



UNIVERSIDADE FEDERAL DE GOIÁS
INSTITUTO DE CIÊNCIAS BIOLÓGICAS
PROGRAMA DE PÓS-GRADUAÇÃO EM
ECOLOGIA E EVOLUÇÃO



Frederico Augusto Martins Valtuille Faleiro

**PRIORIDADES ESPACIAIS PARA A CONSERVAÇÃO DE
MAMÍFEROS DO CERRADO EM UM MUNDO EM
MUDANÇA**

Orientador: Dr. Rafael Dias Loyola

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Dissertação apresentada à Universidade Federal de Goiás, como parte das exigências do Programa de Pós-graduação em Ecologia e Evolução para obtenção do título de *Magister Scientiae*.

Orientador: Dr. Rafael Dias Loyola

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Assinatura do (a) autor (a)

À minha família, amigos e ao meu amor Carol,
pelo apoio e alegria que me manteve
otimista perante as dificuldades.

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RESUMO

As ações humanas têm desencadeado diversas ameaças a biodiversidade como as mudanças de uso do solo e do clima, sobre-exploração, poluição e introdução de espécies invasoras, que afetam os organismos da escala local até a global. A ciência da conservação espacial para conservação emergiu como uma abordagem quantitativa que tem o objetivo de auxiliar escolhas espaciais que lidem com essas ameaças enquanto minimizam conflitos socioeconômicos e políticos. Aqui nós desenvolvemos soluções espaciais para conservação de mamíferos não voadores do Cerrado considerando os custos socioeconômicos e as oportunidades vindas da governança ambiental (primeiro objetivo). Além disso, nós geramos soluções espaciais que lidem com as mudanças do uso do solo e climáticas levando em consideração as capacidades de dispersão das espécies e as incertezas associadas ao processo de modelagem de distribuição de espécies (MDE) (segundo objetivo). Em ambos objetivos nós consideramos a atual rede de reservas do Cerrado. Nós modelamos a distribuição de 154 espécies combinando as projeções dos modelos e pesado pelo ajuste estatístico para produzir os mapas consenso de distribuição das espécies, agrupados em três distintos tipos de modelos (modelos de envelope, estatísticos e de inteligência artificial), para a atualidade e projetados para o futuro (usado apenas no último objetivo). Para o primeiro objetivo, nós usamos as predições da atual distribuição das espécies para realizar as análises de priorização espacial, indicando os melhores locais para investimento considerando a densidade humana, custo da terra, uso do solo antropogênico, nível de governança ambiental e a distribuição das espécies na perspectiva da análise de demandas conflitantes. Para o segundo objetivo, nós usamos a distribuição atual e futura das espécies para realizar o procedimento de otimização e propor locais para conservação que minimizem os efeitos da dispersão induzida pelas mudanças climáticas, incertezas associadas ao processo MDE e considerando as futuras mudanças na paisagem (através do nosso modelo de uso do solo). A MDE indicou que locais ricos em espécies convergem para locais com alta densidade populacional, alto custo de terra, alta proporção de uso do solo voltado para atividades humanas e diversos níveis de governança ambiental. Houve significativas mudanças nas prioridades espaciais quando as dimensões socioeconômicas e políticas foram incluídas nas análises, fazendo que os locais prioritários mudassem para o norte. Essa mudança espacial reduziu em 68% de potenciais conflitos com população humana, em 72% de conflitos de custo da terra, em 68% de conflitos com o uso do solo antropogênico e 51% de aumento dos possíveis benefícios da governança ambiental. Quando incluímos as mudanças de uso de solo e a incerteza da modelagem no processo de planejamento, os locais prioritários mudaram significativamente na região. Enquanto a

inclusão das mudanças no uso do solo alterou a localização espacial dos locais prioritários em escala regional, os efeitos da mudança climática tenderam a ocorrerem em escala local. Note que nossas soluções já incluíram possíveis corredores de dispersão para ligação entre as atuais áreas prioritárias com aquelas importantes no futuro, tão bem quanto a análise de risco baseado nas incertezas do planejamento. Nossos resultados permitiram lidar tanto com a complexa natureza dos conflitos entre dimensões socioeconômicas e políticas quanto com problema dinâmico imposto principalmente pelas mudanças do uso do solo e climáticas. Assim, nossas análises auxiliam metodologicamente a dar suporte no processo de tomada de decisão e a consequente tradução dos resultados de planejamentos de conservação em ações de conservação.

