is usually found in open and transitional babaçu forests (GREGORIN, 2006), yet we recorded this species in the Amazonian region, far west than its known distribution limit. The occurrence of species outside of their proposed distributions, according to the literature, highlights the ecotone effects of the terrestrial environment in Maranhão, which also contributes to the high levels of biodiversity and shows that this transitional zone among several biomes can appear to be much more

species rich than when considering these biomes separately (MARIMON et al., 2006; MEWS et al., 2012; MARIMON et al., 2014).

Considering only the list of species, independent of the size of the sampling areas, Oliveira et al. (2010) recorded 57 non-volant mammal species in an inventory of Mato Grosso state, which is also characterized as a transitional area between the Amazon and Cerrado biomes and is located in the middle of a region known as the Amazonian Deforestation Arc for its high deforestation rates. Comparing these biomes separately, an inventory conducted in Amazonia National Park, located in the state of Pará, compiled a list of 86 species in an area 10 times smaller than the territory of Maranhão (OLIVEIRA et al., 2016), while 52 species were registered just in Mirador State Park, which includes only 2% of all Cerrado vegetation occurring in the state of Maranhão (OLIVEIRA et al., 2014).

In spite of the diverse criteria, as well as constant updates to the list, the Amazon and Cerrado biomes support at least 399 and 251 mammal species, respectively (PAGLIA et al., 2012). However, it is also observed that states closer to major urban centers, and where most researchers are concentrated, register numbers of species close to those observed in the current study. For example, in Mato Grosso do Sul, a very large state territory presenting a diversity of biomes, including Cerrado, Atlantic Forest and Pantanal, Tomas et al. (2017) compiled a list of 93 species. Recently Brandão et al. (2019) listed 168 non-volant mammals for Mato Grosso, a state straddling the Amazon-Cerrado ecotone. Cherem et al. (2004) elaborated a list of 118 non-volant species occurring in the state of Santa Catarina, while Rocha et al. (2004) documented 104 species for the state of Rio de Janeiro, the latter presenting fewer biomes and fauna typical of Atlantic Forest. In São Paulo, a state with a much greater tradition of executing biological inventories, Vivo et al. (2011) compiled a list of 127 non-volant mammal species, which suggests that the species diversity so far recorded for the state of Maranhão is representative, although with significant gaps in the effort to sample such an enormous habitat diversity as that presented by the two dominant biomes. It should also be mentioned that very few scientific studies of non-volant mammals occurring in the state of Maranhão have been published in the primary literature, with much of the available information on this subject having appeared in unconventional outlets and/or formats, such as technical and research reports, dissertations, theses and congress proceedings with restricted disclosure and dissemination, contributing to our collective lack of comprehensive information about this group of animals.

The interaction between geomorphological and climatic aspects typical of ecotones favors the evolutionary process of genetic and ecological diversification in communities and populations (BRASIL, 2007). Thus, the relatively large number of mammal species presented here as occurring in Maranhão is a direct reflection of the state being located in a transitional region between three major biomes, the Amazon, Caatinga and Cerrado. Because of this high-level of species richness and diversity of habitats, Maranhão requires special consideration in conserving the integrity of these dynamic and not very stable environments (Marimon et al. 2014). The presence of such an ecological stress zone would also justify the observation of a non-diminishing west-east trend in species richness, whereby the most diverse mammal communities are located in lowland forests along the Amazon basin to the Andes and less species diversity is characteristic of the drier, more easterly boundaries of the region toward Pará-Maranhão (EISENBERG & REDFORD, 1999).

Finally, it is noteworthy that Maranhão is currently being subject to intense habitat fragmentation, primarily due to the impacts of expanding commercial farming and livestock activities. The study sites sampled for the current study correspond to habitat remnants that act as vital refuges for non-volant mammals and countless other wildlife species. Considering that landscape integrity is a good indicator of biodiversity, conservation actions in such areas, even fragmented landscapes, are of fundamental importance to the protection of natural resources and the variety of flora and fauna (DE ARAÚJO et al., 2016; BRAZIL 2018). Additional studies of the mammalian fauna of Maranhão, and other parts of the Northeast region of Brazil, are necessary for a better understanding of species diversity, abundance and distribution. The lack of information, both taxonomic and geographical, regarding non-volant mammals of Maranhão also reinforces the need for further work, such as that presented here, which can result in more accessible scientific publications that document the important biodiversity occurring in this rapidly changing landscape.

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Capítulo 2[1]

Non-volant mammalian species composition in the Amazon, Cerrado, and Caatinga ecotone of Brazil's midnorth.

[1] Capítulo a ser submetido aos Anais da Academia Brasileira de Ciências

Introduction

Since the discovery of the latitudinal diversity gradient, one of the first ecological patterns to be observed, up to the present day there have been several heuristic theories seeking to understand spatio-temporal patterns of biodiversity (ROSENZWEIG, 1995; HAWKINS, 2001; MAGURRAN, 2004). However, these patterns are often difficult to discern due to knowledge gaps in species richness and relations in certain areas (WHITTAKER et al., 2005). Biodiversity is not evenly nor randomly distributed on Earth. There are areas with exceptionally high species diversity, and these patterns are strongly influenced by ecological and historical characteristics. In this context, the so-called endemism areas deserve attention, as they are considered part of the primary biogeographic homology hypothesis (MORRONE, 2001).

The Neotropical region has a high species richness and endemism and is where seven of the 35 biodiversity hotspots are located (TUNDISI & TUNDISI, 2008; WILLIAMS et al., 2011). In Brazil specifically there are three main vegetation formations: (i) forests, represented by the Amazon and Atlantic Forest biomes; (ii) savannas in the Cerrado, Caatinga, and Pantanal; (iii) the praires in the Pampas (IBGE, 2012). The Amazon and the Atlantic forests were connected in the past due to a favorable climate through oscillatory periods during the Quaternary, in the so called Pleistocene Refugia, with several studies supporting this (HAFFER, 1969; WANG et al., 2004; TCHAICKA et al., 2007; CABANNE et al., 2008; MARTINS et al., 2009; VILAÇA & SANTOS, 2010).

In the Amazonian region of the Brazilian Midnorth lies the Belém Center of Endemism, one of the most biodiverse and threatened areas in the entire Amazon (OLIVEIRA et al., 2011). Adjacent to it, the savannas of the Cerrado are still poorly known, nevertheless they suffer from the highest rates of habitat loss in the entire country (BRAGANÇA, 2016; BEZERRA, 2018). The ecotone formed by these two biomes gives the Midnorth region of Brazil a high species richness.

Comparing the species composition of different areas is challenging, as there are issues such as survey effort, area size, and environmental characteristics that need to be taken into account. Not to mention the taxonomic uncertainties of some taxa (POMBAL, 1995). The gallery forests in the Cerrado for example, are considered biological corridors for forest species and relicts from the Amazon and Atlantic

forests, but could they influence the similarity between mammalian communities? The Brazilian Mid-north region lacks in-depth mammalian studies (REDFORD & FONSECA, 1986; HAFFER, 1969; VIEIRA & OLIVEIRA, 2020), which makes it impossible to disregard any of the scarce mammalian inventories carried out in the region.

Despite the difficulty in comparing faunas, we found ways to justify similarities or differences between assemblages of non-volant mammals based on the region´s biogeography. Thus, our objective was to describe the species composition of nonvolant mammals in Brazil´s Midnorth, adding information about the biogeographic distribution as a way of making comparisons possible with adjacent domains.

Materials and methods:

Study site

Our study area corresponds to Maranhão state, which represents most of Brazil´s Midnorth region (Figure 1). The state´s relief dates back to the beginning of the Paleozoic through the end of the Mesozoic era, It is rugged in the south (highest point at Chapada das Mangabeiras = 809 m asl) and becomes flatter towards the Atlantic Ocean. The vast majority of the state (72.8%) is composed of plains with elevations lower than 200 m asl. Rugged terrain with elevations above 600 m asl represent just 3.1% of the state´s surface. There are five major geomorphological formations: (a) *chapadões*, plateaus which are concentrated in the south; (b) small peaks along flat surfaces as a result of erosion cycles, predominantly in the central and coastal regions; (c) alluvial plains where the main rivers of the region converge; (d) *lençois maranhenses,* composed of sand dunes, lagoons, and shrubby vegetation known as *restingas*, in the eastern coastline; (e) western coastline, covered by mangroves. The region´s proximity to the Equator, coupled with its location between the Amazon (hot and humid) and the drier Cerrado, the influence of the Atlantic ocean, the relief and the vegetation cover result in a transitional climate from humid to semi-arid. Annual mean temperature ranges between 21.8 °C and 31.9 °C; annual mean rainfall ranges from 800 mm to 2800 mm (MARANHÃO, 2002).

Data analysis

We analyzed the species records from “Non-volant mammalian species richness in the ecotonal Brazilian midnorth: checklist for Maranhão State” de Vieira & Oliveira (2020). In that work, the nonvolant mammals of 15 study sites across the state, were analyzed. The study sites covered the Amazon and Cerrado regions of the state, as well as areas of transitional vegetation between both biomes. All species were classified by conservation status, and taxonomic classifications were based on seguiram Paglia et al. (2012), Brandão et al. (2015), Gardner (2008), Miranda et al. (2015), Patton et al. (2015), Percequillo et al. (2015), Quintanela et al. (2020). The checklist includes native species only, and the threat classification followed IUCN criteria (ver.13 – IUCN, 2020), also used in 2018 by the Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio) to conduct the threat assessments of Brazilian wildlife.

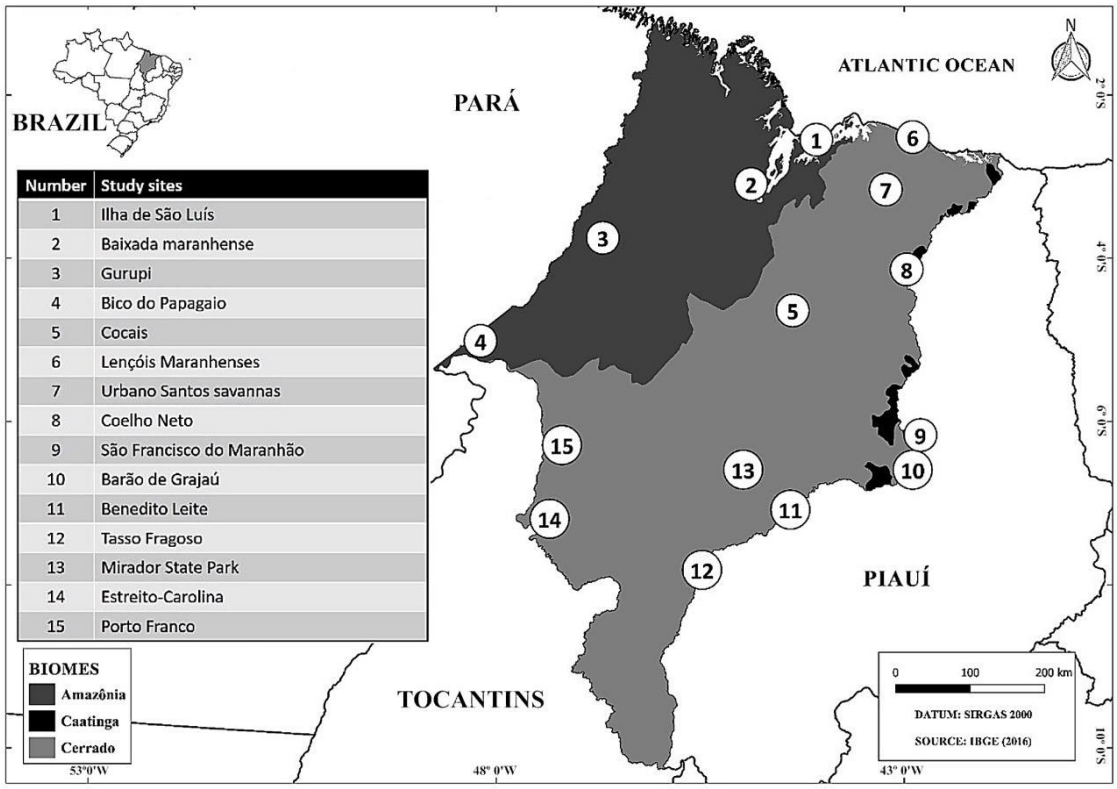

Figure 1. Study site locations in Maranhão State, Brazil´s Midnorth.

Data from IBGE (2012) were used to classify the different vegetation types found in the region: Dense evergreen forest, open evergreen forest, semideciduous seasonal forest, Cerrado (savanna), transitional vegetation formations, vegetation refugia, pioneer vegetation, and secondary vegetation (Table 1). For ecoregion

classification, we followed Arruda (2003). To compare nonvolant mammal communities among the different vegetation formations, we run a similarity analysis using Jaccard Index (MAGURRAN, 2004).

Table 1. Record distribution by biome. ecoregion. and phyto-ecological regions.

Site ID	Biome	Ecoregion	Phyto-ecological region
1	Amazon	Tocantins-Araguaia-Maranhão Moist Forests	Secondary forest
2	Amazon	Tocantins-Araguaia-Maranhão Moist Forests	Wetlands (secundary)
3	Amazon	Tocantins-Araguaia-Maranhão Moist Forests	Evergreen rainforest
4	Amazon	Tocantins-Araguaia-Maranhão Moist Forests	Evergreen rainforest
5	Amazon	Maranhão-Babaçú Forests	Secondary forest
6	Cerrado	Maranhão-Babaçú Forests	Pioneer vegetation
7	Cerrado	Maranhão-Babaçú Forests	Seasonal semideciduous forest
8	Cerrado	Maranhão-Babaçú Forests	Seasonal semideciduous forest
9	Cerrado	Cerrado	Seasonal semideciduous seasonal forest (secundary)
10	Cerrado	Cerrado	Cerrado/Caatinga ecotone (secundary)
11	Cerrado	Cerrado	Cerrado
12	Cerrado	Cerrado	Cerrado
13	Cerrado	Cerrado	Cerrado
14	Cerrado	Cerrado	Cerrado
15	Cerrado	Cerrado	Cerrado/Amazon ecotone (secundary)

To evaluate the influence of environmental variables on species distribution and the breath of environmental niche, we run a Principal Component Analysis (PCA) (HJIMANS et al., 2005). Species were grouped as occurring predominantly in the Amazon, Cerrado, or both biomes (PAGLIA et al., 2012). All analyses were conducted in R ver. 4.0 (R CORE DEVELOPMENT, 2020), using packages ‘factoextra’ (KASSAMBARA & MUNDT, 2020) and "FactoMineR"” (HUSSON ET AL., 2020). The variables used included elevation and 19 bioclimatic variables, the latter are derived from temperature (11 variables) and rainfall (8 variables) and were extracted from the WorldClim database (Table 2). Elevation was extracted from the United States Geological Survey.

Table 2. List of bioclimatic variables

Variable	Description
BIO 1	Annual Mean Temperature
BIO 2	Annual Mean Diurnal Range
BIO 3	Isothermality
BIO 4	Temperature Seasonality (Standard Deviation)
BIO 5	Max Temperature of Warmest Month
BIO 6	Min Temperature of Coldest Month
BIO 7	Annual Temperature Range
BIO 8	Mean Temperature of Wettest Quarter
BIO 9	Mean Temperature of Driest Quarter
BIO 10	Mean Temperature of Warmest Quarter
BIO 11	Mean Temperature of Coldest Quarter
BIO 12	Annual Precipitation
BIO 13	Precipitation of Wettest Month
BIO 14	Precipitation of Driest Month
BIO 15	Precipitation Seasonality
BIO 15	Precipitation of Wettest Quarter
BIO 16	Precipitation of Driest Quarter
BIO 17	Precipitation of Warmest Quarter
BIO 18	Precipitation of Coldest Quarter
BIO 19	Annual Mean Temperature

Results

We gathered 5.236 independent records of monvolant mammals in Maranhão, that comprised a total of 89 species (Table 3). This represents 12.70% of the total mammalian species richness proposed by Paglia et al. (2012) and 11.2% of that proposed by Quintanela et al. (2020). A total of 23 species (25.84%) are included in the Brazilian Red List of Threatened Species (ICMBio, 2018). Of these, the order Carnivora is the most representative (10 species), followed by primates (5 species) and Artiodactyla (3 species).

Table 3. Checklist of non-volant mammal species registered as occuring in the state of Maranhão, Brazil. *(to be continued)*

TAXON
DIDELPHIMORPHIA
Didelphidae
Caluromys philander (Linnaeus, 1758)
Chironectes minimus (Zimmermann, 1780)
Didelphis albiventris Lund, 1840
Didelphis marsupialis Linnaeus, 1758
Gracilinanus agilis(Burmeister, 1854)
Marmosa murina (Linnaeus, 1758)
Marmosops (Sciophanes) cf. *parvidens* (Tate, 1931)
Metachirus nudicaudatus (É. Geoffroy, 1803)
Marmosa (Micoureus) demerarae
Monodelphis americana (Müller, 1776)
Monodelphis domestica (Wagner, 1842)
Philander opossum (Linnaeus, 1758)
Thylamys karimii (Petter, 1968)
PILOSA
Bradypodidae
Bradypus variegatus Schinz, 1825
Cyclopedidae
Cyclopes didactylus (Linnaeus, 1758)
Megalonychidae
Choloepus didactylus (Linnaeus, 1758)
Myrmecophagidae
Myrmecophaga tridactyla Linnaeus, 1758
Tamandua tetradactyla (Linnaeus, 1758)
CINGULATA
Dasypodidae
Cabassous unicinctus (Linnaeus, 1758)
*Dasypus kappleri** Krauss, 1862
Dasypus novemcinctus Linnaeus, 1758
Dasypus septemcinctus Linnaeus, 1758
Euphractus sexcinctus (Linnaeus, 1758)
Priodontes maximus (Kerr, 1792)
Tolypeutes tricinctus (Linnaeus, 1758)
PRIMATES
Aotidae
Aotus azarae infulatus (Kuhl, 1820)
Atelidae
Alouatta ululata Elliot, 1912
Alouatta belzebul (Linnaeus, 1766)

Table 3. Checklist of non-volant mammal species registered as occuring in the state of Maranhão, Brazil. *(to be continued)*

TAXON
Alouatta caraya (Humboldt, 1812)
Callitrichidae
Callithrix jacchus (Linnaeus, 1758)
Saguinus niger (É. Geoffroy, 1803)
Cebidae
Cebus kaapori Queiroz, 1992
Sapajus apella (Linnaeus, 1758)
Sapajus libidinosus (Spix, 1823)
Saimiri sciureus (Linnaeus, 1758)
Pitheciidae
Chiropotes satanas (Hoffmannsegg, 1807)
CARNIVORA
Canidae
Cerdocyon thous (Linnaeus, 1766)
Chrysocyon brachyurus (Illiger, 1815)
Lycalopex vetulus (Lund, 1842)
Speothos venaticus (Lund, 1842)
Procyonidae
Nasua nasua (Linnaeus, 1766)
Potos flavus (Schreber, 1774)
Procyon cancrivorus (G. Cuvier, 1798)
Mustelidae
Eira barbara (Linnaeus, 1758)
Galictis cuja (Molina, 1782)
Galictis vittata (Schreber, 1776)
Lontra longicaudis (Olfers, 1818)
Pteronura brasiliensis (Gmelin, 1788)
Mephitidae
*Conepatus semistriatus** (Boddaert, 1785)
Felidae
Leopardus pardalis (Linnaeus, 1758)
Leopardus tigrinus (Schreber, 1775)
Leopardus wiedii (Schinz, 1821)
Leopardus colocolo (Molina, 1782)
Panthera onca (Linnaeus, 1758)
Puma concolor (Linnaeus, 1771)
Herpailurus yagouaroundi (É. Geoffroy, 1803)
PERISSODACTYLA
Tapiridae
Tapirus terrestris (Linnaeus, 1758)
CETARTIODACTYLA

Table 3. Checklist of non-volant mammal species registered as occuring in the state of Maranhão, Brazil. *(to be continued)*

TAXON
Tayassuidae
Tayassu pecari (Link, 1795)
Pecari tajacu (Linnaeus, 1758)
Cervidae
Blastocerus dichotomus (Illiger, 1815)
Mazama americana (Erxleben, 1777)
Mazama gouazoubira (G. Fischer, 1814)
Mazama nemorivaga (F. Cuvier, 1817)
Ozotoceros bezoarticus (Linnaeus, 1758)
RODENTIA
Sciuridae
Sciurus aestuans Linnaeus, 1766
Cricetidae
Calomys expulsus (Lund, 1841)
Cerradomys scotti (Langguth & Bonvicino, 2002)
Hylaeamys megacephalus (G. Fischer, 1814)
Holochilus sciureus Wagner, 1842
Necromys lasiurus (Lund, 1841)
Nectomys rattus (Pelzeln, 1883)
Oecomys cf. *bicolor* (Tomes, 1860)
Oligoryzomys cf. *nigripes* (Olfers, 1818)
Rhipidomys emiliae (J. A. Allen, 1916)
Rhipidomys cf. *macrurus* (Gervais, 1855)
Thalpomys cf. *lasiotis* (Thomas, 1916)
Wiedomys pyrrhorhinos (Wied-Neuwied, 1821)
Caviidae
Galea spixii (Wagler, 1831)
Hydrochaeris hydrochaeris (Linnaeus, 1766)
Kerodon rupestris (Wied-Neuwied, 1820)
Cuniculidae
Cuniculus paca (Linnaeus, 1766)
Dasyproctidae
Dasyprocta prymnolopha Wagler, 1831
Erethizontidae
Coendou prehensilis (Linnaeus, 1758)
Echimyidae
Dactylomys cf. *dactylinus* (Desmarest, 1817)
Echimys chrysurus (Zimmermann, 1780)
Makalata cf. *didelphoides*
Proechimys roberti Thomas, 1901
Thrichomys laurentius (Thomas, 1904)

Table 3. Checklist of non-volant mammal species registered as occuring in the state of Maranhão, Brazil. *(conclusion)*

TAXON
LAGOMORPHA
Leporidae
Sylvilagus brasiliensis (Linnaeus, 1758)

The species found in the Tocantins-Araguaia /Maranhão Humid Forests ecoregion are typically Amazonian, while those in the Cerrado ecoregion are associated with the homonymous biome. Species richness was greatest in the Tocantins-Araguaia / Maranhão Humid Forests (75), followed by the Cerrado ecoregion (74) and the Maranhão Babaçú Forests (59). These last two ecoregions showed a similarity of 72.7%, while the least similarity was between the two forest ecoregions (59.5%) (Table 4). Species richness was highest in evergreen forests (75 species), followed by Cerrado (72 species), secondary vegetation (68 species), seasonal semideciduous forests (45 species), and pioneer formations (21 species) (Table 5). Species similarity, as measured by Jaccard´s Index, was highest between secondary forests and Cerrado (Table 6). Dense evergreen forests also showed a high similarity with secondary vegetation, 67.1%. Species similarity was lowest between dense evergreen forests and pioneer vegetation formations, 26.3%.