Palavras-chave: Conflitos de conservação, planejamento sistemático de conservação, priorização espacial para conservação, análise por múltiplos critérios, Zonation, Convenção da Diversidade Biológica, aquecimento global, modelos de distribuição de espécies, incertezas, Cerrado Brasileiro, mamíferos.

ABSTRACT

The human actions has triggered many threats to biodiversity like land-use and climate changes, overexploitation, pollution, and introduction of invasive species, which can affect organisms both at local and global scale. The science of spatial conservation prioritization emerged as a quantitative approach to support the spatial decisions in face of these threats, while minimizing the socioeconomic and political conflicts. Here we developed spatial solutions to the conservation of non-flying mammals from Brazilian Cerrado considering the socioeconomic costs and the opportunities of environmental governance (first objective). Further, we generated solutions to face the land-use and climate change taking into account the dispersal abilities of species and uncertainties in the species distribution modeling (SDM) process (second objective). We considered the current network of reserves of the Cerrado in both objectives. We built SDMs for 154 species combining model projections weighted by their statistical fit to produce consensus maps of species distribution grouped in three distinct types of models (envelope, statistical and machine-learning models), for both current future scenarios of climate (used only in the last aim). For the first goal, we used the current predicted distribution to run spatial prioritization analyses indicating the best sites for the conservation investment considering human population density, land cost, anthropogenic land use, level of environmental governance, and the distribution of species in trade-off analyses. For the second goal, we used both current and future predicted distribution to run optimization procedures and propose priority sites for conservation, while minimizing species climate-forced dispersal distance , the mean uncertainty associated to the SDM process, and taking into account the future changes in the landscape (by our land use model). SDMs indicated that species-rich sites converge to regions with high population density, high land cost, high anthropogenic land use, and with diverse levels of environmental governance. There was a significant change in spatial priorities when socioeconomic and political dimensions were included in analyses: top priority sites moved towards the north. This spatial change reduced by 68% the potential conservation conflicts with human population, by 72% the likely conflicts arising from land cost and by 68% anthropogenic land use. It also increased by 51% the beneficial effect of environmental governance. Including land-use changes and the modeling uncertainty in the conservation planning process changed significantly the spatial distribution of priority sites in the region. While the inclusion of land-use models altered the spatial location of priority sites at the regional scale, the effects of climate change tended to take place at the local scale. Note that, our solutions already include

possible dispersal corridors linking current and future priority sites for mammal conservation, as well as a formal risk analysis based on planning uncertainties. Our results allowed dealing with both complex nature of conflicts among socioeconomic and political dimensions, and the dynamic problem imposed mainly by land-use and climate change. Thus, our analyses figure as a methodological prospect supporting the decision-make process and the consequent translation of conservation planning outcomes into conservations actions.

Key words: Conservation conflicts, systematic conservation planning, multi-criteria analysis, Zonation, Convention on Biological Diversity, global warming, species distribution models, uncertainties, Brazilian Cerrado, mammals.

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INTRODUÇÃO GERAL

Áreas prioritárias para conservação no tempo e no espaço: indo além da representação biológica e do paradigma de lugar

As ações humanas têm desencadeado diversas ameaças a biodiversidade como as mudanças de uso do solo e do clima, sobre-exploração, poluição e introdução de espécies invasoras, que afetam os organismos da escala local até a global (Schipper et al. 2008; Brook et al. 2008; Hoffmann et al. 2010; Barnosky et al. 2011; Maclean & Wilson 2011; Mantyka-Pringle et al. 2011). Sendo as mudanças de uso do solo e climáticas consideradas as piores ameaças a biodiversidade (Sala et al. 2000; Thomas et al. 2004; Pereira et al. 2010) e seus efeitos sinérgicos (interação entre as duas ameaças) são ainda maiores (Brook et al. 2008; Asner et al. 2010; Mantyka-Pringle et al. 2011).

Tais ameaças têm impulsionado o desenvolvimento e integração de diversos campos da ciência a fim de entender e guiar ações para sua minimização (Dawson et al. 2011). Uma das respostas científicas a crise global de diversidade é a ciência da priorização espacial para conservação que utiliza de métodos quantitativos para auxiliar escolhas espaciais que tenham o melhor retorno de investimentos em conservação (Ferrier & Wintle 2009). Esse ramo da ciência apesar de relativamente novo, têm gerado grande conhecimentos teóricos, conceituais e metodológicos que auxiliam no processo de tomada de decisão em situações reais de conservação (Moilanen et al. 2009).

No entanto mesmo com o forte desenvolvimento científico, raramente os planejamentos são traduzidos em reais ações de conservação, criando uma lacuna de entre a ciência e a implementação (Knight et al. 2009). Tal lacuna tem sido justificada pela falta de interação de critérios puramente biológicos com fatores sociais, econômicos, políticos e institucionais durante o processo de planejamento (O'Connor et al. 2003; Sarkar et al. 2006; Naidoo et al. 2006; McBride et al. 2007; Knight et al. 2008, 2009). Em parte a falta de integração de critérios biológicos (espécie, fisionomias vegetais, processos ecossistêmicos) com critérios não biológicos tem as raízes na incapacidade dos biólogos em lidar com assuntos fora de suas tradições de pesquisa, dificuldade de obtenção desses dados e falta e/ou incapacidade de lidar com métodos de outros campos científicos (economia, sociologia, etc), além da relutância em

deixar que outros fatores não biológicos ditem em partes os resultados dos planejamentos (Naidoo et al. 2006; Ban & Klein 2009).

Tal situação é agravada por evidências de que os planejamentos de conservação são mais sensíveis a critérios não biológicos do que a variação nos grupos taxonômicos (Bode et al. 2008). Assim a desconsideração desses critérios pode aumentar a representação de aspectos biológicos, mas por outro lado aumenta também os conflitos de conservação com outras atividades humanas, como áreas de interesse turístico, agrícolas, influência de cidades, altos custos de terra (Balmford et al. 2001; Moffett & Sarkar 2006; Rangel et al. 2007; Carwardine et al. 2008). E como consequência há uma menor chance desses planejamentos serem transformados em ações reais de conservação (Knight et al. 2008) ou um aumento do risco de extinção, caso tais planejamentos sejam convertidos em ações, como no estabelecimento de reservas ou de áreas para restauração ecológica (Cardillo et al. 2004; Gaston 2005).

Apesar dessas dificuldades em se incorporar fatores socioeconômicos, políticos e institucionais nos planejamento de conservação, alguns avanços têm sido feito em busca de superar o foco aos aspectos puramente biológicos. Os custos econômicos podem ser integrados de várias formas, mas duas delas merecem destaque: análise de custos e benefícios (do inglês “cost–benefit analysis”) e análise de minimização dos custos (do inglês “cost-effectiveness analyses”) (Naidoo et al. 2006; Engel et al. 2008).

A análise de custos e benefícios necessita da quantificação dos bens (alimentos, fitoterápicos, fibras, alimentos, etc) e serviços (purificação do ar e da água, regulação climática, polinização de plantações, decomposição, etc) ecossistêmicos de uma determinada área em termos monetários para sua aplicação (de Groot 2002; Engel et al. 2008). Em seguida se faz uma comparação entre o valor que a área geraria por uma determinada atividade econômica e seu valor ecossistêmico, assim é possível escolher áreas destinadas para atividades econômicas e para preservação ambiental (Naidoo et al. 2006). Essa abordagem tem a vantagem de quantificar ambos os fatores em uma mesma unidade de medida (valor monetário), mas tem a desvantagem de ser limitada a medir valores sobre uma lógica antropocêntrica, sendo menos tangíveis valores de existência das espécies ou mesmo valores ainda não descobertos, como o fornecimento de compostos químicos para fabricação de medicamentos (Naidoo et al. 2006).

Devido a tais limitações, os planejamentos de conservação de maneira geral tem utilizado a análise de minimização dos custos, que busca minimizar diferentes custos econômicos que competem com o valor biológico de uma determinada área (Moffett & Sarkar 2006; Naidoo et al. 2006). Assim a maior necessidade dessa abordagem é a disponibilidade de dados e/ou de métodos que quantifiquem o valor econômico de uma área em termos monetários ligados, por exemplo, a aquisição de terra, manejo, prejuízos a atividades econômicas nas proximidades (predação do gado, destruição de plantações, etc), ou custos de oportunidades ou não monetários que envolvem qualquer atividades que poderiam ser desenvolvidas na área, podendo ser medidas em número de sacas de soja, número de cabeças de gado, toneladas de peixe, etc (Moffett & Sarkar 2006; Naidoo et al. 2006; Ban & Klein 2009).