Table 4. Similarity in species composition among ecoregions.

Jaccard Index	Tocantins-Araguaia-Maranhão Moist Forests	Maranhão-Babaçú Forests	Cerrado
Tocantins-Araguaia-Maranhão Moist Forests	**-**	**0.595**	**0.674**
Maranhão-Babaçú Forests		**-**	**0.727**
Cerrado			**-**

Table 5. Species richness by phyto-ecological region.

Phyto-ecological region	Richness
Evergreen rainforest	75
Cerrado	72
Secondary vegetation	68
Seasonal semideciduous forest	45
Pioneer vegetation	21

Table 6. Similarity in species composition among phyto-ecological regions.

Jaccard Index	Secondary Forest	Evergreen rainforest	Seasonal semideciduous forest	Cerrado	Pioneer vegetation
Secondary Forest	-	0.671	0.600	0.853	0.313
Evergreen rainforest		-	0.519	0.652	0.263
Seasonal semideciduous forest			-	0.581	0.404
Cerrado				-	0.274
Pioneer vegetation					-

When comparing the species composition among points within each phyto-ecological region, the highest similarity is found among points in the Gurupi region with 82.7% (Table 7). In the Cerrado biome, Mirador State Park and the Tasso Fragoso region have a similarity of 75.8%. The localities of Estreito-Carolina and Porto Franco, which are located in an ecotonal region, have a similarity of 69.6% in nonvolant mammal species. Within the Babaçú forests, the least similar sites were São Luís Island and the Baixada Maranhense region, with a similarity of only 37.0%. Finally, the species composition of Baixada Maranhense and Barão de Grajaú was highly different, with a similarity of just 13.3%. At the biomatic level, nonvolant mammal species richness was very similar among the two main biomes in the state, with 65 species for the Amazon and 66 for the Cerrado. This similarity was corroborated through the scatterplot from the principal component analysis (PCA), which further reinforces the idea that the study area is located in an ecotone between these biomes.

Table 7. Similarity in species composition among study sites.

Jaccard	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	0,370	0,353	0,329	0,339	0,406	0,380	0,407	0,349	0,216	0,279	0,271	0,242	0,339	0,345
2		1	0,191	0,171	0,231	0,259	0,208	0,227	0,175	0,133	0,222	0,208	0,164	0,180	0,189
3			1	0,827	0,526	0,271	0,507	0,155	0,342	0,141	0,269	0,469	0,500	0,549	0,573
4				1	0,538	0,286	0,562	0,169	0,355	0,184	0,299	0,558	0,588	0,620	0,653
5					1	0,358	0,655	0,226	0,545	0,333	0,414	0,672	0,677	0,667	0,656
6						1	0,404	0,400	0,250	0,167	0,209	0,309	0,317	0,311	0,340
7							1	0,311	0,411	0,294	0,382	0,548	0,585	0,625	0,638
8								1	0,200	0,296	0,216	0,250	0,200	0,217	0,185
9									1	0,341	0,548	0,466	0,438	0,409	0,377
10										1	0,405	0,309	0,254	0,311	0,268
11											1	0,464	0,391	0,385	0,306
12												1	0,758	0,667	0,603
13													1	0,696	0,662
14														1	0,730
15															1

Sites: 1 = São Luís Island, 2 = Baixada Maranhense, 3 = Gurupi region, 4 = Bico do Papagaio and adjacent regions, 5 = Cocais, 6 = Lençóis Maranhenses, 7 = Urbano Santos, 8 = Coelho Neto/MA region, 9 = São Francisco do Maranhão, 10 = Barão de Grajaú/MA, 11 = Leite/MA, 12 = Tasso Fragoso/MA, 13 = Mirador State Park, 14 = Estreito-Carolina/MA, 15 = Porto Franco/MA.

Discussion

1. Considerations about the natural environment of Maranhão State

The high species richness in Maranhão reflects successive historical events related to the geological evolution of the state´s territory (BROWN & LOMOLINO, 2006). However, a sample bias resulted in a high similarity between cerrado and Babaçu forests. Records from the Maranhão Babaçú Forests ecoregion are associated with open environment species, mainly due to the concentration of these records in the eastern part of the ecoregion, closer to the savannah and towards the Caatinga. Another possible explanation for this unexpected high resemblance can be explained by the similarity between the small mammal assemblage of these two ecoregions, given that the species that forest areas of the Cerrado share about 69% of species with the Amazonian domain (COSTA, 2003).

The phyto-ecological regions in the state do not form continuous patches, yet they repeat their life forms in similar environments. Our analysis suggests few differences in nonvolant mammal species composition among the four phyto-ecological regions:

secondary vegetation, evergreen dense forest, pioneer vegetation, and seasonal semi-deciduous seasonal forests. The low similarity observed between dense rain forest and pioneer formation is certainly due to the huge difference in the vegetative composition of these two regions. Secondary vegetation, despite dominating the state's vegetation cover, especially in the north-central area of Maranhão, is not the richest in species (DE ARAÚJO et al, 2016). These similarities can be explained by the fact that secondary vegetation lies in close proximity to both evergreen forests and Cerrado vegetation. Furthermore, secondary vegetation itself is the result of habitat loss in evergreen forests and Cerrado, there by also explaining the high similarity in species composition.

The greatest similarity observed, considering points located within the same phytoecological region, was among points located in the Gurupi region. This is because they are in a region within the limits of the Belém Center of Endemism, that despite extensive habitat loss continues to harbor pristine and dense forests. The justification for the greater similarity found in the cerrado phytoecological region, between the mastofauna of Mirador State Park and the region of Tasso Fragoso, is that these two regions are located in the same biome and notably close to each other. The high similarity found between the non-flying mastofauna between the points of Estreito-Carolina and Porto Franco is also a reflection of proximity and because they share the same ecotonal Amazon-Cerrado region. Babassu palm forests are associated with areas where the Amazon forest once existed, so their composition of non-flying mammal species should reflect this. The low similarity within the same phytoecological region as observed between Ilha de São Luís and Baixada Maranhense is çikely more related to faunal extinction in the Baixada region than to efforts employed. Although part of secondary vegetation, Baixada Maranhense and Barão de Grajaú are partially located in different biomes in the state, Amazon and Cerrado, which reflects in low similarity.

Despite knowledge gaps, prior research suggests some taxonomic groups have equivalent species among different biomes, for example in primates: *Alouatta belzebul* and *Alouatta caraya* or *Sapajus apella* and *Sapajus libidinosus* (SILVA JUNIOR, 2002; GREGORIN, 2006). On the other hand, some of the distributional patterns are still poorly defined, making it hard to establish range delimitations of some species, such as the opossums *Didelphis marsupialis* and *Didelphis albiventris* (GARDNER, 2008) or the grisons *Galictis cuja* and *Galictis vittata* (OLIVEIRA, 2009). The species

we recorded within the Amazon region of the state tend to be associated with this biome, but many are not exclusively found on it. The same is true for the species recorded within the Cerrado. There were few species whose range limits were in agreement with prior research, some examples include species listed as being exclusive to the Amazon: *Marmosops (Sciophanes)* cf. *parvidens*, *Dasypus kappleri*, *Cebus kaapori*, *Chiropotes satanas* and *Mazama nemorivaga*. Still, several species priorly defined as exclusive to the Amazon were recorded outside the biome limits and its transitional zone, some as far east as the Parnaíba river: *Didelphis marsupialis, Aotus azarae infulatus, Sapajus apella, Sciurus aestuans, Rhipidomys emiliae, Echimys chrysurus, Makalata* cf. *didelphoides*. Some species typically associated with the Cerrado were found throughout the state, disregarding the proposed biome limits, examples of this include *Gracilinanus agilis* and *Monodelphis domestica*. Records of *Chrysocyon brachyurus*, *Ozotoceros bezoarticus* and *Calomys expulsus* included localities in Bico do Papagaio which is within the limits of the Amazon biome (in an ecotonal area) but, nevertheless, all records came from savanna vegetation areas. Medium-sized mammals tended to occur throughout the entire state, which is expected as most of them have wide distributions. Some of the most commonly recorded species include *Tamandua tetradactyla*, *Euphractus sexcinctus*, *Cerdocyon thous*, *Procyon cancrivorus*, *Cuniculus paca* and *Dasyprocta prymnolopha*; all these species are generalists and are found in several habitats. Few of the study sites could be considered strongholds for some of the species, the major ones would be the Gurupi area (Biological Reserve and Indian Reservations) for some threatened primate species, and Mirador State Park. It is worth noting that the species distribution among forest and savanna environments reflects the periodic expansions and reductions of forests in South America during the recent past. This is supported by the disjunct distribution of *Alouatta belzebul*, *Cyclopes didactylus*, *Sciurus aestuans* and *Bradypus variegatus*, which are present in the Amazon and in the eastern Cerrado, towards the Atlantic Forests of northeast Brazil (VIVO, 1997).

Carmignotto (2005) found differences in the small mammal assemblages of forest and open environments in areas of Atlantic Forest, spliting the community into two distinct groups. This pattern was not observed in Maranhão, given the high similarity (77.5%) of the small mammal community in localities from the Amazon and Cerrado. As for phytoecological patterns, the species recorded in areas of secondary vegetation, with several stages of natural succession, were mostly forest species,

which denotes their adaptability to degraded areas. As expected, forest species predominated at sites located within dense evergreen and semi-deciduous seasonal forest. This pattern was also observed at sites within the Cerrado, certainly due to a combination of factors such as the presence of gallery forests, anthropic activities, and the presence of dry forests that intensify the wildlife similarity between the Amazon and Cerrado biomes.

The scatter plot from the principal component analysis (PCA) showed some environmental differences between species associated with the Amazon and the Cerrado, but with a certain degree of overlap between their respective groups (Figure 2). As for the species recorded in both biomes, there is extensive overlap with the Amazon and Cerrado clusters, further supporting the notion that the study area is located in an ecotone between these biomes. The first component explained 57.7% of the variation in the data, while the second component explained 18.4% of the variation (Figure 2). The variables that contributed most to the first component were: minimum temperature of the coldest month (7.53%), annual temperature range (7.28%), elevation (7.02%), mean temperature of the coldest quarter (6.90%), and precipitation of the wettest month (6.71%). For the second component, the most important variables were: mean temperature of the warmest quarter (19.87%), maximum temperature of the warmest month (10.96%), temperature seasonality (10.29%), mean annual temperature (9.31%) and precipitation in the driest quarter (7.65%).

These results suggest our sampling was extensive and covered the spectrum of habitats in the state. As such we found species that are forest-dependent, species that are savanna-dependent, and generalist species that thrive in both habitats.

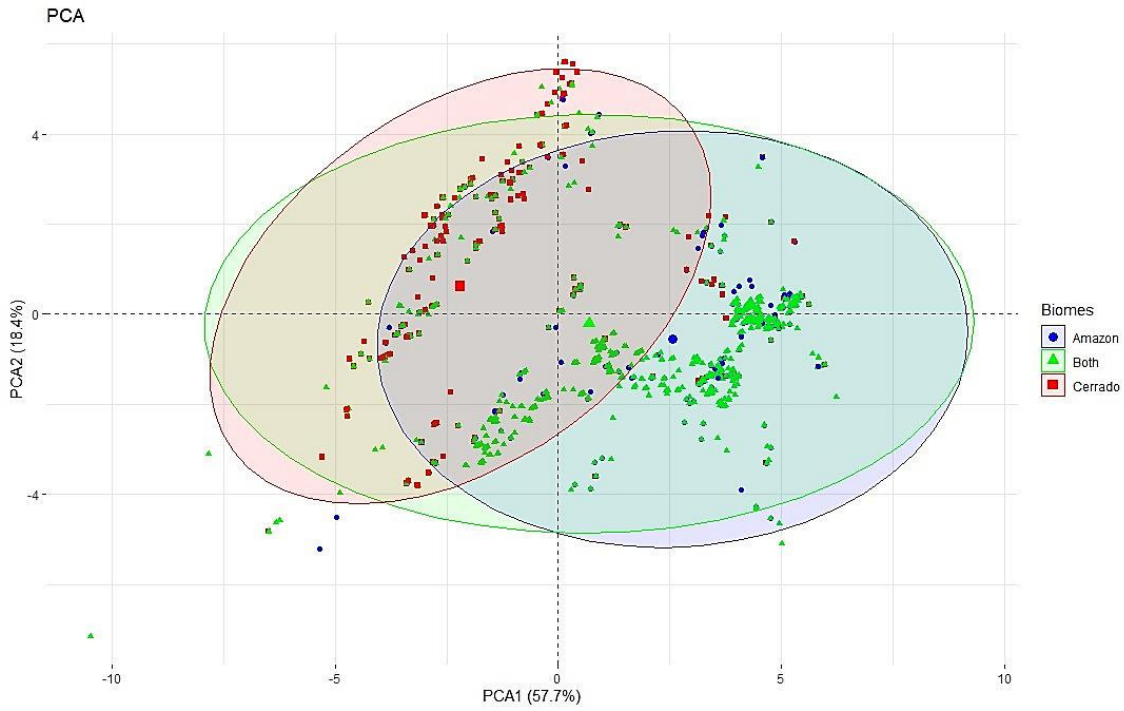

Figure 2. Principal Component Analysis scatterplot.

2. Ecotonal biogeographic uniqueness of nonvolant mammals in Maranhão state.

Order Didelphimorphia: Of the 13 species that occur in the state, only *Didelphis marsupialis*, *Didelphis albiventris* and *Gracilinanus agilis* showed an unusual distribution across the state. *D. marsupialis*, previously mentioned as exclusively Amazonian, has already had its presence registered, and here corroborated, in the Cerrado portion of the state (GARDNER, 2008; MELO & SPONCHIADO, 2012). Highly adapted to anthropogenic and generalist environments, *D. marsupialis* and *D. albiventris* illustrate the ecotonal aspects of Maranhão, where the former prefers wet forests while the latter is more frequent in deciduous forests or open areas typical of the Cerrado (CRUZ-SALAZAR et al. 2014; KRAUSE & KRAUSE, 2006; FOWLER, 2001). *Gracilinanus agilis* has a wide distribution in the Northeast and despite being more associated with open formations in the Cerrado and Caatinga, it was registered in the Amazon portion of the state, considerably expanding its distribution area as already reported by Oliveira et al. (2007).

Order Pilosa: of the eight species present in this order, five were recorded in our study. Of those, only the two-toed sloth (*Choloepus didactylus*) is an Amazon endemic

reported only for the Gurupi area, whereas the giant anteater seems to have a currently restricted distribution mostly tied to the protected areas in the Amazon and Cerrado. The silky anteater distribution is uncertain in Maranhão, likely due to sampling, but seems to be common in the mangrove parts. Miranda et al. (2017) reports that the *Cyclopes* genus comprises at least seven species, among which the 'Northeast' population, here represented by *Cyclopes didactylus*, probably on the right bank of the Amazon River for the states of Maranhão and Piauí. Tectonic and climatic events that occurred in South America during the tertiary and quaternary periods seem to have influenced the evolutionary history and separation of the Cyclopedidae and Myrmecophagidae families (DELSUC et al., 2004).

Order Cingulata: Maranhão has at least one representative from all Cingulata genera. It was previously recorded the unexpected presence of *Dasypus kappleri* (OLIVEIRA et al., 2007). *Priodontes maximus* shows a rather limited range in Maranhão, we recorded it only in protected areas of the Gurupi region and in unprotected areas of the middle Parnaíba, currently undergoing an expansion of agriculture (ANACLETO & MARINHO- FILHO, 2001). The species is currently perceived as extinct in Mirador area. *Tolypeutes tricinctus* is another threatened species and was also only recorded through interviews in conservation areas, notably Mirador State Park and Nascentes do Parnaíba National Park (LIMA, 2009).

Order Primates: Species of the genus *Alouatta* are more adaptable to changes in habitat to certain levels, allowing them to survive certain levels of fragmentation and degradation of the environment, and this is reflected in the distribution of *Alouatta* records in the state (BRAVO & SALLENAVE, 2003; MONTICELLI & MORAIS, 2015). The eastern limit of the disjunct distribution of *Alouatta belzebul* went far beyond the |Babassu palm forest in the state, expanding its distribution area to the Cerrado located in the middle course of the Parnaíba River (GREGORIN, 2016). The records of *Callithrix jacchus* between the Parnaíba River and the west bank of the Itapecuru River, close a knowledge gap for the species in the state (SILVA JR., 1999). *Aotus azarae infulatus* and *Sapajus apella* are two primates that, although present in the Cerrado and therefore no longer exclusive to the Amazon biome, appear as recent records for these savanna areas in the state (PINTO & ROBERTO, 2016; LIMA et al. 2017). Restricted to the Amazon, *Chiropotes satanas* is known only from the western region of the state, in Gurupi, Bico do Papagaio, and adjacent areas, where it uses both

pristine and disturbed forests, even though it is regarded as dependent on primary forests with high fruit productivity (PORT-CARVALHO et al., 2015; BUSS et al., 2017). Like *C. satanas*, *Saguinus niger* is also endemic to the Brazilian Amazon, occurring in the states of Maranhão and Pará (RYLANDS et al., 1993; RYLANDS & MITTERMEIER, 2008). Classified as Vulnerable, *S. niger* is mostly restricted to the western region of the state, although recent studies indicate the presence of this species in areas of the Amazon-Cerrado ecotone (GARBINO et al., 2015). It is not restricted to primary habitats, occurring at the edges of forest fragments, secondary forest and urban forest remnants with a certain degree of disturbance (BERGALLO et al., 2012). *Cebus kaapori*, described only in 1992, is a species so rare and difficult to observe that there is little data on its general biology as well as habitat use patterns (OLIVEIRA et al. 2014; FIALHO et al., 2015). This Eastern-Amazon endemic is found in the 'deforestation arch', mostly in the Gurupi area. It is considered the most threatened primate in the Amazon, due to the combination of a restricted geographical distribution, rarity, high hunting pressure and high environmental degradation in its area of occurrence. (FIALHO et al., 2015; BUSS et al. 2017).