Os aspectos sociais também tem recebido ênfase nos planejamentos e são muitas vezes intimamente relacionados aos fatores econômicos, principalmente aqueles ligados com os custos de oportunidades, como o número de pessoas afetadas pela redução de áreas agrícolas, cidades, extrativismo, etc. Porém alguns aspectos podem ser medidos sem uma ligação tão forte com fatores econômicos. O tamanho ou densidade da população humana tem sido o foco de grande parte dos trabalhos, tanto pela facilidade de dados, quanto por ser um fator importante na determinação do risco de extinção das espécies e representar de maneira simples o conflito social, medido em número de pessoas afetadas pelo plano de conservação (Cardillo et al. 2004; Gaston 2005). O tamanho populacional tem a vantagem de ser predita com certa precisão em tempos futuros, sendo possível incluí-la como uma medida de futuros conflitos (Loyola et al. 2009). Além desses existe a possibilidade de incluir conflitos com fatores culturais, como a presença de áreas sagradas para determinadas comunidades (Cameron et al. 2008).

Os aspectos políticos tem sido foco de recentes estudos em escala global, considerando o nível de corrupção dos países como uma medida de governança (O'Connor et al. 2003; Garnett et al. 2011; Eklund et al. 2011). Tais estudos partem da premissa que os investimentos econômicos podem ser melhor aproveitados por países com menor corrupção, já que os recursos seriam melhor geridos para se alcançar os objetivos de conservação (Garnett et al. 2011; Eklund et al. 2011). Assim em escala global os planejamentos que consideram apenas critérios biológicos e econômicos (preço da terra) tendem a destacar a importância de países em desenvolvimento, no entanto quando o fator político é incluído, as prioridades mudam

para países desenvolvidos, onde o preço da terra é alto, o valor biológico é baixo, mas a governança é alta (Eklund et al. 2011). No entanto os cientistas vêm debatendo essa possível ligação entre corrupção e conservação (Ferraro 2005; Smith & Walpole 2005; Katzner 2005; Walpole & Smith 2005) e análises não tem encontrado suporte para tal pressuposto (Barrett et al. 2006). Assim mais do que modelar ou obter dados que possam ser usados como conflitos, é preciso testá-los e discuti-los para garantir suas validades.

Neste contexto a análise por múltiplos critérios (AMC) é uma forma de se tratar problemas em que se tenha diversas dimensões envolvidas na determinação da solução final (Moffett & Sarkar 2006). Existindo basicamente dois protocolos que podem ser combinados para gerar planos de conservação: o protocolo iterativo e o terminal (Moffett & Sarkar 2006). O iterativo ou análise de demandas conflitantes (do inglês “trade-off analyses”) considera todos os critérios ao mesmo tempo, fazendo um balanço entre cada critério para selecionar ou ranquear as área (Moffett & Sarkar 2006; Moilanen et al. 2011). Já o protocolo terminal primeiramente busca alcançar os alvos de conservação e em seguida as áreas são ordenadas do menor “custo” para o maior “custo”, sendo enviesado para a valorização dos aspectos biológicos das áreas (Moffett & Sarkar 2006). A utilização de poucos critérios tem a vantagem de serem facilmente analisadas e interpretadas, no entanto a utilização de poucos fatores pode não captar os verdadeiros conflitos de conservação envolvidos (Moffett & Sarkar 2006; Rangel et al. 2007). Alguns métodos se limitam a utilização de apenas uma medida de “custo”, sendo possível agregar diferentes medidas para considerar diferentes dimensões dos conflitos, mas por outro lado possuem limitações na identificação da influenciaram de cada fator nos resultados, sendo mais transparentes os métodos que não necessitam dessa agregação (Sarkar et al. 2006; Moilanen et al. 2011).

Apesar dos contextos socioeconômico e político terem sido pouco explorados, a variação temporal das dimensões envolvidas nos planejamentos tem sido ainda menos estudada (Possingham et al. 2009; Hannah 2010). Até o momento os planejamentos têm lidado com problemas estáticos no tempo, desconsideram mudanças temporais tanto dos alvos de conservação, quanto dos aspectos socioeconômicos e políticos envolvidos (Naidoo et al. 2006; Possingham et al. 2009; Hannah 2010). Esse foco a planejamentos estáticos no tempo tem suas raízes no paradigma de lugar, em que cada local teria sua própria diversidade de espécies, ecossistêmica e genéticas que não sofreriam mudanças ao longo do tempo (Hannah

2010). Porém as mudanças climáticas e de uso do solo impõe um novo paradigma ao estabelecimento de prioridades de conservação, já que esses fatores induzem fortes mudanças na distribuição espacial das espécies (Parmesan 2006). Além disso, mudanças socioeconômicas e políticas são ainda mais dinâmicas e incertas temporalmente que as encontradas nos sistemas naturais, sendo também afetadas pelas mudanças climáticas (Naidoo et al. 2006; Hannah 2010). As espécies têm respondido de diferentes formas as mudanças climáticas, no entanto o deslocamento para acompanhar o seu nicho tem destaque em mudanças rápidas, como as ocasionadas pelas mudanças climáticas decorrente das ações antrópicas (Parmesan 2006; Dawson et al. 2011). No entanto tais deslocamentos podem ser impedidos pelas mudanças de uso do solo, resultando assim em efeitos ainda maiores sobre o risco de extinção das espécies (Brooks et al. 2008; Asner et al. 2010; Hof et al. 2011; Mantyka-Pringle et al. 2011). Esses efeitos têm impulsionado o desenvolvimento de métodos que lidem com priorizações espaciais dinâmicas (Williams et al. 2005; Lawler 2009; Mawdsley et al. 2009; Hannah 2010; Dawson et al. 2011; Mawdsley 2011). As principais ideias consistem na elaboração de planos de conservação que liguem ou reduzam a distância entre as áreas adequadas climaticamente na atualidade com áreas adequadas em períodos futuros para cada espécie (Williams et al. 2005; Hannah et al. 2007; Carroll et al. 2010). Propondo ainda programas de migração assistida para espécies com dificuldades em dispersar para áreas futuras devido à baixa capacidade de deslocamento natural ou modulada por mudanças na paisagem (Dawson et al. 2011). Tais ideias tem o suporte metodológico dos modelos de distribuição de espécies (MDE) que são de grande importância tanto para determinar o atual padrão de distribuição das espécies quanto para prever suas distribuições no futuro (Hannah et al. 2007; Franklin 2009; Carroll et al. 2010). Além disso, é possível modelar a perda de habitat no futuro com o intuito de minimizar futuros conflitos de conservação (Jetz et al. 2007; Asner et al. 2010). Já outros fatores socioeconômicos e políticos são ainda mais difíceis de serem modelados devido a maior dinâmica temporal desses fatores, porém o desenvolvimento de métodos nessas áreas é altamente necessário no processo de negociação e tomada de decisão, pois ambos são feitos no contexto socioeconômico e político.

Assim futuros trabalhos podem direcionar esforços para tanto entender a ligação desses fatores com os aspectos biológicos, como a relação entre política e biodiversidade a fim de

dar suporte em análises de priorização espacial para conservação e aumente assim suas aplicabilidades em ações concretas de conservação.

A fim de contribuir para superação dos problemas apresentados, buscamos nessa dissertação testar a influência de critérios socioeconômicos e políticos na determinação de áreas prioritárias para conservação de mamíferos não voadores do Cerrado, bem como em medir os ganhos e perdas inerentes à análise de demandas conflitantes (primeiro capítulo).

Encontramos que as regiões com maior riqueza de espécies estão principalmente em regiões com alta densidade populacional, alto custo econômico, alto nível de uso do solo antropogênico e com diversos níveis de governança ambiental. Assim houve um deslocamento das prioridades para o norte do bioma, quando esses fatores foram incluídos na análise. Permitindo reduções em 68% de potenciais conflitos com população humana, em 72% de conflitos de custo da terra, em 68% de conflitos com o uso do solo antropogênico e 51% de aumento dos possíveis benefícios da governança ambiental.

Já no segundo capítulo buscamos estabelecer áreas para conservação de mamíferos não voadores do Cerrado buscando encontrar soluções espaciais que minimizem os efeitos das mudanças climáticas e mudanças no uso do solo levando em consideração a capacidade de dispersão das espécies e as incertezas do processo de modelagem de distribuição de espécies.

A inclusão de mudanças na paisagem mudou nossas prioridades em escala regional, em direção ao norte do bioma, enquanto a inclusão da incerteza dos modelos teve mudanças na escala local. Além disso nossas análises encontraram soluções que minimizaram a distância entre áreas climaticamente adequadas no presente e no futuro.

Dessa forma nossos planejamentos podem ser utilizados tanto como um protocolo metodológico em outras regiões quanto no auxílio ao processo de tomada de decisão.