Order Carnivora: of the 33 species of carnivores present in Brazil, 20 of them (grouped into five families) occur in Maranhão. Most of them have well defined and typically widespread distributions within the state, with the exception of *Potos flavus*, *Galictis vittata* and *Pteronura brasiliensis*. In Maranhão, Oliveira (2009) reported the occurrence of the two *Galictis* species associated with the Cerrado / Amazon ecotone, with *G. vittata* being restricted to Amazonia, whereas *G. cuja* occurs in the state's Cerrado biome and its transitional contact zone. We obtained several records of *G. cuja*, including some within the Amazonian portions of the state, where the species uses forest edges and areas severely altered and inhabited by man (at least 5 roadkill records near pasture areas). This range expansion can be associated with an increase in open vegetation formations due to changes in land use (MICHALSKI & PERES, 2005; OLIVEIRA, 2009). *Galictis vittata* is often found near water bodies and wetlands, preferring savanna and forest environments, but in Maranhão we only recorded the species in forested sites. Both *Galictis* species further support the notion of Brazil´s midnorth being an ecotone. The other mustelid, the giant otter (*Pteronura brasiliensis*), has a historically contradictory distribution in the state. In this study, we recorded the species in the Gurupi region, but the species was either already

considered absent in the state (RODRIGUES et al., 2013; IUCN 2015), exclusive to the Gurupi Biological Reserve (OLIVEIRA et al., 2007) or with specific records in the Mearim- Grajaú (SILVA-JÚNIOR, 2001) or in the municipality of Buriticupu (PRIST et al., 2017). *Potos flavus* has a wide distribution in the Amazon (EMMONS & FEER, 1997; EISENBERG & REDFORD, 1999), but we have very limited records of this species. The Mephitidae hog-nosed skunk (*Conepatus semistriatus*) is spreading its range into the Amazon, as a consequence of habitat conversion (Oliveira et al. 2007). Of the seven species of the Felidae family found in the state, *Leopardus colocola* is the rarest, being restricted to the Cerrado environments of south-central Maranhão. This is the order with the greatest number of threatened species, as half of all carnivores in the state are in the Brazilian Red List of Threatened Species (ICMBio, 2018). Habitat loss, disease transmission by domestic carnivores and retaliatory killing are the main threats to felids in Maranhão.

Order Perissodactyla: The Brazilian tapir, although with a widespread range in Brazil, in Maranhão has a rather restricted range. All records were restricted to the southern and extreme western regions. It occurs along the medium-upper course of the Parnaíba River as well as in the Estreito and Carolina region and throughout the Amazon. All these regions contain features such as gallery forests and seasonally flooded areas associated with permanent water sources, in which the tapir thrives (EISENBERG, 1989; MEDICI, 2014).

Order Cetartiodactyla: five species occur in the state and most are widely distributed, with the exceptions of *Blastocerus dichotomus* and *Mazama nemorivaga*. With the historic distribution of the species reaching the southern part of the state, *B. dichotomus* has recent records only for the Nascentes do Rio Parnaíba National Park (LIMA, 2009). There is also a historical record from the late 1990s from the Rio Farinha region (surrounding the Chapada das Mesas National Park). The species has been recorded as originally reaching as far north as the Cerrado of Mirador State Park area, where it is long extinct. Unlike the widely distributed *M. gouazoubira*, *M. nemorivaga* was only recorded in the transitional area of Bico do Papagaio. This species overlap had already been reported by Rossi (2010), when proposing sympatry between both species in the Amazon and transition areas of Maranhão and Mato Grosso. *Pecari tajacu* occurs in the two biomes of the state but is more common in the Amazon as well as along the medium-upper course of the Parnaíba River. *Tayassu*

pecari has a more restricted distribution in the state, being extinct in Mirador State Park area, and overall has a distribution similar to that of *B. dichotomus*. The more pristine areas of the Amazon in Maranhão are the main stronghold for *T. pecari*, as well as for *Mazama nemorivaga* and *Mazama americana*. Finally, the Cerrado/Pantanal's *Ozotocerus bezoarticus*, was also recorded in the Amazon-Cerrado ecotone area of Bico do Papagaio, besides the savannas of Mirador State Park.

Order Rodentia: Despite the difficulties of sampling this group in scientific studies, reflecting the high morphological diversity, 24 species belonging to 7 families, were recorded. Cases of possible expansion of distribution can be applied when we analyze the records of *Cerradomys scotti* and *Oligoryzomys* cf. *nigripes*, two rodents associated with forest and open formations that reached the Amazon-Cerrado ecotone in the Estreito-Carolina and Bico do Papagaio region. The tolerance to the modification of the habitat of these two species, including agricultural areas, can help in their dispersion beyond their usual occurrence (BONVICINO et al., 2017). Likewise, *Rhipidomys emiliae*, *Echimys chrysurus* and *Makalata* cf. *didelphoides*, typically Amazonian species, were recorded in typical Cerrado regions of the state, i.e., expanding its distribution in the state through the records of the medium course of the Parnaíba River and the Mirador State Park. Part of this is due to the role that gallery forests and dry forest patches played in the dispersion of small mammals from the Amazon and the Atlantic Forest to open formations associated with drier climates in the central and north / northeast regions from Brazil (COSTA, 2003; BEZERRA et al., 2005; CARMIGNOTTO, 2005).

Order Lagomorpha: There is only one species in Maranhão, *Sylvilagus brasiliensis*, and it has a wide distribution, being mostly found in forest edges. *S. brasiliensis* is one of the few species of the genus that occurs exclusively in Latin America, although recent studies indicate that this is, in fact, a species complex (RUEDAS et al. 2017; RUEDAS & SMITH, 2018).

Concluding remarks

The state of Maranhão is located in one of the three main ecotones in the country, the Cerrado-Amazon. The numbers presented here show a high beta diversity, response to environmental variations, notably the climate, vegetation and soil type. The mammalian species in Brazil's midnorth have a complex evolutionary history. Their ancestral lineages were influenced by several vicariance events associated with the great processes of reorganization of the regional landscape. The fauna of the Neotropical region is the result of several historical events, among them the periodic expansion and retraction of forests. The formation of the Panama isthmus made possible the exchange of flora and fauna between North and South America, with the eventual expansion of rainforests, and consequently the retraction of the Cerrado towards the central region of Brazil. However, topographic and river barriers made the dispersion of many species unfeasible. Evidence points out to climate and vegetation changes in the Neotropics during the Tertiary and Quaternary periods to explain the origin of the Amazon and Cerrado species in Brazil's midnorth. However, given the intense geomorphological dynamics of the Amazon, no hypothesis based on a single geological or paleoecological process will be sufficient to explain the biogeographic patterns observed in present day. Biogeography shows that the search for the origin of a biota starts from the study of the evolutionary history of endemic taxa, since the analysis of widely distributed taxa does not provide enough elements to discern the history of a phytogeographic region. However, it was not only the expansion-retraction events of the humid forests on the spaces occupied by open formations that contributed to the latter's biodiversity. Added to this is the effect of habitat loss on the abundance, movement patterns and persistence of many species in formerly unusual environments. And the similarity in mammalian species composition of the Amazon and Cerrado supports this for Maranhão state.

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Capítulo 3[2]

Assessing priority areas for mammalian conservation in the Amazon rainforest-savanna-semiarid shrub-woodlands ecotonal area of the Brazilian mid-north

[2] Capítulo a ser submetido ao Journal of Mammalian Evolution.

Introduction

Biodiversity is declining at an alarming rate, and it is likely that a high number of populations and species will become extinct within the next few decades (LOREAU LIU et al., 2006). As we enter a potential sixth mass extinction (BARNOSKY et al., 2011), it is imperative to efficiently allocate limited funding for conservation, so that we are able to preserve biodiversity in the long-term (LEAN & MACLAURIN, 2016).

Brazil is the most biodiverse country on Earth, with more than 13% of the World's species living within its borders (MMA, 2018). This high biodiversity is partly due to the fact that the country holds the largest tropical rainforest on Earth (the Amazon rainforest) and two of the largest biodiversity hotspots worldwide (the Atlantic Forest and the Cerrado) (MITTERMEIER & RYLANDS, 2018). Nevertheless, Brazil faces several challenges for biodiversity conservation. The country must resume its responsibilities related to the Convention of Biological Diversity/CBD, and it must also develop conservation actions that are cost efficient, maximizing the resources available (OLSON et al., 2002). This latter challenge is the most urgent, as although protected areas remain the most efficient way for biodiversity conservation, anthropogenic activities represent an increasing threat for them (COSTA et al., 2015; FEARNSIDE, 2017; SANTOS, 2018).

Habitat loss ranks among the main threats for ecosystems and their respective wildlife (IUCN, 2020). Among threatened species, mammals deserve special attention for assuming the role of "focal species", acting as conservation ambassadors of biodiversity in general. Combining several of these focal species could more adequately expand the inclusion of proper habitat and protection for a myriad of other species (LAMBECK, 1997).

The current state of need for biodiversity knowledge, coupled with an unstable financial scenario and an ever increasing rate of environmental devastation, heightens the need to develop strategies that could better take advantage of the information already available on the distribution of species and their environmental requirements (PHILLIPS et al., 2004; COSTA et al., 2010). In the last decade, advances in technology have resulted in a new field of study, applying geographic information systems to biodiversity conservation (SIQUEIRA, 2005). An array of modeling techniques has been developed to predict the geographic distribution of species based on the environmental characteristics of their areas of occurrence. Using a database of

species presence records, the models use extrapolations from algorithms to design areas suitable for the target species (ZIMMERMANN et al., 2010). One of the applications of distribution modeling is precisely to assist in determining priority areas for conservation (ORTEGA-HUERTA & PETERSON 2004; YOUHUA, 2009).

The Brazilian mid-north, despite its ecological uniqueness is under a series of major threats (PINHEIRO & DORNAS, 2009; ABAD, 2019). The Amazonian part is highly disturbed and is currently restricted to a meager 25% of the original formation, whereas the savannas of the Cerrado hotspot comprise Brazil's new agricultural frontier and have the highest rates of habitat removal in the country (LORENSINI et al. 2015; IMESC, 2019). In this threat scenario, the main effort to define conservation priorities was achieved through the project "Priority Actions for Biodiversity Conservation in Brazilian Biomes" (MMA, 2016). One of the pillars of this methodology is representativeness, a way of estimating the presence of species of interest. Through the geographic distribution of species, with the help of geographic information systems and predictive modeling, it is possible to identify important areas for the conservation of the taxonomic group of interest.

This study seeks to identify conservation priority areas in the ecotonal area of the Brazilian mid-north, focusing on the state of Maranhão, using a predictive modeling approach of terrestrial mammals threatened with extinction. In addition, it aims to identify whether there are areas relevant to the conservation of these animals in unprotected areas or outside areas already defined as priorities for the state (MMA, 2018).

Material and methods

Species records

We used data from unpublished surveys, inventories and ecological studies conducted in the state of Maranhão and the neighboring areas in the states of Pará and Piauí spanning from the early 1990s to the present (T.G. Oliveira unp. database). These also included records from scientific collections in universities, most of which came from the Vertebrate Collection of Maranhão State University in the city of São Luís. Additionally, we searched for species records in online databases such as SpeciesLink (http://splink.cria.org.br) and the Global Biodiversity Information Facility (https://www.gbif.org/). We also conducted a literature review in order to obtain

presence records from threatened nonvolant mammalian species. We georeferenced records without available coordinates, using information from the Brazilian Institute of Geography and Statistics (IBGE, ftp://geoftp.ibge.gov.br/Organizacao/Localidades/) and using the coordinates from the municipality where the species was recorded. Maps were elaborated using shapefiles. All analyses were done on QGIS ver 3.4.2.

Selected species

We selected all nonvolant mammalian species found on the IUCN and the Brazilian Red List of Threatened Species (IUCN, 2016; ICMBio, 2018), as long as they had presence records within our sampled sites (Table 1). Threatened species are important in conservation studies, given their role as flagship and umbrella species, which enhances the conservation of all other species that share the same landscape. These species act as "focal species", be it because of their rarity, degree of threat, or because of their ecological requirements (LAMBECK, 1997; FLEISHMAN ET AL., 2000).

Table 1. Selected nonvolant mammalian species for this study, by threat category and number of records obtained.

Ordem	**Espécie**	**Categoria de Ameaça**	**Nº de Registros**
Primates	*Alouatta belzebul*	VU	29
Primates	*Cebus kaapori*	CR	13
Carnivora	*Chrysocyon brachyurus*	VU	21
Carnivora	*Lycalopex vetulus*	VU	90
Carnivora	*Leopardus tigrinus*	EN	83
Carnivora	*Leopardus wiedii*	VU	20
Carnivora	*Leopardus colocola*	VU	25
Carnivora	*Panthera onca*	VU	43
Carnivora	*Puma concolor*	VU	54
Cetartiodactyla	*Tayassu pecari*	VU	50
Cetartiodactyla	*Tapirus terrestris*	VU	28

Legend: Threat Categories (ICMBio, 2018): CR = Critically Endangered, EN = Endangered, VU = Vulnerable.

Climatic and environmental variables

We extracted climatic and topographic variables from the WorldClim and USGS (United States Ecological Survey), respectively. We run Pearson correlations to test for collinearity between the variables, excluding variables with $r > 0.8$. The variables were temperature seasonality (Bio4), maximum temperature of warmest

month (Bio5), minimum temperature of coldest month (Bio6), mean temperature of warmest month (Bio10), mean precipitation of driest month (Bio14), precipitation seasonality (Bio15), mean precipitation wettest month (Bio16), mean precipitation of warmest quarter (Bio18), mean precipitation of coldest quarter (Bio19). Besides these, we also used ecoregion (WWF) and land use for the year 2019 (MapBiomes).

Modeling procedures

We run species distribution models using the maxent algorithm, implemented in MaxEnt 3.3 (PHILLIPS et al., 2006), with 5,000 iterations. The maxent algorithm has been widely used for modeling the distribution of rare and threatened species (De MARCO JÚNIOR & SIQUEIRA, 2009). We evaluated predictive performance of the models using ROC curves, which indicate the probability of the model correctly discriminating between presence and absence points (PHILLIPS et al., 2006). AUC values range from 0 to 1, where 0.5 would indicate the model is no better than a random guess, and 1.0 a perfect model in discriminating presences and absences. We use a threshold of 0.70 to designate high suitability areas (ELITH et al., 2006; GUISAN et al., 2006; WILLIAMS et al., 2009). We generated 10 models for each species, and selected the most conservative one, with the highest statistical significance which minimizes the omission error. Afterwards, the selected models for each species were combined in order to generate a more robust prediction of their potential distribution in the state (GIANNINI et al., 2012). We used environmental data from the Brazilian Ministry of Environment and MapBiomas in order to evaluate overlap between high suitability areas for the species modeled and protected areas, remaining natural vegetation patches, and priority areas (MMA, 2018).

Priority Areas

Based on each species' potential distribution, we identified the most suitable areas for conservation of the sampled species. We overlap the model averaging the models of all species, with the maps of protected areas and remaining natural vegetation patches. We also analyzed the degree of overlap between areas of highest suitability and areas already defined as of conservation priority for Maranhão state. Finally we considered as priority areas for conservation those with natural vegetation

cover and with high environmental suitability for our sampled species, and that are not part of any existing protected area.

Results

We obtained a total of 465 occurrence points for the selected species (Figure 1). Distribution maps agreed with the empirical knowledge available about the species' respective distributions, though for some species we obtained overestimates in the extent of occurrence (Figure 2). An average of all species best models, considering the remaining natural vegetation cover, showed that the most suitable areas are in the Gurupi region (including Indigenous Lands and the Biological Reserve) as well as the remaining Cerrado areas, particularly Mirador State Park, Chapada das Mesas National Park, and Nascentes do Rio Parnaíba National Park (Figure 3).

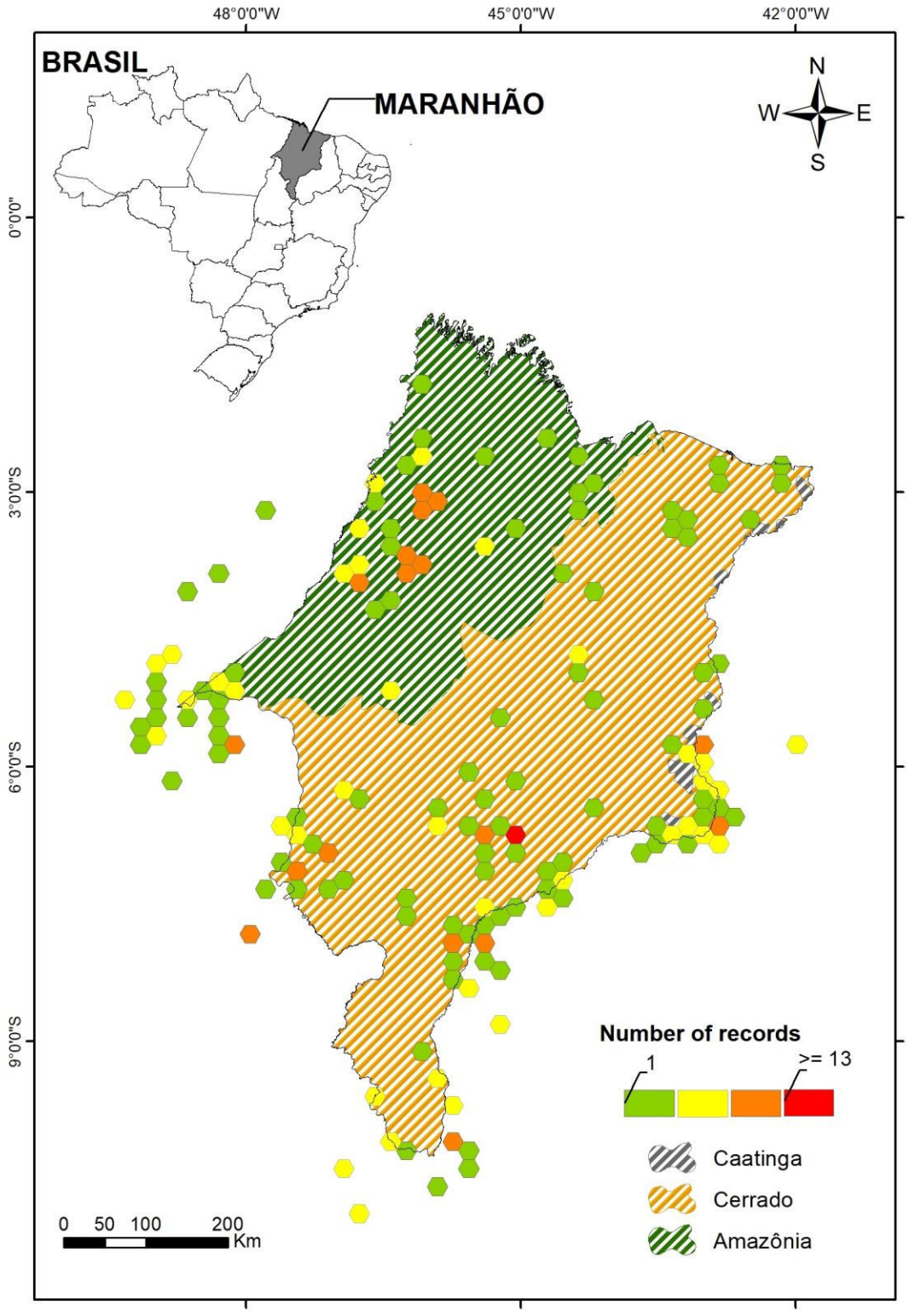

Figure 1. Occurrence records of threatened nonvolant mammal species in Maranhão State.