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CAPÍTULO I

Submetemos este capítulo para a revista “Diversity and Distributions”

Exploring the socioeconomic and political trade-offs in biodiversity conservation: a case study of the Cerrado Biodiversity Hotspot, Brazil

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Running Title: Socioeconomic and political costs of conservation

ABSTRACT

Aim. To developed spatial trade-off analyses to the conservation of mammals considering the benefits of biodiversity conservation and the socioeconomic costs of it – taking into account the current level of environmental governance in the planning region.

Location. The Cerrado Biodiversity Hotspot, Brazil

Methods. We built species distribution models (SDMs) for 154 mammals inhabiting the Cerrado. We combined model projections weighted by their statistical fit to produce consensus maps of species distribution grouped in three distinct types of models (envelope, statistical and machine-learning models). We used these models to run spatial prioritization analyses indicating the best sites for the conservation investment. We compared six different conservation scenarios considering human population density, land cost, anthropogenic land use, level of environmental governance, and the distribution of species using trade-off analyses. We considered the current level of biodiversity protection in all scenarios.

Results. SDMs indicated that species-rich sites converge to regions with high population density, high land cost, high anthropogenic land use, and with diverse levels of environmental governance. There was a significant change in spatial priorities when socioeconomic and political dimensions were included in analyses: top priority sites moved towards the north. This spatial change reduced by 68% the potential conservation conflicts with human population, by 72% the likely conflicts arising from land cost and by 68% anthropogenic land use. It also increased by 51% the beneficial effect of environmental governance.

Main conclusions. Our results reinforce that using only the biological criterion for the proposition of spatial conservation priorities can undermine conservation plans given the complex nature of conflicts among socioeconomic and political dimensions of the conservation problem. Our trade-off analyses figure as a methodological prospect supporting

the decision-make process and the consequent translation of conservation planning outcomes into conservations actions.

Key words: Conservation conflicts, conservation planning, mammals, multi-criteria analysis, spatial prioritization, Zonation.

INTRODUCTION

The science of spatial conservation prioritization emerged as a quantitative approach to support the spatial choices that provide best returns for conservation investment to alleviate the current biodiversity crisis (Ferrier & Wintle, 2009). Spatial conservation planning should consider many criteria to ensure the balance between biodiversity conservation and other types of land use, catalyzing the implementation of on-the-ground conservation actions (Ferrier & Wintle, 2009). Here we provide a series of trade-off analyses as a decision-support tool that reduce socioeconomic constraints and take advantage of political opportunities for mammal conservation in the Cerrado Biodiversity Hotspot.

Spatial prioritization analysis is only one step in the conservation planning process (Knight *et al.*, 2006), and its applicability to effective conservation actions is higher when social and human dimensions are taken into consideration (Knight *et al.*, 2008, 2009; Naidoo *et al.*, 2006). Yet, many studies have indicated spatial conservation priorities based only on the biological value of candidate areas (McBride *et al.*, 2007; Moffett & Sarkar, 2006; Naidoo *et al.*, 2006). Such an approach usually provides optimal solutions in terms of biodiversity representation, but its implementation is limited given the pervasive conflicts between conservation and others competing land uses in the landscape (Balmford *et al.*, 2001; Naidoo *et al.*, 2006; Rangel *et al.*, 2007). This results in a lack of conservation opportunity (Knight *et al.*, 2008).

The combined use of biological, economic, social, political and institutional dimensions of biodiversity conservation has received attention in recent studies, and their importance has been highlighted in conservation planning (Eklund *et al.*, 2011; McBride *et al.*, 2007; Sarkar

et al., 2006). Further, the outcome of spatial conservation plans appears to be more sensitive to these dimension than to the variation among the taxonomic group analyzed (see Bode *et al.*, 2008). However, political factors such as governance and its interaction with other variables still have received little focus. Furthermore the relationship between political factors and conservation of biodiversity has been discuss (Walpole & Smith, 2005; Ferraro, 2005; Katzner, 2005; Smith & Walpole, 2005; Laurance, 2004) and tested by some empirical analyzes (Burn *et al.*, 2011; Smith *et al.*, 2003; Barrett *et al.*, 2006; Agnew *et al.*, 2009) however the incorporation of political factors have been underexplored in conservation planning. The measures of governance has been incorporated in conservation planning as the probability of success in the conservation investment (Wilson *et al.*, 2011; McBride *et al.*, 2007), as a cost (bad governance) or opportunity (good governance) in the choice of priority areas (Eklund *et al.*, 2011; O'Connor *et al.*, 2003), and as a factor that reduce the total budget invested and result the real budget spent in the conservation target (Garnett *et al.*, 2011). In fact, political governance has been debated in a global context given the necessity of a good translation of investment into conservations actions (Eklund *et al.*, 2011), although this has not been explored at scales below national level.