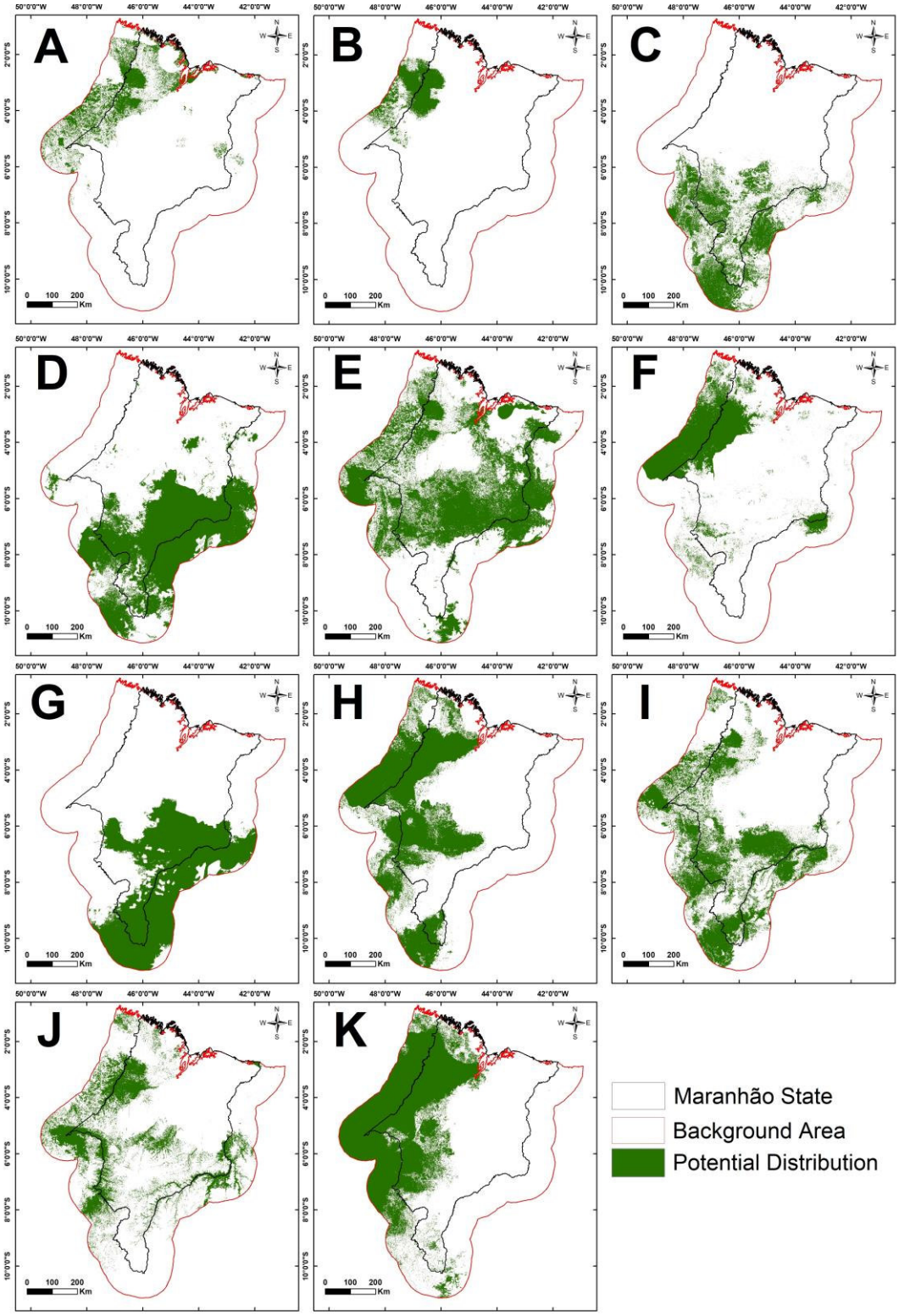

Figure 2. Species distribution modeling for: *Alouatta belzebul* (A), *Cebus kaapori* (B), *Chrysocyon brachyurus* (C), *Lycalopex vetulus* (D), *Leopardus tigrinus* (E), *Leopardus wiedii* (F), *Leopardus colocola* (G), *Panthera onca* (H), *Puma concolor* (I), *Tayassu pecari* (J), and *Tapirus terrestris* (K).

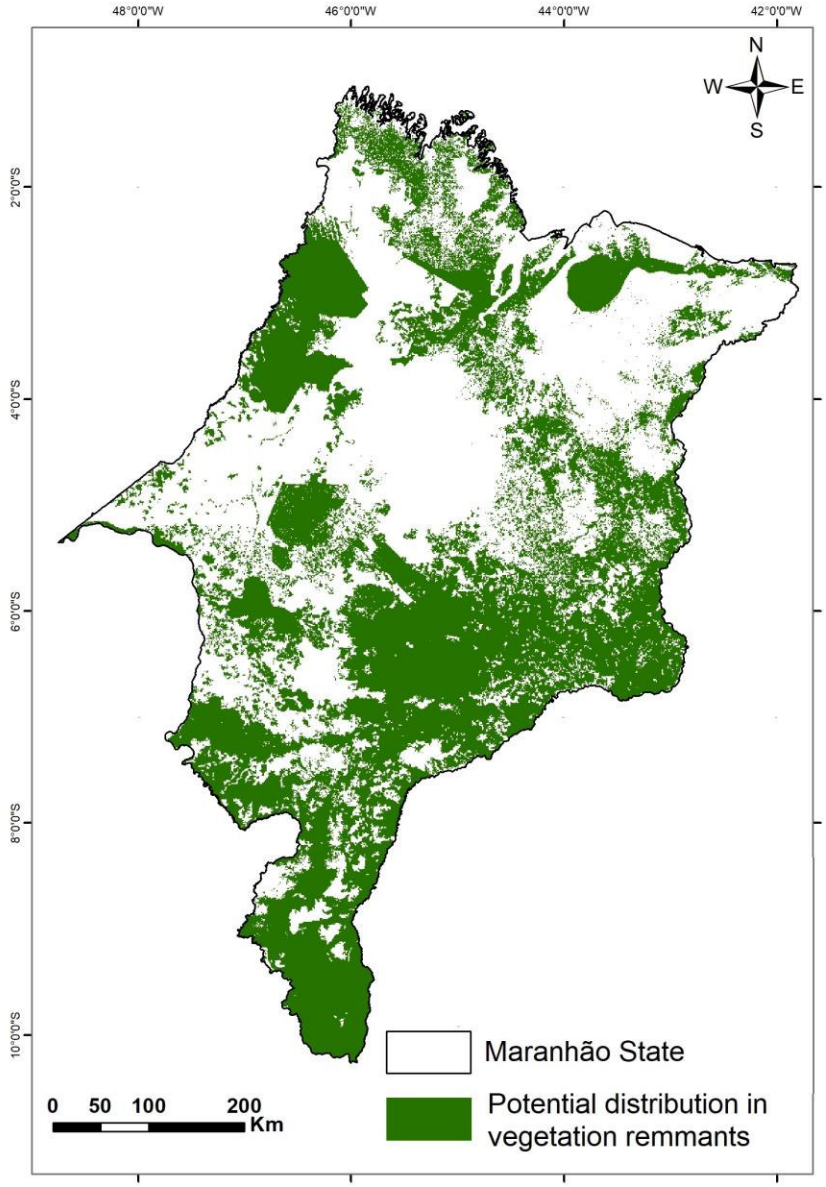

Figure 3. Potential distribution of threatened nonvolant mammalian species, obtained by averaging the models for each species and considering natural vegetation remnants.

Priority areas for conservation in Maranhão State

There is a complete overlap (100%) between the most suitable areas for our species assemblage and the current protected area system in the state, with strongholds in Gurupi Biological Reserve, Nascentes do Rio Parnaíba National Park, Chapada das Mesas National Park, and Mirador State Park (Figure 4). There was also high suitability in certain indigenous territories, such as Awa, Caru, Krikati, Rodeador, Kanela and Alto Turiaçu (Figure 5), the Brazilian government is required by law to protect these areas.

With regard to vegetation classes, the most suitable areas are located in evergreen dense forest (94%), Cerrado and other savanna formations (87%), and seasonal semideciduous forests (81%).

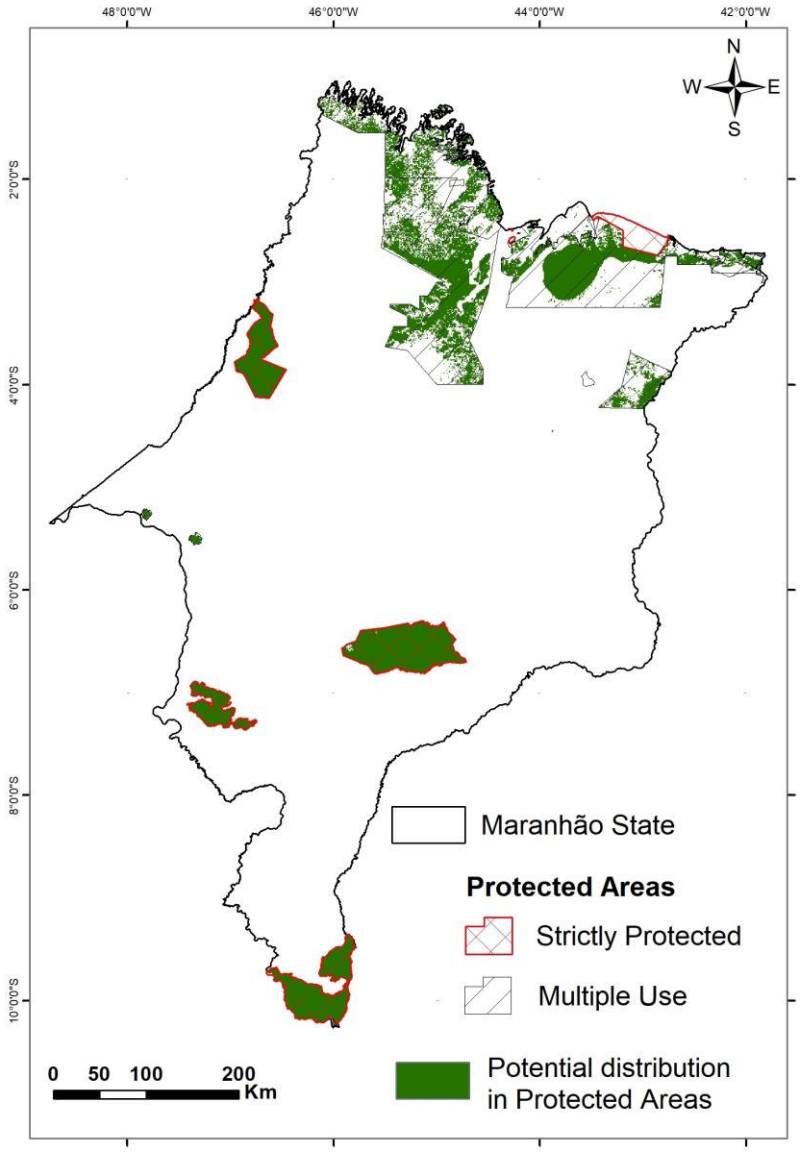

Figure 4. Overlap between species distribution and protected areas in Maranhão state.

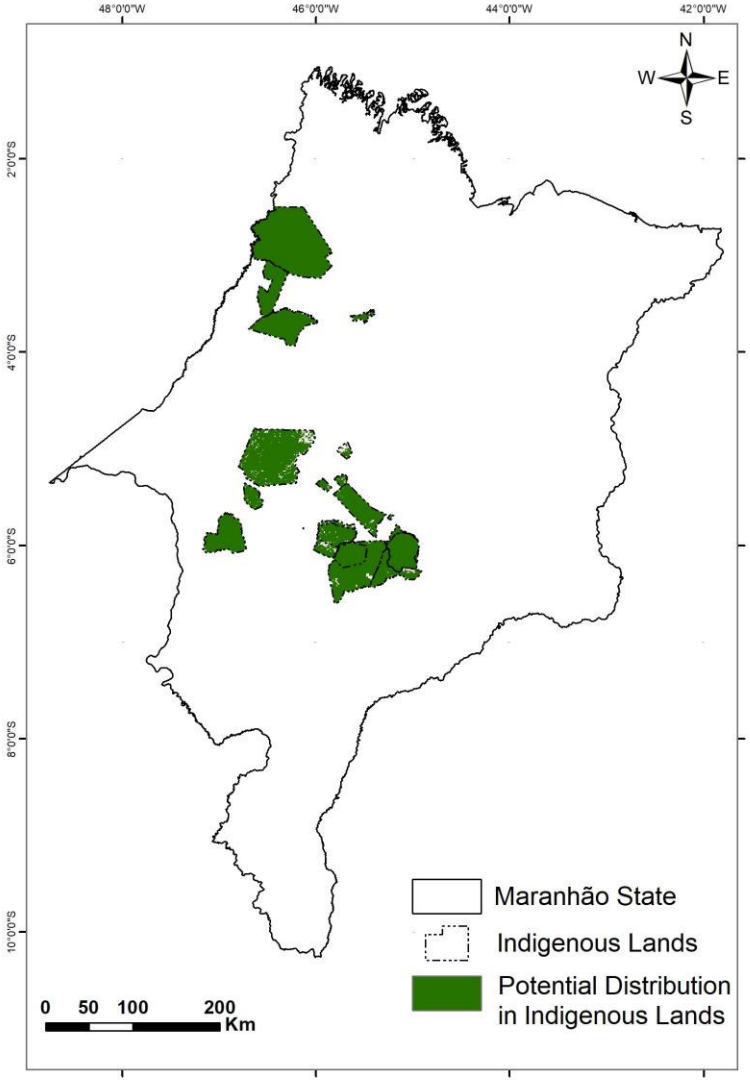

Figure 5. Overlap between species distribution and indigenous territories in Maranhão State.

Overlap between the most suitable areas for mammals and the map of priority conservation areas (MMA, 2018) showed six important areas in the Amazon (overlap values = 85.02-99.92%) with high biodiversity and conservation priority, all of them are located in the Gurupi Complex. In the Cerrado, there were four areas of high conservation priority (overlap values = 71.19-99.94%) and high habitat suitability, all these areas are located in the southern tip of Maranhão. Overall the models showed a 71.36% overlap between areas of high suitability and areas already identified as conservation priorities.

Conservation priority areas for nonvolant mammals in the state totaled 67,916 km^2 (Figure 7). These areas correspond to the overlap between the highest habitat suitability zones (identified by averaging the models of each species) and the remaining areas of natural cover, excluding areas already identified as priority by MMA as well as conservation areas and indigenous territories.

MaxEnt projections generated a priority map, based on overlap of the average of all distribution models for each species (Figure 8). The highest priority areas are located adjacent to protected areas in the Gurupi and Bico de Papagaio regions, as well as Chapadas das Mesas National Park, of these only the latter is fully protected. The areas of least conservation priority are mostly covered by secondary vegetation (de ARAUJO et al., 2016), and it is worth noting the large block in the savannas of the Southeast part of the state.

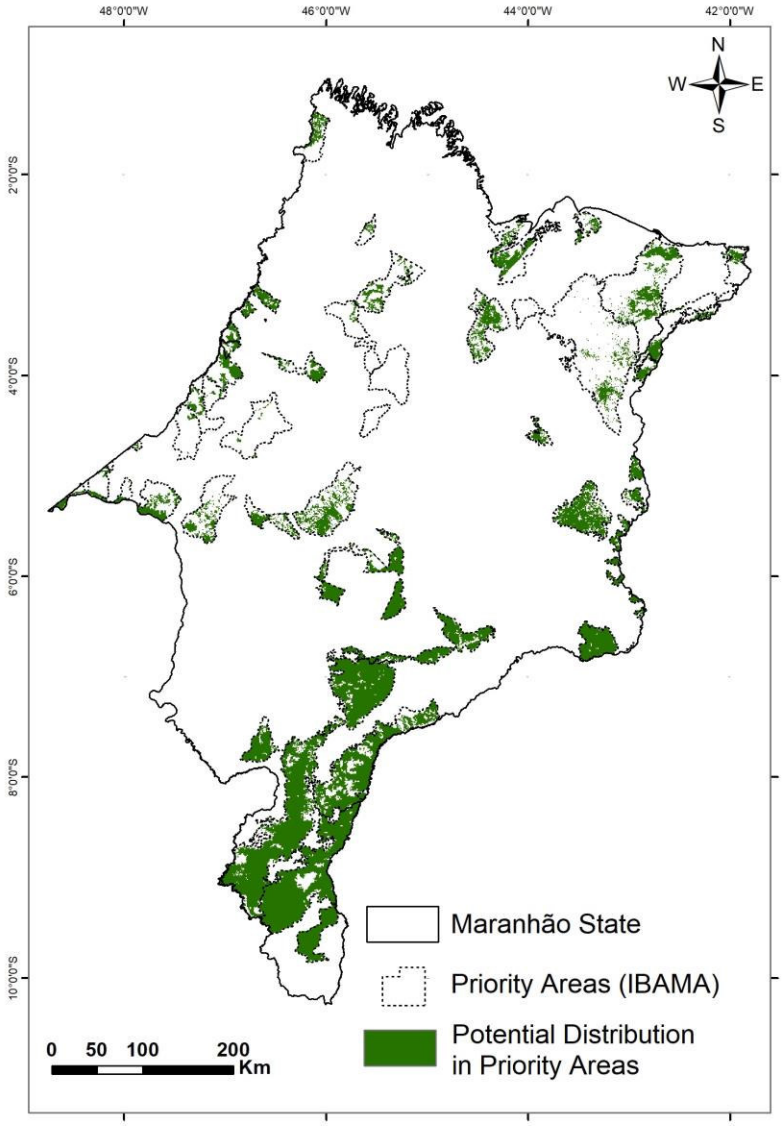

Figure 6. Overlap in species distribution, estimated by averaging the models of each species, and the conservation priority areas in Maranhão.

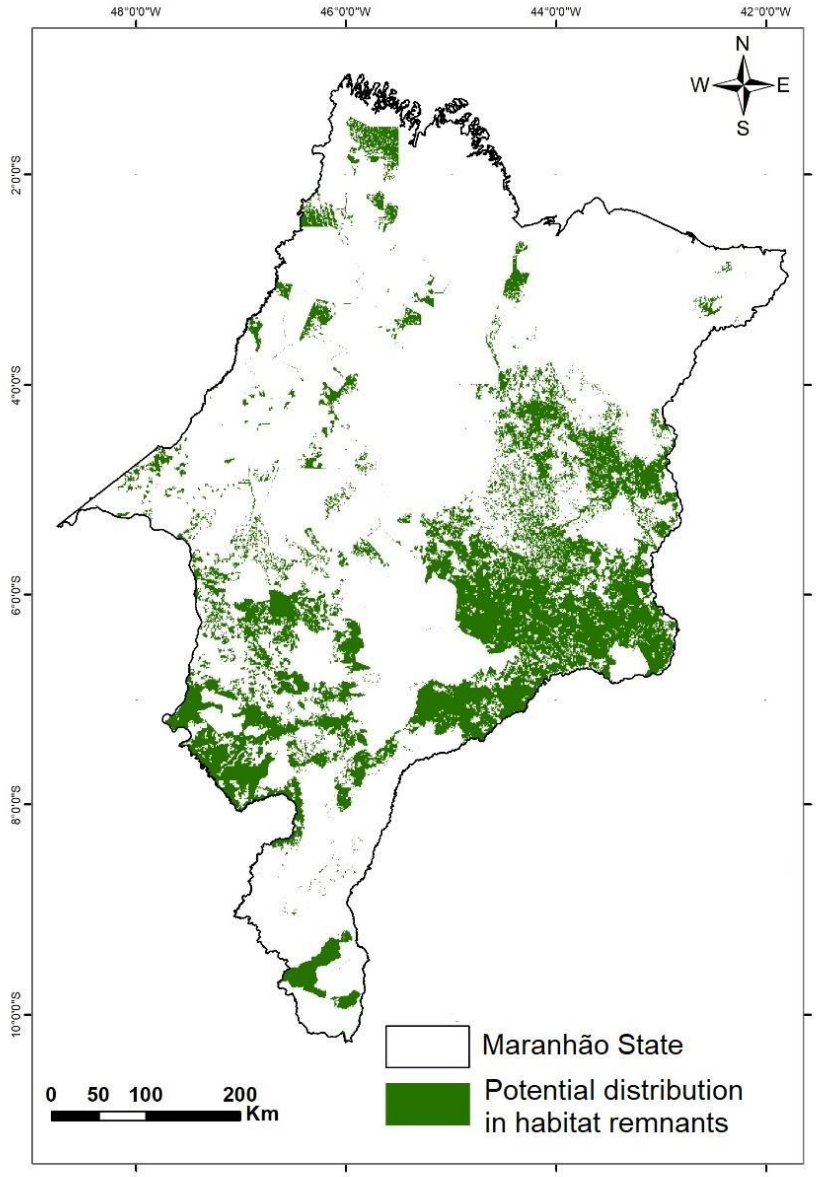

Figure 7. Conservation priority areas for threatened nonvolant mammals in Maranhão state.