The development of spatial conservation plans involving both biodiversity and socioeconomic constraints have been discussed under the multi-criteria analysis (MCA) approach (Moffett & Sarkar, 2006). One way to solve MCA is through trade-off analysis (Moffett & Sarkar, 2006). Trade-off analysis explores the cost of relaxing one goal in order to achieve an increase in another goal. This means that hard choices will be needed to translate the planning in actions (McShane *et al.*, 2011), although it provides the opportunity to explore the trade-offs we are interested in.

Here we applied spatial trade-off analyses to the conservation of non-flying mammals, considering the benefits of biodiversity conservation and the socio-economic costs of it, and taking into account the current level of environmental governance in the planning region. Further, we reduced uncertainty in the species distribution using the ensemble of forecasting approach (Araújo & New, 2007) and considering habitat specificity of each species (Lemes *et al.*, 2011).

We used the Cerrado Biodiversity Hotspot (Brazil) as a case study for our approach, and mammals as our model group. The Cerrado is a critical region to test for the influence of socioeconomic and political actions in conservation since it has key features that are common to others regions of the world. These features are: high rates of land conversion, positive socioeconomic impact from agriculture, low level of legal protection (i.e. reserves), and a high prominence in global conservation schemes (Brooks *et al.*, 2006; Klink & Machado, 2005; Loyola *et al.*, 2009). Thus our approach can indicate some guidelines and a protocol to biodiversity conservation within the Cerrado, as well as in others regions of the globe. As for the mammals are facing many threats from local to global scale, having an extinction rate higher than the background rate (Barnosky *et al.*, 2011), and conservation actions are extremely needed (Schipper *et al.*, 2008). Moreover, mammals is a relatively well-studied group for which data such as geographic distribution, type of preferred habitat and taxonomy exist and is well established.

MATERIAL AND METHODS

Data sources and processing

We updated previous lists of the Cerrado's non-flying mammals (Marinho-filho & Juarez, 2002; Marinho-Filho *et al.*, 2007;) and obtained their 154 species range maps from International Union for Conservation of Nature (IUCN version 2011; www.iucnredlist.org). We gridded the extent of occurrence maps to a grid of 0.1° x 0.1° of latitude/longitude that covered the full extent of Cerrado. We used current climatic variables (annual mean temperature, mean diurnal range in temperature, temperature seasonality, annual precipitation, precipitation seasonality and precipitation of coldest quarter) from the WorldClim repository (www.worldclim.org/current). These variables were generated by interpolated climate data from 1950-2000 periods (Hijmans *et al.*, 2005).

We reclassified land-use classes in 2008 (our “current landscape”; <http://siscom.ibama.gov.br/monitorabiomas/index.htm>) to forest, savanna, grassland and anthropic (e.g. agriculture, pasture, urban influence) and quantified the proportion of each class in each grid cell. Then, we compiled habitat preferences (forest, savanna and grassland) for each species from the literature (papers, books and theses) to obtain the species' preferential habitat.

We obtained socioeconomic and politic data from different sources. We used the human population size at 2010 from last Brazil national sense (delivered by The Brazilian Institute of

Geography and Statistics, and available at <http://www.ibge.gov.br>) to calculate the population density per municipality (thousands of people per km²) as a proxy to social conflict. We measured social conflict as the number of people affected by the establishment of protected areas (Ferrier & Wintle, 2009; Moffett & Sarkar, 2006). We used the Gross Domestic Product (GDP) per municipality at 2009 (<http://www.ibge.gov.br>) as a proxy to land cost (see Balmford *et al.*, 2003); and used municipality's finances (provided by National Treasury in <http://www.stn.fazenda.gov.br>) to obtain the percentage of GDP invested in environmental programs by each municipality (available from 2004 to 2010). Then, we calculated its average to this period and used this value as a proxy to municipality environmental governance. Finally, we used the percentage of anthropogenic land use (described below) to avoid selecting regions with others priorities such as urbanization and agriculture areas. Regions with high anthropogenic use provide fewer opportunities for the establishment of protected areas than native ones and offer more threats. Finally we re-scaled the variables for municipality calculating the average of each variables to each cell grid.