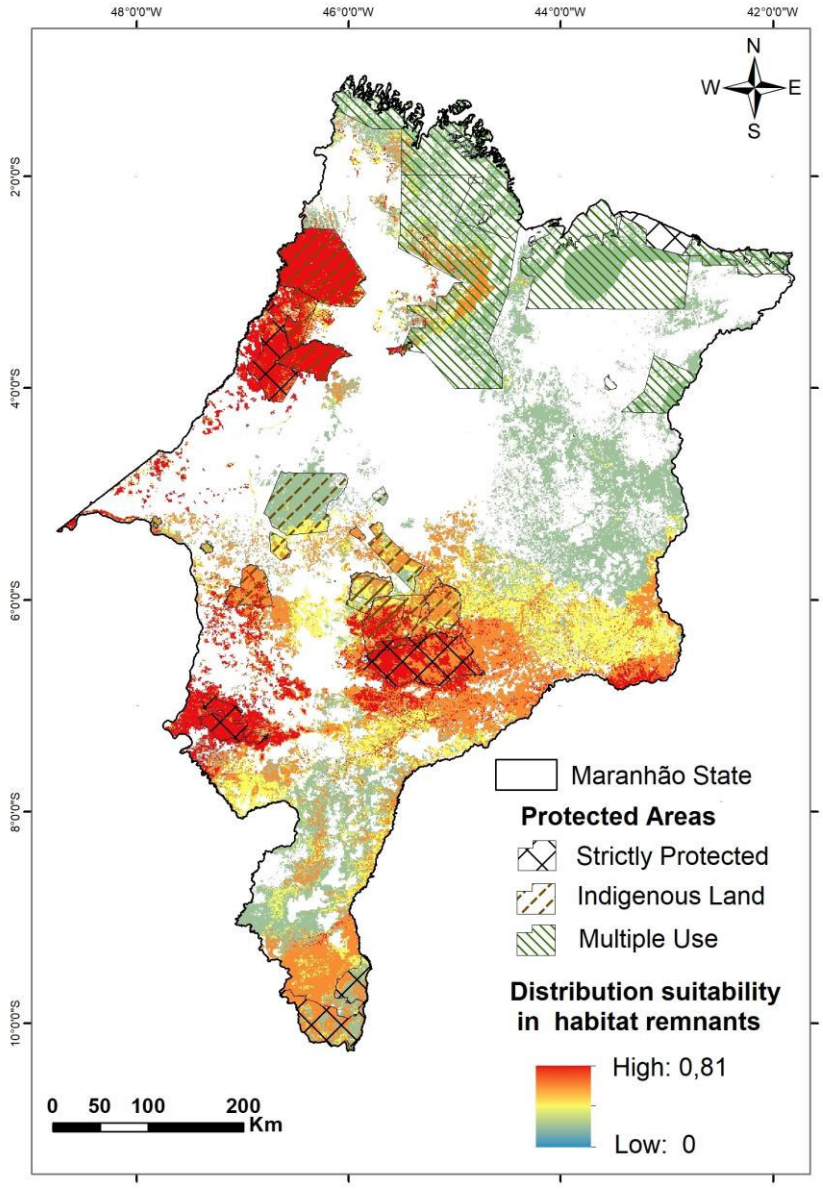

Figure 8. Conservation priority areas in Maranhão state.

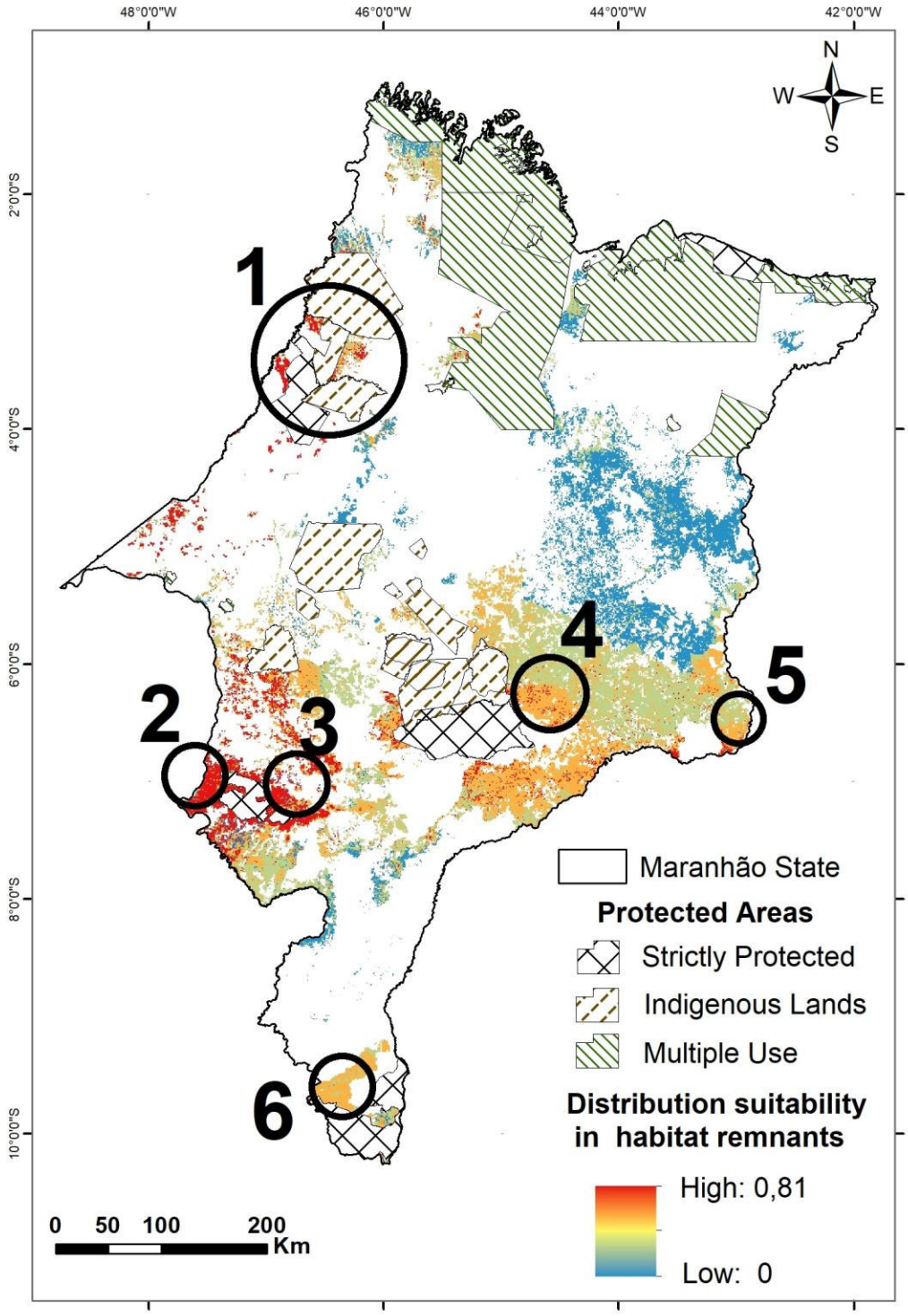

Figure 9. Conservation priority areas according to overlap in species distribution. 1.- Gurupi region; 2 and 3 – Chapada das Mesas National Park and adjacent regions; 4.- Mirador State Park and adjacent Indigenous territories; 5.-Middle Parnaíba River, São Francisco do Maranhão region; 6.- Chapadas do Alto Río Parnaíba Region.

Discussion

Threatened mammalian species

Distribution maps for each species are in agreement with empirical knowledge of each species. *Alouatta belzebul* is a primate species endemic to Brazil, with a disjunct distribution in the Amazon and Atlantic Forest (LANGGUTH et al., 1987; BONVICINO et al., 1989; GREGORIN, 2006). This species is not exclusively found in primary forests, nevertheless its most suitable habitats in Maranhão are all located in pristine environments. Even though large Amazonian rivers serve as important distribution barriers (AYRES & CLUTTON-BROCK, 1992; CORTÉS-ORTIZET al.2003), the models predicted the species also to be distributed in the forests along the Paraníba region. *Cebus kaapori* is another primate species endemic to Brazil, being found in the states of Pará and Maranhão (QUEIROZ, 1992; BUSS et al., 2014). Just like *A. belzebul*, this species is not restricted to pristine environments as there are records from areas with secondary vegetation. Modeling showed its distribution is limited to the Gurupi complex region, part of the Belém Center of Endemism.

Leopardus colocola, *Chrysocyon brachyurus* and *Lycalopex vetulus* are carnivores widespread throughout South America, being found mostly in savanna formations. *Chrysocyon brachyurus* is found in several habitats while *Lycalopex vetulus* is the only canid species endemic to the Brazilian Cerrado (BAGNO et al., 2004; DALPONTE, 2009; QUEIROLO et al., 2011; PAULA et al., 2013). Modeling for these species showed similar results, with the highest environmental suitability in the savanna regions, mostly in southern Maranhão, which is the best-preserved area (Araujo et al., 2016). Notwithstanding, *L. colocola* and *L. vetulus* had higher suitability in the southeast, whereas C. *brachyurus* had higher suitability in the southwest, and recent studies suggest the species has expanded its distribution towards protected and nonprotected areas within the Amazon domain (SILVA-DIOGO et al., 2020).

Just like canids, the felids also occur in a wide variety of habitats, ranging from open environments to forested landscapes (SANDERSON et al., 2003; NOWAK, 2005; SUNQUIST & SUNQUIST, 2017). The maps for *Leopardus tigrinus* suggest uniform environmental suitability throughout the state, mostly in the Cerrado and Caatinga portions. Despite being rare in the Amazon, the models suggest the species has suitable habitat in the forest formations of the Gurupi region. It is worth noting

that these models indicate habitat suitability rather than true occurrence (HURLBERT & WHITE, 2005; HEIKKINEN et al., 2006). *Panthera onca* and *Puma concolor* had similar results in terms of environmental suitability, however the latter species was less dependent of the Amazon forest regions. Both species show high suitability in the savannas of Central-southern Maranhão, particularly in the extreme southern tip of the state. *Leopardus wiedii* had a disjunct distribution within the state. Its distribution seems to be restricted to the Gurupi region, as well as gallery forests along the Rio Parnaíba and the Amazon-Cerrado transitional areas of the Chapadas das Mesas National Park.

The ungulates, *Tapirus terrestris* and *Tayassu pecari*, are large-bodied mammals with large habitat requirements, and are often targeted by poachers. *T. terrestris* used to have a widespread distribution in South America, but in recent decades populations of the species have been declining and becoming ever more restricted to wet forests (FERREGUETTI et al., 2017). *T. pecari* also used to be widespread, but now a days it suffers from several threats in its remaining range (KEUROGHLIAN et al., 2012). In Maranhão state, our models showed that both species main stronghold is the Gurupi region. For *T. pecari* there were also some suitable areas in the Amazon-Cerrado ecotone and some forested areas along the Parnaíba river. Thus, the modeling for both species is in agreement with the known distribution and ecological requirements of both species.

Conservation status and threats of priority areas

The main threat for the Amazonian region of Maranhão is deforestation. Most of the vegetation cover in the region has been lost recently, mostly due to illegal deforestation, which occurs also inside protected areas (CELENTANO et al., 2018; SOUSA JR, 2018). The remaining forests are mostly located in the Gurupi region, in the Gurupi Biological Reserve and adjacent indigenous territories, totaling 17.900 km^2 (CELENTANO et al., 2018). These areas are the only ones left that could potentially harbor sustainable populations of large-sized mammals, and if they were to disappear in the long term, some of the species could experience local extinctions. An example of this is the case of the jaguar (*Panthera onca*), which would become extinct within the next 100 years in a scenario where the Gurupi regions is isolated and experiencing a rate of habitat loss of 3% per year (OLIVEIRA et al., 2012).

Despite having lost more than half of its original vegetation cover, the Brazilian Cerrado does not seem to have the same levels of awareness as those of the Amazon (STRASSBURG et al., 2016). While deforestation rates declined in the Amazon between 2009-2012 (INPE, 2018), during the same period the Cerrado experienced a marked increase in habitat loss. In Maranhão, the Cerrado holds 12.5% of the protected areas, only 5.7% of which is fully protected. This is very similar to the percentage at the national level, as only 8.21% of Brazil´s territory is fully protected (BRASIL, 2013). The advance of agricultural encroachment, results in a disorganized and massive habitat loss, compromising inclusive economic growth as well as the environment which contrast with the advantages of large-scale production (BISPO, 2020).

We found threatened species in altered environments, however the long-term survival of these is dependent upon the preservation of adjacent blocks of native cover (LOVEJOY et al., 1986; FONSECA et al., 2018). Establishing protected areas that provide the environmental requirements of these species could prevent their local extinctions, as they should be able to guarantee their survival, provided they are connected.

Identifying conservation priority areas

As a signatory of the Convention on Biological Diversity, Brazil has the goal of protecting 17% of its terrestrial biomes. In this study, we identified 7,336 km^2 (10.6%) and 60,580 km^2 (87.5%) of high priority areas for conservation in the Amazon and Cerrado, respectively. We observed that Maranhão state still has 54.3% of remaining vegetation cover. However, the percentage proposed by CBD may not be enough in the long term, specially as most of the area is not fully protected (only 8.1% are fully protected). Although with a certain degree of protection, non-fully protected areas do not hold a representative sample of Brazilian biodiversity, instead several threatened species occur outside protected areas that should be prioritized for protection. Thus, the additional 67,916 km^2 that we identified in this study as high priority have the potential to greatly improve the conservation prospects for threatened mammalian species, even more so if these areas were to be connected.

There are three issues that we must consider when interpreting the results of this study: (a) we only modeled 11 out of 23 threatened species (ICMBio, 2018), this is because they were the ones with enough records for a species distribution model; (b)

overlaying the priority areas identified in this study with the existing protected area system (all categories of protection), results in 48% of the areas having high suitability for the species modeled, however without guaranteeing their long-term survival due to habitat loss; (c) we considered the existence of priority areas based on our predictor variables, without taking into account the size of these areas or the amount of habitat left. Thus, studies of long-term population viability are needed, as well as determining the minimum area requirements for each species. Combining these measures would give us a better outlook at what is needed for long-term effectiveness in biodiversity conservation in the state.

Habitat fragmentation results in biodiversity loss at different time scales: in the short term, it can result in the disappearance of the most sensitive species, while in the long-term a previously large habitat patch could become an isolated island in a fragmented landscape or even disappear completely (WILCOX, 1980; SHAFER, 1990; PIRES et al., 2006). Thus, the results suggest that in order to preserve the threatened nonvolant mammalian fauna in the state, existing conservation areas must be fully protected. Furthermore, it is necessary to guarantee the connection among these protected areas through biological corridors, allowing genetic flow among wildlife populations. Despite that most of our sampled species are highly mobile and able to roam over vast distances even in fragmented landscapes, we cannot guarantee their long-term survival due to this mobility. Similarly, we cannot assume that small habitat patches are relicts with the same representative species of larger patches (PIRES, 2006). The southern tip of the state, which is where most of the priority areas are located, requires immediate conservation actions as the area is under intense anthropogenic pressure (SODRE, 2017; BISPO, 2020). In short, protecting these landscapes will allow the long-term conservation of a large share of Brazilian biodiversity.

In light of extensive habitat loss in the Amazonian region of Maranhão, we suggest the following: (1) prioritize the protection of Gurupi and adjacent regions as well as Bico do Papagaio region, which along the existing protected areas would provide an area large enough to allow for ecological processes and species maintenance (PERES, 2005). With regards to the Cerrado our findings disagree with Diniz-Filho et al. (2008) and Marini et al. (2009), who advocate for prioritizing conservation efforts in the Cerrado of Central Brazil. We found high suitability for several threatened species in the threatened savannas of southern Maranhão, which

also show a better prospective for connectivity, as the northern savannas are better preserved overall than those found elsewhere are. As such we suggest prioritizing the areas around Chapada das Mesas National Park (2 and 3), as well as the ones connecting Mirador State Park (4) with indigenous territories to the north (5), and the region along the Parnaíba river due to the number of records of threatened species there. The area in the southern part of the state should also be priority, as it buffers the Nascentes do Parnaíba National Park. It is located in the largest protected block of Cerrado vegetation in the country and provides habitat for several threatened species. Due to the problems in creating new conservation areas, such as lack of habitat restoration and neglecting possible biological corridors, we suggest a traditional conservation approach (despite it being too general) towards the buffer zones: a large protected area is better than both a small one and a group of smaller ones (DIAMOND, 1981; WILCOX, 1980; PIRES et al., 2006).

Conclusions

- Distribution maps for all species agree with previous knowledge about their ecology and environmental requirements.
- The model estimated by averaging the models of each species, suggest that the highest environmental suitability for our species assemblage is in the Cerrado.
- Potential distribution of the species assemblage had an overlap of 71.36% with areas already identified as priority areas, reinforcing the importance of these areas for wildlife conservation.
- Priority areas for threatened nonvolant mammals in Maranhão state totaled 69 thousand km^2; the areas are mainly concentrated in the Gurupi region and around the Chapada das Mesas National Park.
- Habitat loss is the main anthropogenic threat for nonvolant mammals in the state.
- Protecting the priority areas identified in this study will improve the conservation prospects of the mammalian fauna of Maranhão, with viable populations in the long-term.

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4. CONSIDERAÇÕES FINAIS

O presente trabalho fecha uma importante lacuna de conhecimento para os mamíferos não-voadores presentes no estado, uma vez que apresenta a primeira lista oficial destas espécies para o meio norte do Brasil. Além da lista o trabalho também registra novas ocorrências para o estado assim como amplia a distribuição da área de ocorrência para outras espécies.

O Maranhão é um dos estados brasileiros que abrigam a Amazônia que possui o menor grau de ocupação do espaço com áreas protegidas, apresentando alto grau de desmatamento e de fragmentação florestal. Não obstante a riqueza biológica proveniente do encontro de biomas que ocorre no estado e das enormes pressões sobre os mesmos, é fato, ainda, o baixo índice de informações levantadas sobre estes no Estado, e mais ainda se considerarmos sob o aspecto do conhecimento sistemático. Apresentar uma lista com 89 espécies é contribuir para esse conhecimento. Portanto, conhecer os componentes dessa da biodiversidade, sistematizá-los e pô-los à disposição das ações de conservação e desenvolvimento sustentável é essencial para subsidiar informações para futuros planos e programas no âmbito da gestão dos seus recursos naturais.

Um dos grandes desafios para os tomadores de decisão sobre a conservação da biodiversidade é o estabelecimento de prioridades essenciais, sejam elas nacionais, regionais e locais, para que se tenha eficiência tanto nas decisões políticas quanto na aplicação dos recursos financeiros. Áreas protegidas são áreas dedicadas à proteção e manutenção da diversidade biológica e dos recursos naturais e culturais associados, manejados através de instrumentos legais ou outros instrumentos efetivos. A metodologia de modelagem aqui proposta definiu 69 mil km^2 de áreas prioritárias para a conservação de mamíferos no estado, concentradas no entorno das áreas protegidas da região do Gurupi, do Parque Nacional da Chapada das Mesas, conectando o Parque Estadual do Mirador com as reservas indígenas adjacentes, médio curso do Rio Parnaíba e extremo sul do estado, margeando o Parque Nacional das Nascentes do Rio Parnaíba. Apesar do estado possuir 19% dos seus remanescentes naturais protegidos por unidades de conservação, estas áreas não abrigam de forma representativa sua biodiversidade, deixando de fora outras áreas com igual ou superior riqueza biológica, representatividade e endemismos. No entanto, o cenário pode ser bem mais esperançoso se consideramos o acréscimo de 69 mil km^2 das áreas definidas como prioritárias para esse trabalho, principalmente se estas áreas mantiverem conectividade para evitar isolamento e consequentemente extinção de populações.

Por fim, conservar as áreas prioritárias definidas nesse estudo, aumentarão as chances de manutenção de populações viáveis das espécies assim como possibilitarão o deslocamento natural entre áreas que julgarem mais adequadas. Preservar esses remanescentes é garantir espaço para novas descobertas, incrementando a lista para o estado e consequentemente aumento sua biodiversidade.

APÊNDICES

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Inventory

Non-volant mammalian species richness in the ecotonal Brazilian midnorth: checklist for Maranhão State

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Abstract: The state of Maranhão, located in the westernmost portion of the Northeast Region of Brazil, is characterized by a dynamic and unstable ecotone among the Amazon, Caatinga and Cerrado biomes that presents a high degree of biodiversity with high vulnerability to anthropogenic activities. Despite the enormous potential for sheltering high levels of species diversity and abundance, little is known about many aspects the state's biodiversity, especially with regard to mammalian fauna. A capture-recapture methodology using live-traps was employed to inventory the non-volant, small mammal community. In addition, we recorded medium and large mammals based on direct and indirect observations, camera-trap surveys, and interviews. An extensive literature search of published research was also performed to maximize the elaboration of a complete mammal species checklist for Maranhão. A total of 89 non-volant mammal species, representing 9 orders and 27 families were recorded in the state of Maranhão. Of these taxa, 25.84% are included in the Brazilian Red List for endangered species, while 20 are considered as being endemic to Brazil. The preservation status of some areas, coupled with the strong presence of agro-pastoral environments, contributed to some unusual species occurrences, while the state's ecotonal nature was noted by the numbers of species associated with the Amazon (N=65) and Cerrado (N=66) biomes.. Given the rapid development and effects of numerous anthropogenic impacts occurring in the state, it is a crucial time to quantify, even at specific scales, the environmental richness of Maranhão. The significant levels of biodiversity, high degree of endemism, and the presence of numerous rare and endangered species characterizes Maranhão as being among the most biologically important parts of Brazil. Nonetheless, many gaps in our basic knowledge regarding the biodiversity of this area remain, such that the execution of additional biological inventories is imperative, as are greater efforts to clarify certain species limits and necessary taxonomic revisions, most notably that for small mammals.

Keywords: *mammals; ecotone; biodiversity; endemism; Maranhão.*

Riqueza de espécies de mamíferos não-voadores no meio norte ecotonal brasileiro: checklist para o Estado do Maranhão

Resumo: A denominação de estado ecótono, por estar localizado na região meio-norte do Brasil, entre a Amazônia a Caatinga e o Cerrado, confere ao Maranhão não só áreas ricas e abundantes de espécies, mas também à necessidade de cuidados especiais na sua conservação, por se tratarem de ambientes de dinâmicos e, portanto, pouco estáveis. Apesar de seu enorme potencial para abrigar altos níveis de riqueza e abundância de espécies da flora e fauna, o Maranhão ainda possui uma riqueza biológica pouco conhecida, notadamente quanto à sua mastofauna. A metodologia empregada para inventariar a comunidade de pequenos mamíferos não-voadores foi a de captura-recaptura, utilizando armadilhas do tipo live-traps. Para os mamíferos de médio e grande porte utilizou-se a visualização direta e indireta através da transecção de trilhas pré-estabelecidas assim como entrevistas e uso de armadilhas fotográficas. Para maximizar a busca das espécies já registradas para o estado foram também realizadas buscas de literatura através de plataformas digitais confiáveis. Foram registradas 89 espécies de mamíferos não-voadores no território maranhense, distribuídos em 9 ordens e 27 famílias. Dos táxons listados 25.84% constam na lista brasileira dos animais ameaçados de extinção, enquanto que 20 são endêmicos do território brasileiro. O estado de conservação de algumas áreas aliado à forte presença de ambientes agro-pastoris contribuíram para ocorrências não usuais, enquanto que a natureza ecotonal foi notada pela proximidade do número de espécies associadas aos biomas Amazônia (N=65) e Cerrado (N=66). Em tempos de desenvolvimento aliada a inúmeros impactos antrópicos sobre o meio ambiente é salutar que se quantifique, mesmo que em escalas específicas, a riqueza ambiental do estado. Diversidade expressiva, endemismo, espécies raras e ameaçadas destacam o Maranhão como um dos principais estados do meio norte do Brasil, entretanto são muitas as lacunas de conhecimento, o que torna imperativo não somente novos trabalhos de inventários mas também maiores esforços na precisão taxonômica das espécies, notadamente na de pequenos mamíferos.

Palavras-chave: *mamíferos, ecótono, biodiversidade, endemismo, Maranhão.*

Introduction

Maranhão is among the least known states of Brazil in terms of its biodiversity, either due to the classic veil line proposed by Preston (1948) or the geographical bias in funding allocated to support biological inventory studies (Magnusson et al., 2016). Nevertheless, its extensive area presents many attributes that allow for high levels of biodiversity, diverse vegetation in particular. Roughly 64.1% of the territory of Maranhão occurs within the Cerrado biome, 34.8% within the Amazon biome and 1.1% is classified as part of the Caatinga biome (Stella 2011).

A total of 138 municipalities in Maranhão occur within the Cerrado biome, 110 within the Amazon biome and 15 within the Caatinga biome. The Amazon represents the largest continuous area of rainforest in the world and is recognized for its extreme ecological importance and essential environmental services (MMA, 2007). Such recognition is supported by the large variety and complexity of ecosystems presented by the biome, which affords progressive increases in species richness (Peres 2005). The Cerrado biome is considered to be the most diverse tropical savanna in the world, also presenting a large variety of habitats and remarkable alternation of species between different phytophysiognomies (Medeiros et al. 2011).

Despite the natural richness of these biomes, Maranhão is currently experiencing a period of increasing agriculture, urban expansion and a growing population density, all of which can have direct impacts on local fauna (Stehmann & Sobral 2017). Although it covers about 64.1% of the state territory and presents one of the highest rates of preservation, with 71.9% of its natural vegetation remaining, the Cerrado biome in Maranhão is also considered highly threatened (Stella 2011, Brazil 2015). For example, the MATOPIBA region (an acronym designated by using the initials for the states of Maranhão, Tocantins, Piauí and Bahia) represents a large portion of the Cerrado biome in which the average devoted to cotton, corn and soybean production has grown by 400% between 1990 and 2010 (Lorensini et al. 2015). Historically covering 34.8% of the state territory, the Amazon biome portion of Maranhão is also highly threatened, having been reduced to remnants representing just 23.82% of its original area due to the drastic transformations of forest and non-forest ecosystems, this is the lowest percentage of remaining vegetation among the nine Brazilian Amazon States (Santos 2007, Stella 2011, IMESC 2019).

Mammals occurring in the state of Maranhão are closely linked to the vegetation of the environment and strongly related to the quality and size of habitat remnants (Chiarello 1999, Peres 2000). Despite the extensive literature regarding mammal species composition of the Amazon and Cerrado biomes in general, there is little knowledge about mammalian distributions in Maranhão (i.e. Wallacean Shortfall). Mammal species can influence the entire dynamic of the ecosystems in which they occur, having important ecological roles in the dispersal of seeds, spores and plant propagules, as well as regulating natural prey populations. A proper biological inventory of mammal species for Maranhão is necessary to achieve a better understanding regarding the conservation status of habitat remnants in the state.

Therefore, given that the biodiversity of Maranhão is so rich and equally threatened by trends in socio-economic development, the state deserves special attention setting priorities for the region that result in positive outcomes for conservation, sustainable use and the benefits derived of this biological diversity for the rest of the country. Part of the conservation concerns for Maranhão are due to a systematic lack of knowledge regarding its fauna, notably that of non-volant terrestrial mammals, including information gaps for many geographic areas and greater degrees of knowledge for certain mammalian orders relative to others.

Currently there is no single checklist for the species of mammals occurring in the state of Maranhão, our comprehensive knowledge is limited to isolated records in a few publications and mostly addressing species composition of the Cerrado and Amazon biomes independently (Ávila-Pires 1989, 1992, Oliveira et al. 2007, 2011). Basic information on the geographic occurrence and abundance of mammal species at various locations, as well as actions seeking to estimate the actual species richness of this region, are needed. Therefore, the main objective of the current study is to present a comprehensive checklist for non-volant mammal species known to occur in the state of Maranhão.

Materials and Methods

1. *Study area*

The study corresponds to the Brazilian state of Maranhão, with roughly 331,983 km^2. The state has transitional conditions between the super humid climate of the Brazil's northern region and the semi-arid climate of the northeast region of the country, with a predominance of forest vegetation, open fields and Cerrado habitats, and a large variety of ecosystems including mangroves, sand dunes, estuaries, extensive beaches and lake basins (Köppen, 1948, Maranhão 2002). Additionally, the *Mata dos Cocais* area, a *babassu* palm formation that is classified by IBGE (1992) as an Open Ombrophilous Forest, stands out for its uniqueness and is considered a characteristic landscape of Maranhão (Rios 2001). The average annual temperature for the whole area is 26ºC, with a large temperature range between the northern and southern portions of the state, a rainfall regime that is highly correlated with the geographic occurrence of the different biomes, annual precipitation of around 1,100 mm in the southwestern region where the Cerrado biome is dominant and often exceeding 2,000 mm annually in Amazon biome areas (Pinto et al. 2011, Brasil 2013).

2. *Data collection*

Inventories were realized at 15 study sites throughout the state of Maranhão, selected to include portions of the Amazon and Cerrado regions, as well as transitional areas between the two biomes in the most diverse plant formations (Figure 1). Because the percentage of Caatinga cover in the state is negligible (ca. 1.1%), we decided to only sample sites within the Amazon and Cerrado biomes of the state. Live-traps appropriate for small mammals and camera traps were installed at sampling locations along predetermined transects of varying sizes within each of the study sites. The total sampling effort resulted in 71,082 nights/live-trapping, 1,283 transect km/traveled and 9,639 nights/camera-trapping (Table 1). The data presented here have been collected since 1994, but with greater consistency from 2004-2018. Additional information regarding biological inventories from different parts of Maranhão acquired from the bibliographic survey was also included.

3. *Small mammals*

The current small mammal survey was performed using the standard methodology of installing live-traps in capture lines along the selected sampling locations at each of the study sites. A capture station consisting of Sherman (8 x 8 x 23 cm) and Tomahawk (14 x 14 x 40 cm) live-traps was established every 20 m, the first type being deployed at each capture station and the second type at alternating stations. In closed-canopy habitats, Sherman live-traps were installed at a height of 1.5–2.5 m above ground at alternate stations to Tomahawk live-traps located on the ground. Peanut butter mixed with banana and/or other fruits was used to bait the live-traps, which were actively deployed for seven consecutive nights-(Auricchio & Salomão 2002, Lambert et al. 2006, Umetsu & Pardini 2007). The sampling protocol for small mammals is outlined in Table 1. All marsupial and small rodent species identifications were based on published systematic studies, as well as other important compilations regarding the taxonomy and geographic distribution of these groups (Paglia et al. 2012, Brandão et al. 2015, Gardner 2008, Miranda & Da Silva 2015, Patton et al. 2015, Percequillo et al. 2015, Quintela et al. [in press]). Species identifications were later confirmed by specialists. Voucher specimens were also collected for reference, comparison and confirmation of certain species identifications with other scientific materials and under the appropriate federal government collecting permits including: IBAMA 38/2010, IBAMA 45398-3, IBAMA 113/2004, IBAMA 2001.009125/2008-67, IBAMA 08/2010, IBAMA 035/2009/CGFAP, IBAMA 036/2009/CGFAP, IBAMA 037/2009/CGFAP, IBAMA 038/2009/CGFAP, IBAMA 39/2009/CGFAP, SEMA/MA 05/2017). Voucher specimens collected during the current study have been deposited in the vertebrate natural history collections of the *Universidade Estadual do Maranhão* and the *Museu Paraense Emílio Goeldi* (Supplementary material).

4. *Medium and large-sized mammals*

A variety of non-invasive sampling methods were used in the current study to identify medium and large-sized mammal species, including evidence from bones, skin, tracks, carcasses, vocalizations and photographs. To this end, camera-traps were deployed along several walking transects, while additional trails were also surveyed on foot and at different times of the day during the entire data collection period realized at each of the sampling areas, a standard methodology for this type of study (Oliveira et al. 1988, Oliveira & Cassaro 2005, Wilson & Delahay 2001). Whenever necessary, species identifications were supported by consulting several field guide references (Emmons & Feer 1997, Oliveira & Cassaro, 2005, Bonvicino et al. 2008).

The mammal species detected here were also classified by their appropriate threat categories according to criteria of the International Union for Conservation of Nature - IUCN (Version 13 - IUCN, 2017),

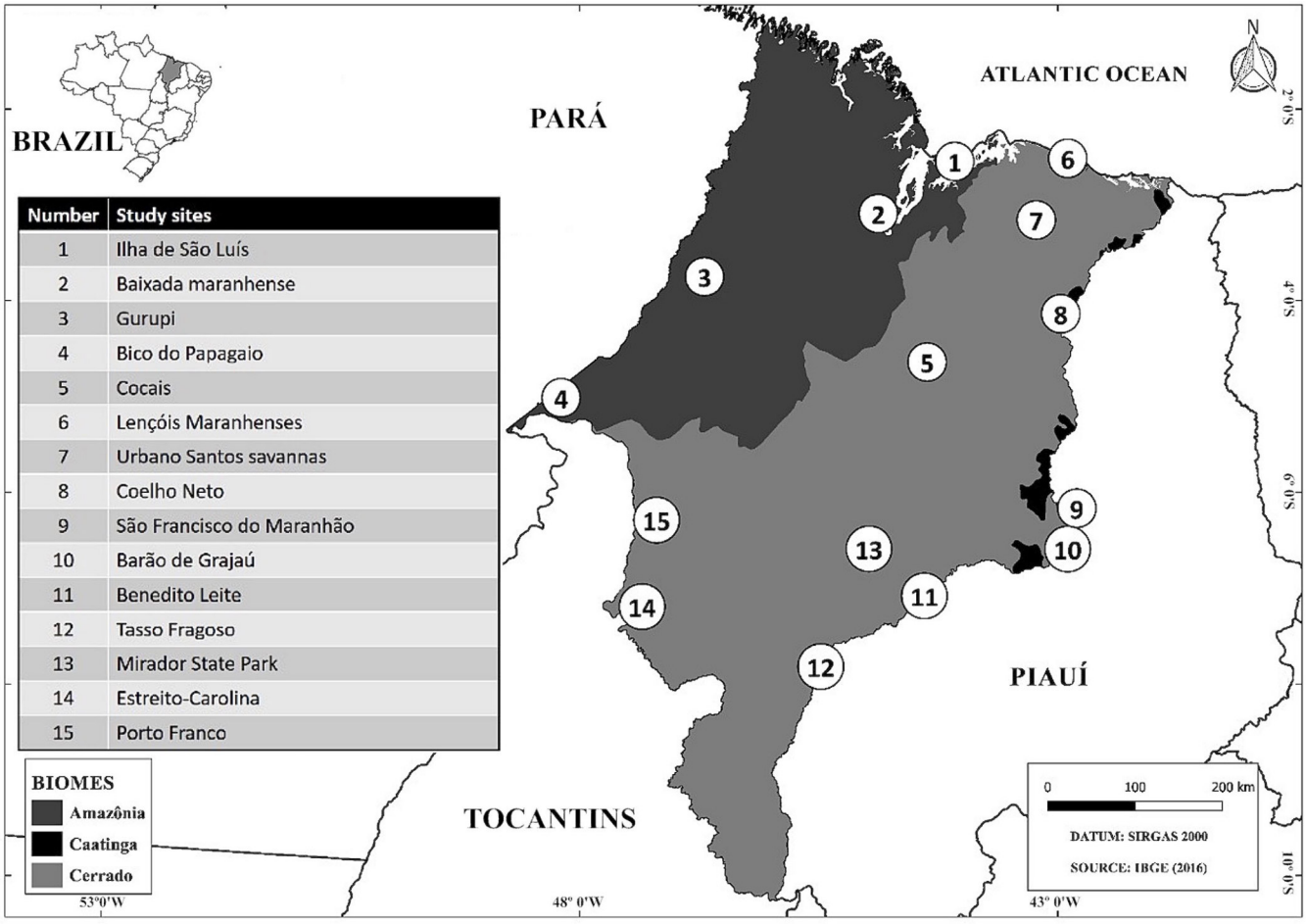

Figure 1. Location of study sites where non-volant mammal species were sampled in the state of Maranhão, Brazil.

Table 1. Geographic locations and sampling efforts for the study sites included in elaborating the current non-volant mammal species checklist for the state of Maranhão, Brazil.

	Sampling locations	Sampling periods	Central geographic coordinates	Sampling effort		
				Live-traps (nights/trapping)	Walking transects (km)	Camera-traps (nights/ trapping)
1	Ilha de São Luís	2010-2015	2°38'43.69" S / 44° 8'55.42" O	21.568	211	5.548
2	Baixada Maranhense	2017-2018	3°11'18.98" S / 44°56'52.29" O	2.520	15	-
3	Região do Gurupi	2003-2014	3°50'50.20" S / 46°45'52.37" O	10.080	98	25
4	Região do Bico do Papagaio e adjacências	1994/2008-2010	5° 6'40.00" S / 48°15'46.26" O	14.173	398	560
5	Região dos Cocais	2012-2013	4°44'19.71"S / 44°26'16.19" O	2.520	17	70
6	Região dos Lençóis Maranhenses	1994	2°36'46.53" S / 42°58'4.05" O	-	30	-
7	Cerrados de Urbano Santos	2005	3°15'21.21" S / 43°17'49.94" O	1.536	15	70
8	Região de Coelho Neto/MA	2008	4°14'5.25" S / 43° 2'27.73" O	2.520	17	70
9	Região de São Francisco do Maranhão	2009	6°15'54.25" S / 42°52'23.11" O	1.688	78	395
10	Região de Barão de Grajaú/MA	2009	6°41'24.58" S / 43° 2'29.19"O	2.110	82	410
11	Região de Benedito Leite/MA	2009	7°10'47.26" S / 44°32'23.00" O	1.960	66	355
12	Região de Tasso Fragoso/MA	2009	7°55'3.55" S / 45°37'18.59" O	1.822	85	420
13	Parque Estadual do Mirador	2013-2018	6°41'17.43" S / 45° 7'5.13" O	3.936	30	1.616
14	Região de Estreito-Carolina/MA	2002	7°17'29.34" S / 47°29'22.82" O	2.651	117	-
15	Região de Porto Franco/MA	2009	6°23'15.13" S / 47°20'17.73" O	1.978	25	100
	Total Effort			71.062	1.283	9.639

these same criteria were also used in the most recent evaluation of the conservation status for threatened fauna in Brazil (ICMBio, 2018).

Results

A total of 89 non-volant, wild mammal species were confirmed as occurring within the state boundaries of Maranhão (Table 2, Figures 2 and 3). Considering mammal species occurrences by biome, a total of 66 species were found to be associated with the Cerrado biome, and 65 species with the Amazon, 5 of which were recorded exclusively in the Amazonian region of the state.

Considering only non-volant mammals that are known to occur in Brazil, species richness in Maranhão represents 12.70% of the total richness proposed by Paglia et al. (2012) and 11.2% of that proposed by Quintela et al. (in press). (Table 3). The mammal species diversity of Maranhão is representative of 27 families and 9 orders. The three most diverse non-volant mammal orders in Brazil are the Rodentia, Primates and Didelphimorphia, although many taxonomic aspects of the first and last of these groupings are still poorly defined. Regarding the mammalian fauna of Maranhão according to the current results, the order Rodentia is the most representative (24 species), followed by Carnivora (20 species) and relegating Didelphimorphia (13 species) to the rank of third most diverse mammal order for the state.

A total of 23 of the 89 species recorded here, or 25.84%, are included in the Brazilian Red List of threatened and endangered animals (ICMBio, 2018). Of these 23 species, the order Carnivora is the most highly represented (10 species), followed by Primates (5 species) and Artiodactyla (3 species). Regarding IUCN threat of extinction categories, mammal species classified as being Vulnerable (VU) were the most highly represented (18 species).

Discussion

Systematic biological inventories are essential for assessing the conservation status of a region's biodiversity and help in providing guidelines to select priority areas for environmental protections (Diniz-Filho et al. 2004, Jenkins et al. 2015). The current study employed different approaches to collecting information regarding mammal species occurrence in Maranhão in order to create the most comprehensive state checklist possible. Nonetheless, and despite all of

Table 2. Checklist of non-volant mammal species registered as occuring in the state of Maranhão, Brazil.

TaxoN	Threat Category	Common Name	Biome	End Br	Type Of Record	Sampling Location
DIDELPHIMORPHIA						
Didelphidae						
Caluromys philander (Linnaeus, 1758)		Mucuri / Bare-tailed Woolly Opossum	Am, MA, Ce, Pt		C, V, Io	L3, L5, L6, 1, 2, 3, 4, 5, 7, 9, 11, 14
Chironectes minimus (Zimmermann, 1780)		Mucura-d'água / Water Opossum	Am, MA, Ce, Pt, Pp		Io, I	L4, L6, 3, 4
Didelphis albiventris Lund, 1840		Mucura / Guaiba Dwarf Mouse Opossum	Ce, Ca, Pt, Pp		C, V, Io	L3, L5, L6, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14
Didelphis marsupialis Linnaeus, 1758		Mucura / Common Opossum	Am		C, V, Io	L3, L5, L6, 1, 2, 3, 4, 5, 7, 9, 10, 11, 12, 14, 15
Gracilinanus agilis (Burmeister, 1854)		Mucuri / Agile Gracile Opossum	Ce, Ca, Pt		C	L3, L4, L5, L6, 1, 3, 4, 5, 7, 9, 10, 11, 12, 13, 14, 15
Marmosa murina (Linnaeus, 1758)		Mucuri / Linnaeus's Mouse Opossum	Am, MA, Ce, Pt		C	L3, L5, L6, 1, 3, 4, 5, 7, 8, 9, 10, 12, 13, 14, 15
Marmosops (Sciophanes) cf. *parvidens* (Tate, 1931)		Mucuri / Slender Opossum	Am		C	L6, 3, 4
Metachirus nudicaudatus		Mucura / Guianan Brown Four-eyed Opossum	Am, MA, Ce, Pt		C	L4, L6, 3, 4
Marmosa (Micoureus) demerarae		Mucuri / Woolly Mouse Opossum	Am, MA, Ce, Ca		C	L6, 2, 3, 4, 5, 9, 11, 12, 13
Monodelphis americana (Müller, 1776)		Mucuri / Northern Three-striped Opossum	MA, Ce		C	L6, 3, 4
Monodelphis domestica (Wagner, 1842)		Mucuri / Gray Short-tailed Opossum	MA, Ce, Ca, Pt		C	L3, L6, 1, 3, 4, 5, 7, 8, 9, 10, 11, 12, 14, 15
Philander opossum (Linnaeus, 1758)		Mucura-de-quatro-olhos / Gray Four-Eyed Opossum	Am, Ce, Pt		C	L3, L6, 3, 4, 14
Thylamys karimii (Petter, 1968)		Mucuri / Karimi's Fat-tailed Mouse Opossum	Ce, Ca	x	C	L3, 4, 10, 11, 12, 13, 14, 15
PILOSA						
Bradypodidae						
Bradypus variegatus Schinz, 1825		Preguiça / Brown-throated Sloth	Am, MA		V, Io, I	L2, L3, L5, L6, 1, 3, 4, 5, 6, 7, 9, 13, 14, 15
Cyclopedidae						
Cyclopes didactylus (Linnaeus, 1758)		Tamanduaí / Silky Anteater	Am, MA, Ce		V, I	L2, L5, L6, 1, 3, 4, 6
Megalonychidae						
Choloepus didactylus (Linnaeus, 1758)		Preguiça-real / Linnaeus's Two-toed Sloth	Am		V, I	L5, L6, 3, 4
Myrmecophagidae						
Myrmecophaga tridactyla Linnaeus, 1758	VU	Tamanduá-bandeira / Giant Anteater	Am, MA, Ce, Ca, Pt, Pp		V, Io, I	L3, L5, L6, 3, 4, 5, 9, 12, 13, 14, 15
Tamandua tetradactyla (Linnaeus, 1758)		Mambira / Tamandua	Am, MA, Ce, Ca, Pt, Pp		V, Io, I	L2, L3, L6, 1, 2, 3, 4, 5, 6, 7, 8, 10, 12, 13, 14, 15
CINGULATA						
Dasypodidae						
Cabassous unicinctus (Linnaeus, 1758)		Tatu-rabo-de-couro / Southern Naked-tailed Armadillo	Am, MA, Ce, Ca, Pt		Io, I	L3, L5, L6, 3, 4, 5, 7, 9, 13, 14, 15
Dasypus kappleri[1] Krauss, 1862		Tatu-quinze-quilos / Greater Long-nosed Armadillo	Am		Io, I	L4, L6, 3, 4
Dasypus novemcinctus Linnaeus, 1758		Tatu-comum / Nine-banded Armadillo	Am, MA, Ce, Ca, Pt, Pp		V, Io, I	L2, L3, L5, L6, 1, 3, 4, 5, 6, 7, 8, 9, 12, 13, 14, 15
Dasypus septemcinctus Linnaeus, 1758		Tatu-xina / Seven-banded Armadillo	Am, MA, Ce, Ca, Pt, Pp		V, Io, I	L3, L5, 4, 5, 7, 12, 13, 14, 15

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Euphractus sexcinctus (Linnaeus, 1758)		Tatu-peba / Six-banded Armadillo	Am, MA, Ce, Ca, Pt, Pp		V, Io, I	L2, L3, L5, L6, 1, 3, 4, 5, 6, 7, 8, 9, 11, 12, 13, 14, 15
Priodontes maximus (Kerr, 1792)	VU	Tatu-canastra / Giant Armadillo	Am, MA, Ce, Pt		Io, I	L3, L5, L6, 3, 4, 11, 12, 13
Tolypeutes tricinctus (Linnaeus, 1758)	EN	Tatu-bola-da-caatinga / Brazilian Three-banded Armadillo	Ce, Ca	x	Io, I	L3, L4, L5, 7, 13
PRIMATES						
Aotidae						
Aotus azarae infulatus (Kuhl, 1820)		Quatro-olhos / Feline Night Monkey	Am	x	V, Io, I	L3, L6, 3, 4, 5, 7, 11, 13, 14, 15
Atelidae						
Alouatta ululata Elliot, 1912	EN	Capelão / Maranhão Red-handed Howler Monkey	Am, Ca	x	V, Io, I	L2, L3, 3
Alouatta belzebul (Linnaeus, 1766)	VU	Capelão / Red-handed Howler Monkey	Am, MA	x	V, Io, I	L3, L6, 3, 4, 5, 6, 12, 13, 14, 15
Alouatta caraya (Humboldt, 1812)		Capelão / Black-and-Gold Howler Monkey	MA, Ce, Ca, Pt, Pp		V, Io, I	L6, 14
Callitrichidae						
Callithrix jacchus (Linnaeus, 1758)		Soim / Common Marmoset	MA	x	V	L2, L3, 5, 6, 7, 8, 9, 10, 11, 12, 13
Saguinus niger (É. Geoffroy, 1803)	VU	Soim / Black-handed Tamarin	Am	x	V	L6, 3, 4, 15
Cebidae						
Cebus kaapori Queiroz, 1992	CR	Cairara / Ka'apor Capuchin	Am	x	V, Io, I	L6, 3
Sapajus apella (Linnaeus, 1758)		Macaco-prego / Guianan Brown Tufted Capuchin	Am		V, Io, I	L2, L3, L6, 1, 3, 4, 6, 7, 8, 14, 15
Sapajus libidinosus (Spix, 1823)		Macaco-prego / Bearded Capuchin	MA, Ce, Ca	x	V, Io, I	5, 12, 13
Saimiri sciureus (Linnaeus, 1758)		Mão-de-ouro / Common Squirrel Monkey	Am		V, Io, I	L3, L6, 1, 3, 4, 14, 15
Pitheciidae						
Chiropotes satanas (Hoffmannsegg, 1807)	CR	Cuxiú-preto / Black Saki	Am	x	V, Io, I	L6, 3, 4
CARNIVORA						
Canidae						
Cerdocyon thous (Linnaeus, 1766)		Raposa / Crab-eating Fox	MA, Ce, Ca, Pt, Pp		V, Io, I	L2, L3, L6, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15
Chrysocyon brachyurus (Illiger, 1815)	VU	Lobo-guará / Maned Wolf	Ce, Pt, Pp		Io, I	L3, 4, 12, 13, 14, 15
Lycalopex vetulus (Lund, 1842)	VU	Raposa / Hoary Fox	Ce, Pt	x	V, Io, I	L3, 5, 7, 9, 10, 11, 12, 13, 14, 15
Speothos venaticus (Lund, 1842)	VU	Cachorro-do-mato / Bush Dog	Am, MA, Ce, Pt		V, I	L3, L6, 3, 4, 7, 12, 13, 14, 15
Procyonidae						
Nasua nasua (Linnaeus, 1766)		Quati / South American Coati	Am, MA, Ce, Ca, Pt, Pp		V, Io, I	L2, L3, L6, 1, 2, 3, 4, 5, 6, 7, 8, 12, 13, 14, 15
Potos flavus (Schreber, 1774)		Macaco-da-meia-noite / Kinkajou	Am, MA, Ce		I	L6, 3, 4
Procyon cancrivorus (G. Cuvier, 1798)		Guaxinim / Crab-eating Raccoon	Am, MA, Ce, Ca, Pt, Pp		V, Io, I	L2, L3, L6, 1, 3, 4, 5, 6, 7, 9, 11, 12, 13, 14, 15
Mustelidae						
Eira barbara (Linnaeus, 1758)		Papa–mel / Tayra	Am, MA, Ce, Ca, Pt		V, I	L3, L6, 3, 4, 5, 7, 12, 13, 14, 15
Galictis cuja (Molina, 1782)		Furão / Lesser Grison	MA, Ce, Ca, Pp		C, V, Io, I	L3, L6, 3, 4, 5, 7, 12, 13, 15

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Galictis vittata (Schreber, 1776)		Furão / Greater Grison	Am, MA, Ce, Ca, Pt		V, Io, I	L6, 3, 14
Lontra longicaudis (Olfers, 1818)		Lontra / Neotropical Otter	Am, Ma, Ce, Pt, Pp		V, I	L2, L3, L6, L7, 3, 4, 5, 6, 7, 9, 11, 12, 13, 14, 15
Pteronura brasiliensis (Gmelin, 1788)	VU	Ariranha / Giant Otter	Am, MA, Ce, Pt		V, Io, I	L6, L9, 3, 4, 7
Mephitidae						
Conepatus semistriatus[2] (Boddaert, 1785)		Gambá / Striped Hog-nosed Skunk	Am, MA, Ce, Ca, Pt		C, V, I	L3, L4, L6, 3, 5, 9, 12, 13, 14
Felidae						
Leopardus pardalis (Linnaeus, 1758)		Maracajá-verdadeiro / Ocelot	Am, MA, Ce, Ca, Pt, Pp		V, Io, I	L2, L3, L6, 1, 2, 3, 4, 5, 6, 7, 8, 10, 12, 13, 14, 15
Leopardus tigrinus (Schreber, 1775)	EN	Maracajá-í / Northern tiger cat	Am, MA, Ce, Ca, Pt, Pp		V, Io, I	L2, L3, L6, 3, 4, 5, 6, 7, 9, 10, 12, 13, 14, 15
Leopardus wiedii (Schinz, 1821)	VU	Maracajá-peludo / Margay	Am, MA, Ce, Ca, Pt, Pp		C, V, Io, I	L3, L6, 3, 4, 5, 7, 10, 13, 14, 15
Leopardus colocola (Molina, 1782)	VU	Gato-palheiro / Pampas cat	Ce, Pt, Pp		V, I	L3, 5, 10, 11, 12, 13, 14, 15
Panthera onca (Linnaeus, 1758)	VU	Onça-pintada/preta / Jaguar	Am, MA, Ce, Ca, Pt, Pp		Io, I	L3, L6, 3, 4, 5, 7, 9, 11, 12, 13, 14, 15
Puma concolor (Linnaeus, 1771)	VU	Onça-vermelha / Cougar	Am, MA, Ce, Ca, Pt, Pp		V, Io, I	L3, L6, 3, 4, 5, 7, 12, 13, 14, 15
Herpailurus yagouaroundi (É. Geoffroy, 1803)	VU	Gato-mourisco / Jaguarundi	Am, MA, Ce, Ca, Pt, Pp		V, I	L2, L3, L6, 2, 3, 4, 5, 6, 7, 11, 12, 13, 14, 15
PERISSODACTYLA						
Tapiridae						
Tapirus terrestris (Linnaeus, 1758)	VU	Anta / South American Tapir	Am, MA, Ce, Ca, Pt		V, Io, I	L3, L6, 3, 4, 12, 13, 14, 15
ARTIODACTYLA						
Tayassuidae						
Tayassu pecari (Link, 1795)	VU	Queixada / White-lipped Peccary	Am, MA, Ce, Ca, Pt, Pp		V, Io, I	L3, L6, 3, 4, 12, 13, 14, 15
Pecari tajacu (Linnaeus, 1758)		Caititu / Collared Peccary	Am, MA, Ce, Ca, Pt, Pp		V, Io, I	L2, L3, L6, 3, 4, 5, 6, 7, 12, 14, 15
Cervidae						
Blastocerus dichotomus (Illiger, 1815)	VU	Suçuapara / Marsh Deer	Ce, Pt		Io, I	L3, 13, 14
Mazama americana (Erxleben, 1777)		Veado-mateiro / South American Red Brocket	Am, MA, Ce, Pt		V, I	L3, L6, 3, 4, 5, 7, 12, 13, 14, 15
Mazama gouazoubira (G. Fischer, 1814)		Veado-catingueiro / South American Brow Brocket	Am, MA, Ce, Ca, Pt, Pp		V, I	L2, L3, L6, 3, 4, 5, 6, 7, 12, 13, 14, 15
Mazama nemorivaga (F. Cuvier, 1817)		Veado-foboca / Amazonian Brown Brocket Deer	Am		V, I	4
Ozotoceros bezoarticus (Linnaeus, 1758)	VU	Veado-galheiro / Pampas Deer	Ce, Pt, Pp		Io, I	L3, 4, 12, 13, 14
RODENTIA						
Sciuridae						
Sciurus aestuans Linnaeus, 1766		Quatipuru / Brazilian Squirrel	Am		C	L3, L6, L8, 3, 4, 5, 7, 14, 15
Cricetidae						
Calomys expulsus[3] (Lund, 1841)		Rato-do-chão / Caatinga Laucha	Ce, Ca	x	C	L3, 4, 7, 9, 10, 11, 12, 13, 14, 15
Cerradomys scotti (Langguth & Bonvicino, 2002)		Rato-do-mato / Lindbergh's Rice Rat	Ce, Pt		C	L3, 5, 9, 10, 11, 13, 14, 15
Hylaeamys megacephalus (G. Fischer, 1814)		Rato-do-mato / Azara's Broad-headed Rice Rat	Am, MA, Ce, Pt		C	L8, 5, 9, 12

Continue...

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Holochilus sciureus Wagner, 1842		Rato-d'água / Amazonian Marsh Rat	Am, Ce, Ca		C	L6, 1, 2, 3, 11
Necromys lasiurus (Lund, 1841)		Rato-do-mato / Hairy-tailed Akodont	Am, MA, Ce, Ca, Pt, Pp		C	L3, L6, 1, 3, 4, 7, 8, 11, 12, 13, 14
Nectomys rattus (Pelzeln, 1883)		Rato-d'água / Amazonian Water Rat	Am, Ce, Ca, Pt		C	L3, L6, L8, 3, 4
Oecomys cf. *bicolor* (Tomes, 1860)		Rato-da-árvore / White-bellied Arboreal Rice Rat	Am, Ce, Pt		C	L3, L6, 3, 4, 5, 9, 11, 12, 13
Oligoryzomys cf. *nigripes* (Olfers, 1818)		Rato-do-mato / Black-footed Colilargo	MA, Ce, Ca, Pt, Pp		C	L6, L8, 1, 3, 4, 5, 9, 10, 11, 12, 14
Rhipidomys emiliae (J. A. Allen, 1916)		Rato-da-árvore / Eastern Amazon Climbing Mouse	Am	x	C	L3, L6, L8, 3, 4, 9, 13
Rhipidomys cf. *macrurus* (Gervais, 1855)		Rato-da-árvore / Long-tailed Climbing Mouse	Ce, Ca	x	C	5, 10, 14
Thalpomys cf. *lasiotis* (Thomas, 1916)		Rato-do-chão / Hairy-eared Mouse	Ce	x	C	13
Wiedomys pyrrhorhinos (Wied-Neuwied, 1821)		Rato-de-fava / Red-nosed Mouse	Ca	x	C	9, 10, 11
Caviidae						
Galea spixii (Wagler, 1831)		Preá / Spix's Yellow-toothed Cavy	Am, MA, Ce, Ca, Pt		V, I	L3, L6, 1, 3, 4, 5, 6, 7, 13, 14, 15
Hydrochaeris hydrochaeris (Linnaeus, 1766)		Capivara / Capybara	Am, MA, Ce, Ca, Pt, Pp		V, Io, I	L3, L6, L8, 2, 3, 4, 5, 12, 13, 14, 15
Kerodon rupestris (Wied-Neuwied, 1820)	VU	Mocó / Rock Cavy	Ca	x	V, I	L3, L4, 9, 11, 12, 13, 14
Cuniculidae						
Cuniculus paca (Linnaeus, 1766)		Paca / Spotted Paca	Am, MA, Ce, Ca, Pt, Pp		V, Io, I	L2, L3, L6, 1, 2, 3, 4, 5, 6, 7, 9, 11, 12, 13, 14, 15
Dasyproctidae						
Dasyprocta prymnolopha Wagler, 1831		Cutia / Black-rumped Agouti	Am, MA, Ce, Ca	x	V, Io, I	L2, L3, L6, L8, 1, 2, 3, 4, 5, 6, 7, 8, 9, 11, 12, 13, 14, 15
Erethizontidae						
Coendou prehensilis (Linnaeus, 1758)		Ouriço, porco-espinho / Brazilian Porcupine	Am, MA, Ce, Ca, Pt		V, Io, I	L4, L6, 3, 4, 5, 7, 9, 10, 11, 12, 13, 14, 15
Echimyidae						
Dactylomys cf. *dactylinus* (Desmarest, 1817)		Toró, rato-do-bambu / Amazon Bamboo Rat	Am		C, V, I	L4, L6, L8, 3, 4, 15
Echimys chrysurus (Zimmermann, 1780)		Rato-da-árvore / White-faced Spiny Tree-rat	Am		C, V	L1, L3, L4, L6, L8, 3, 4, 7
Makalata cf. *didelphoides*		Rato-coró / Red-nosed Armored Tree-rat	Am		C, I	L3, L6, L8, 1, 3, 4, 5, 9, 13, 15
Proechimys roberti Thomas, 1901		Rato-de-espinho / Robert's Spiny-rat	Am, Ce	x	C, I	L3, L6, L8, 1, 2, 3, 4, 5, 7, 9, 12, 13, 14, 15
Thrichomys laurentius (Thomas, 1904)		Punaré, rabudo / São Lourenço's Punaré	MA, Ca	x	C, I	L3, 5, 7, 8, 10, 11, 12, 13, 14
LAGOMORPHA						
Leporidae						
Sylvilagus brasiliensis (Linnaeus, 1758)		Coelho, tapeti / Tapeti	Am, MA, Ce, Ca, Pt, Pp		V, Io, I	L3, L6, 3, 4, 5, 7, 9, 11, 12, 13, 14, 15

Legend: Species under taxonomic revision: [1] = *Dasypus beniensis* **(Feijo & Cordeiro-Estrela 2016);** [2] = *Conepatus amazonicus* **(Feijó & Langguth 2013);** [3] = *Calomys mattevii* **(Gurgel-Filho et al.** 2015); Threat category (ICMBio, 2018): CR = Critically Endangered, EN = Endangered, VU = vulnerable; Biome: Am = Amazon, MA = Mata Atlântica/Atlantic Forest, Ce = Cerrado, Ca = Caatinga, Pt = Pantanal, Pp = Pampas; End BR = Endemic to Brazil; Type of Record: C = capture, V = direct observation/camera-trap, Io = indirect observation/tracks or remains, I = Interview; Sampling locations: L1 = Oliveira & Mesquita (1998), L2 = Oliveira & Bogéa (2004), L3 = Oliveira et al. (2007a), L4 = Oliveira et al. (2007b), L5 = Gardner et al. (2008), L6 = Oliveira et al. (2011), L7 = Mesquita & Meneses (2015), L8 = Patton et al. (2015), L9 = Prist et al. (2017), 1 = Ilha de São Luís, 2 = Baixada Maranhense, 3 = Região do Gurupi, 4 = Região do Bico do Papagaio e adjacências, 5 = Região dos cocais, 6 = Região dos Lençóis Maranhenses, 7 = Cerrados de Urbano Santos/MA, 8 = Região de Coelho Neto/MA, 9 = Região de São Francisco do Maranhão, 10 = Região de Barão de Grajaú/MA, 11 = Região de Benedito Leite/MA, 12 = Região de Tasso Fragoso/MA, 13 = Parque Estadual do Mirador, 14 = Região de Estreito-Carolina/MA, 15 = Região de Porto Franco/MA.

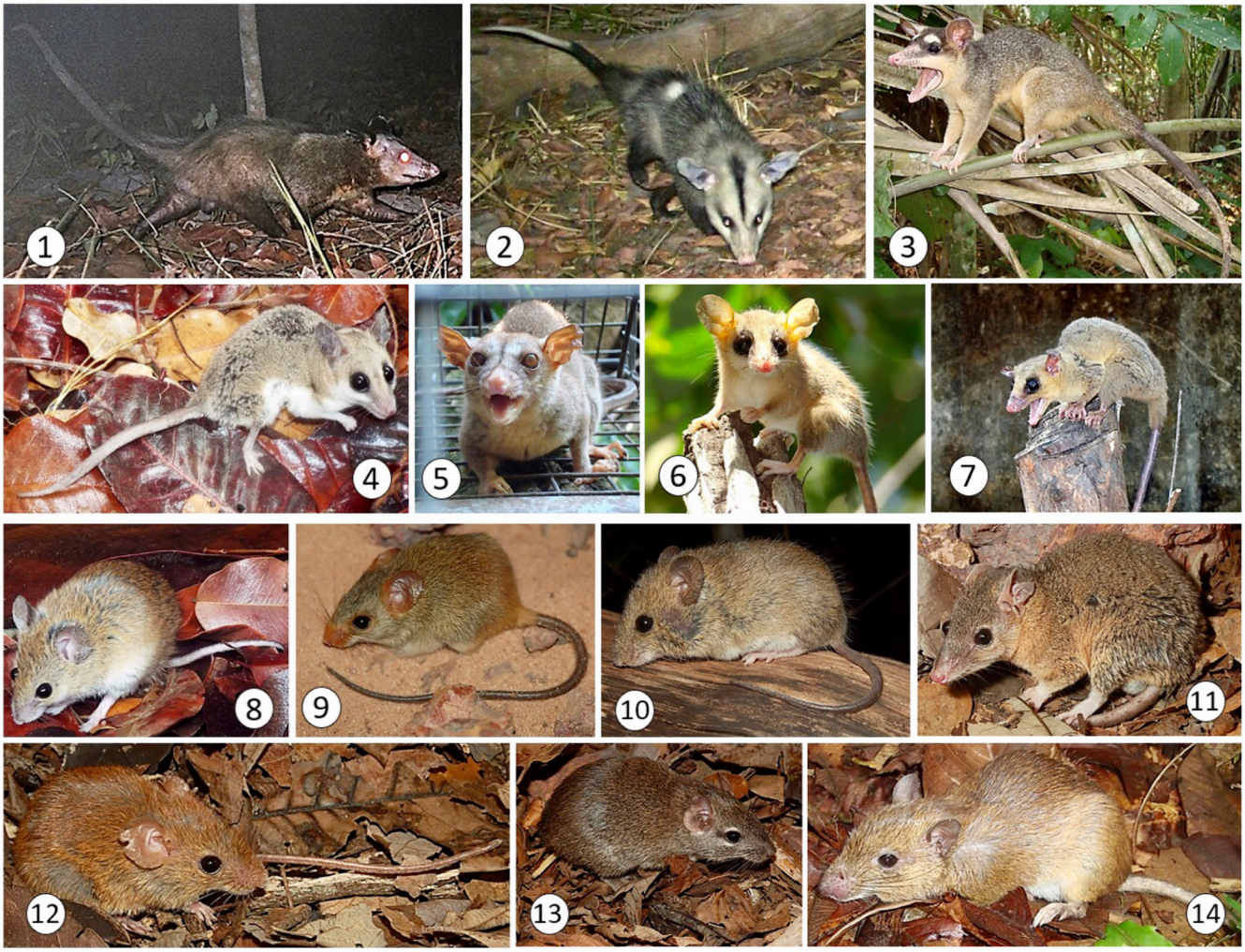

Figure 2. Records of small non-volant mammalian species in Maranhão state, Brazil. 1 = *Didelphis marsupialis*, 2 = *Didelphis albiventris*, 3 = *Phylander opossum*, 4 = *Thylamis karimii*, 5 = *Caluromys philander*, 6 = *Gracilinanus agilis*, 7 = *Marmosa (Micoureus) demerarae*, 8 = *Thalpomys cf. lasiotis*, 9 = *Wiedomys pyrrhorhinos,* 10 = *Calomys expulsus*, 11 = *Monodelphis domestica,* 12 = *Cerradomys scotti,* 13 = *Thrichomys laurentius,* 14 = *Proechimys roberti*

the evidence considered in elaborating the resulting checklist, it is likely that the actual species richness of non-volant mammals for the state of Maranhão is somewhat greater than what is reported here.

Compared to previously published information, the checklist based on the current assessment adds 4 unique records for the state of Maranhão. Oliveira et al. (2007a, 2011) listed 82 species as occurring in Maranhão, while Lima (2009) added one important record of *Tolypeutes tricinctus*, species present in the Nascentes do Rio Parnaíba National Park, the area of which is mostly located within the state boundary of Piauí state and extends into just a small part of Maranhão. Although less representative quantitatively, Oliveira & Mesquita (1998), Oliveira & Bogéa (2004), Oliveira et al. (2007b), Gardner (2008), Mesquita & Meneses (2015), Prist et al. (2017) and Patton et al. (2015) were also consulted, corroborating the occurrence of the species already described for some of the study locations. The last two of these publications represent complete taxonomic revisions and result from international collaborations to most accurately define the identification, distribution and taxonomy of South American mammal species as a whole.

Non-volant mammal species richness in Maranhão in the Amazon (N = 65) and Cerrado (N = 66) regions of Maranhão is similar. This represents 16.3% and 26.3% respectively, of the total species diversity for this group at the national level. Nineteen species were recorded at more than 10 of the study sites, corroborating their characterization as generalists occurring in all of dominant landscapes of Maranhão. Among the 16 that Paglia et al. (2012) listed as being exclusive to the Amazon (Table 2), only *Choloepus didactylus*, *Cebus kaapori*, *Chiropotes satanas*, *Mazama nemorivaga* and *Marmosops* cf. *parvidens* were recorded exclusively in the Amazonian portion of the state. *Didelphis marsupialis*, *Sapajus apella*, *Aotus azarae infulatus*, and *Sciurus aestuans* were recorded outside the Amazon domain, thus confirming their expected presence in forested areas beyond the Amazon-Cerrado ecotone (Feijó & Langguth 2013, Pinto & Roberto, 2016, Lima et al. 2017, Patton et al. 2015). *Rhipidomys emiliae*, *Dactylomys* cf. *dactylinus* and *Makalata* cf. *didelphoides* complete the list of Amazonian species recorded in forested areas within savanna landscapes, thus highlighting the role of these forests as corridors that allow the expansion of small Amazonian mammals into the Cerrado (Redford & Fonseca 1986, Costa 2003, Carmignotto 2005).

Figure 3. Records of medium and large non-volant mammalian species in Maranhão state, Brazil. 1 = *Tamandua tetradactyla,* 2 = *Myrmecophaga tridactyla,* 3 = *Priodontes maximus,* 4 = *Dasypus novemcinctus,* 5 = *Cyclops didactylus,* 6 = *Eira barbara,* 7 = *Lycalopex vetulus,* 8 = *Cerdocyon thous,* 9 = *Speothos venaticus,* 10 = *Nasua nasua,* 11 = *Procyon cancrivorus,* 12 = *Conepatus semistriatus,* 13 = *Galictis cuja,* 14 = *Galictis vitatta,* 15 = *Lontra longicaudis,* 16 = *Leopardus colocola,* 17 = *Herpailurus yagouaroundi,* 18 = *Puma concolor,* 19 = *Leopardus wiedii,* 20 = *Leopardus tigrinus,* 21 = *Leopardus pardalis,* 22 = *Panthera onca,* 23 = *Sapajus apella,* 24 = *Aotus azarae infulatus,* 25 = *Chiropotes satanas,* 26 = *Cebus kaapori,* 27 = *Alouatta caraya,* 28 = *Callithrix jacchus,* 29 = *Saguinus niger,* 30 = *Ozotoceros bezoarticus* , 31 = *Mazama americana,* 32 = *Mazama gouazoubira,* 33 = *Tayassu pecari,* 34 = *Pecari tajacu,* 35 = *Tapirus terrestris,* 36 = *Dasyprocta prymnolopha,* 37 = *Cuniculus paca,* 38 = *Coendou prehensilis,* 39 = *Hydrochaeris hydrochaeris*

Table 3. Comparison of non-volant mammal species richness for recent in Brazil and the states of Maranhão (MA), Mato Grosso do Sul (MS), Mato Grosso (MT), São Paulo (SP), Rio de Janeiro (RJ) and Santa Catarina (SC).

Order	Brazil		State					
	Paglia et al. (2012)	Quintela et al. (in press)	MA	MS	MT	SP	RJ	SC
Didelphimorphia	55	59	13	17	31	24	14	17
Pilosa	8	12	5	2	5	3	4	4
Cingulata	11	12	7	7	9	5	5	5
Primates	118	125	11	6	26	10	9	3
Carnivora	33	35	20	20	21	17	17	26
Perissodactyla	1	2	1	1	1	1	1	1
Artiodactyla	10	10	7	6	7	8	4	7
Rodentia	234	255	24	33	67	58	49	54
Lagomorpha	1	2	1	1	1	1	1	1
Total	471	512	89	93	168	127	104	118

MA = this paper; MS = Tomas et al. (2017); MT = Brandão et al. (2019); SP = Vivo et al. (2011); RJ = Rocha et al. (2004); SC = Cherem et al. (2004);

Echimys chrysurus is the last Amazonian species to reach the forest formations in the Cerrado biome, between the municipalities of Urbano Santos and Vargem Grande, clearly because of the deciduous forests in that region (Oliveira & Mesquita, 1998).

Maranhão state houses 20 species endemic to Brazil (Table 2). It is worth noting the case of Primates, with four out of five species being associated to the Amazonian portion of the state, which currently faces a critical conservation outlook (Oliveira et al 2011). *Cebus kaapori* and *Chiropotes satanas* were recorded in areas of primary and disturbed forests, besides this they are both rare and highly threatened throughout their range (Almeida & Vieira 2010). *Saguinus niger* has a range similar to *C. kaapori* and *C. satanas* within the state, nevertheless the species was recorded more often in disturbed habitats, and this species tends to be common in anthropic environments (Mendes-Oliveira 1996). *Thylamys karimii*, has been reported on the western portion of Maranhão state in the Bico do Papagaio region, yet its single record was in a marginal portion of that region, in open areas of Cerrado savanna as expected (Carmignotto & Monfort 2006, Gardner 2008). *Lycalopex vetulus* and *Thalomys lasiotis* were recorded only in the Cerrado portion of the state; both species are typically associated to the central Cerrado further south, however *L. vetulus* has been expanding its range towards the north and northeast regions of the country, and the same seems likely for *Thalomys lasiotis* (Marinho-Filho et al. 2002, Dalponte 2009, Lemos et al. 2013). Three species were recorded marginally outside their typical biomes, *Wiedomys pyrrhorhinos*, *Kerodon rupestris* and *Callithrix jacchus*, the first two outside the Caatinga (Oliveira et al. 2003, Gonçalves et al. 2005, Oliveira & Bonvicino 2011), while the last one outside the Atlantic Forest. *C. jacchus* is an introduced species (Da Rosa et al. 2017) that has reached the central part of the Maranhão Babaçú Forest ecoregion, this area has witnessed major habitat destruction particularly in the Itapecuru river basin (Silva Jr. 1999).

Certain species that are most often associated with open habitats in the state, such as *Cerdocyon thous* (recorded at all sampling points), *Lycalopex vetulus* and *Galictis cuja*, showed that their actual distributions can extend beyond the proposed limits of savanna or grassland type environments. Nonetheless, these unusual occurrences may be best explained by the effects of expanding agro-pastoral environments on the displacement of both generalists and highly specialized species, which show some tendencies to disperse from disturbed areas through open habitat formations (Michalski & Peres 2005, Umetsu & Pardini 2007, Oliveira 2009).

Among the rare species for Maranhão, *Blastocerus dichotomus* stands out with its distribution reaching the southern limits of the state where there are well-preserved areas of Cerrado near Chapada das Mesas and Nascentes do Parnaíba National Parks. *Tolypeutes tricinctus*, a threatened species that is relatively sensitive to anthropogenic disturbances, was documented by means of personal interviews in the region of Urbano Santos and Mirador State Park, though in the latter, it has apparently not been seen for 20 years. *Alouatta ululata* is usually found in open and transitional babaçu forests (Gregori, 2006), yet we recorded this species in the Amazonian region, far west than its known distribution limit. The occurrence of species outside of their proposed distributions, according to the literature, highlights the ecotone effects of the terrestrial environment in Maranhão, which also contributes to the high levels of biodiversity and shows that this transitional zone among several biomes can appear to be much more species rich than when considering these biomes separately (Marimon et al. 2006, Mews et al. 2012, Marimon et al 2014).

Considering only the list of species, independent of the size of the sampling areas, Oliveira et al. (2010) recorded 57 non-volant mammal species in an inventory of Mato Grosso state, which is also characterized as a transitional area between the Amazon and Cerrado biomes and is located in the middle of a region known as the Amazonian Deforestation Arc for its high deforestation rates. Comparing these biomes separately, an inventory conducted in Amazonia National Park, located in the state of Pará, compiled a list of 86 species in an area 10 times smaller than the territory of Maranhão (Oliveira et al. 2016), while 52 species were registered just in Mirador State Park, which includes only 2% of all Cerrado vegetation occurring in the state of Maranhão (Oliveira et al. 2014).

In spite of the diverse criteria, as well as constant updates to the list, the Amazon and Cerrado biomes support at least 399 and 251 mammal species, respectively (Paglia et al. 2012). However, it is also observed that states closer to major urban centers, and where most researchers are concentrated, register numbers of species close to those observed in the current study. For example, in Mato Grosso do Sul, a very large state territory presenting a diversity of biomes, including Cerrado, Atlantic Forest and Pantanal, Tomas et al. (2017) compiled a list of 93 species. Recently Brandão et al. (2019) listed 168 non-volant mammals for Mato

Grosso, a state straddling the Amazon-Cerrado ecotone. Cherem et al. (2004) elaborated a list of 118 non-volant species occurring in the state of Santa Catarina, while Rocha et al. (2004) documented 104 species for the state of Rio de Janeiro, the latter presenting fewer biomes and fauna typical of Atlantic Forest. In São Paulo, a state with a much greater tradition of executing biological inventories, Vivo et al. (2011) compiled a list of 127 non-volant mammal species, which suggests that the species diversity so far recorded for the state of Maranhão is representative, although with significant gaps in the effort to sample such an enormous habitat diversity as that presented by the two dominant biomes. It should also be mentioned that very few scientific studies of non-volant mammals occurring in the state of Maranhão have been published in the primary literature, with much of the available information on this subject having appeared in unconventional outlets and/or formats, such as technical and research reports, dissertations, theses and congress proceedings with restricted disclosure and dissemination, contributing to our collective lack of comprehensive information about this group of animals.

The interaction between geomorphological and climatic aspects typical of ecotones favors the evolutionary process of genetic and ecological diversification in communities and populations (Brasil, 2007). Thus, the relatively large number of mammal species presented here as occurring in Maranhão is a direct reflection of the state being located in a transitional region between three major biomes, the Amazon, Caatinga and Cerrado. Because of this high-level of species richness and diversity of habitats, Maranhão requires special consideration in conserving the integrity of these dynamic and not very stable environments (Marimon et al. 2014). The presence of such an ecological stress zone would also justify the observation of a non-diminishing west-east trend in species richness, whereby the most diverse mammal communities are located in lowland forests along the Amazon basin to the Andes and less species diversity is characteristic of the drier, more easterly boundaries of the region toward Pará-Maranhão (Eisenberg & Redford, 1999).

Finally, it is noteworthy that Maranhão is currently being subject to intense habitat fragmentation, primarily due to the impacts of expanding commercial farming and livestock activities. The study sites sampled for the current study correspond to habitat remnants that act as vital refuges for non-volant mammals and countless other wildlife species. Considering that landscape integrity is a good indicator of biodiversity, conservation actions in such areas, even fragmented landscapes, are of fundamental importance to the protection of natural resources and the variety of flora and fauna (De Araújo et al. 2016, Brazil 2018). Additional studies of the mammalian fauna of Maranhão, and other parts of the Northeast region of Brazil, are necessary for a better understanding of species diversity, abundance and distribution. The lack of information, both taxonomic and geographical, regarding non-volant mammals of Maranhão also reinforces the need for further work, such as that presented here, which can result in more accessible scientific publications that document the important biodiversity occurring in this rapidly changing landscape.

Supplementary material

The following online material is available for this article:

Table S1 - Specimen identification numbers for individuals that were collected and donated to vertebrate collections at each institution.

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Author Contributions

Odgley Quixaba Vieira: contributed to the conception and design of this study, contribution to data collection data collection, contribution to data analysis and interpretation, contribution to manuscript preparation.

Tadeu Gomes de Oliveira: substantial contribution in the concept and design of the study, contribution to data collection data collection, contribution to data analysis and interpretation, contribution to manuscript preparation, contribution to critical revision, adding intellectual content.

Conflicts of Interest

The authors declares that they have no conflict of interest related to the publication of this manuscript.

Ethics

Data obtained from interviews are in fact reports and accounts from local people without any standardized structure. Some of the data presented were collected starting in 1994 (see Table 1 of paper), which was before the implementation of “Plataforma Brasil” and the Resolution Nº466/12/CNS. The later deals with information obtained, partially or wholly, from humans.

Data availability

This research is part of an ongoing doctoral dissertation with the proposed analyses unfinished as of right now. Therefore data archiving in public repositories is partially unavailable at the moment. Notwithstanding, the development of the databases within this research project is being done jointly with the Ecologic-Economic Zoning of Maranhão State project (ZEE Maranhão) using Geographic Information Systems (GIS). As such, some of the data are available for public use on the official website of ZEE Maranhão.

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