Species distribution models

We used the presence and absence derived from species range maps and the climatic variables to model species distributions. The use of presence and absence data is still incipient in the SDM literature (but see Lawler *et al.*, 2009; Diniz-Filho *et al.*, 2009 for recent examples). Although in regions with poor knowledge about species distribution and under high threat such as the Cerrado such approach may provide a first assessment to identify general priorities that can be revised after data improvement (Lemes *et al.*, 2011). Actually, this

hierarchical approach is one of the proposals of conservation biogeography (Whittaker *et al.*, 2005).

We used nine species distribution modeling methods, which differs both conceptually and statistically (Franklin, 2009), grouped them in three separate sets (distance, statistical and machine-learning methods), and applied the ensemble forecasting approach within each set. Distance methods (henceforth, DIST) were BIOCLIM (Busby, 1991), Euclidian and Gower distances (Carpenter *et al.*, 1993). Statistical methods (STAT) were Generalized Linear Models (GLM; Guisan *et al.*, 2002), Generalized Additive Models (GAM; Hastie & Tibshirani, 1986) and Multivariate Adaptive Regression Splines (MARS; Friedman, 1991) that were represented by the inherent statistical methods of modern regressions (Franklin, 2009). Finally, machine-learning methods (ML) were Maximum Entropy (MaxEnt; Phillips *et al.*, 2006; Phillips & Dudík, 2008), Random Forest (Breiman, 2001), and Genetic Algorithm for Rule Set Production (GARP; Stockwell & Noble, 1992).

We partitioned randomly the data of presence and absence of each species in 75% to calibration (or train) and 25% to validation (or test) and repeated this process 10 times (i.e. a cross-validation) maintaining the observed prevalence of species. We converted the continuous predictions in presence and absences using the ROC curve and calculated the True Skill Statistics (TSS) to evaluate model performance. The TSS range from -1 to +1, where values equal +1 is a perfect prediction and values equal or less of zero is a prediction no better than random (Allouche *et al.*, 2006).

We did the ensembles of forecasts to produce more robust predictions and reduce the uncertainties owing to the modeling process (Araújo & New, 2007; Marmion *et al.*, 2009). We generate 30 projections per species (3 modeling methods x 10 randomly partitioned data) and generated the frequency of projections for each species in each cell grid. We considered the presence of a species only in cells with 50% or more of frequency of projections, but we hold a continuous value when this occurred. Finally we “filtered/corrected” each frequency-of-projection map based on the presence of the species’ preferential habitat (i.e type of vegetation cover) in the cell. Thus, we let the value in frequency of projection only in cells in which the species’ habitat was present, based in the current landscape (following the suggestions of Lemes *et al.* 2011; Rondinini *et al.* 2011) and calculate the average frequency of projection within each set of ensemble projections.

Trade-off analyses

We used the Zonation framework and software (Moilanen *et al.*, 2005) to select the best sites for the conservation of non-flying mammals from the Cerrado minimizing socioeconomic conflict and maximizing environmental governance. We did trade-offs analyses using the Zonation reverse heuristic algorithm, which calculates the marginal loss following the removal of a cell (i.e. the relative contribution of that cell to achieve the conservation goal) using the original core-area cell removal rule (Moilanen *et al.*, 2009 for details). The Zonation algorithm generates a nested hierarchical ranking of the landscape maximizing the highest occurrence level (in our case, the frequency of projections of each species and environmental governance) weighted by the importance of the feature divided by the cost of the cell and accounting for complementarity (Moilanen *et al.*, 2009).

Further, Zonation offers the possibility of penalizing areas according to many factors weighted by their relevance, allowing for a balance among the beneficial (positive weight) and constraints factors (negative weight) to the conservation actions (Moilanen *et al.*, 2011). This method has more transparency in understanding the effect of each factor in the final spatial solutions than aggregating the costs in only one measure (Sarkar *et al.*, 2006; Moilanen *et al.*, 2011). Here we weighted each species equally (+1/154) and the environmental governance with +0.2, whereas human population density, land cost and percentage of anthropogenic land cover were weighted -0.4 each one. Thus we assigned an equal weight to each set of factors (i.e +1.2 and -1.2), therefore not biasing the balance among them (see Moilanen *et al.*, 2011, for a similar approach).

We modulated the importance of protected areas of Cerrado (<http://mapas.mma.gov.br/i3geo/datadownload.htm>) using a mask layer that forced the inclusion of the current established protected areas in the analyses, so that our final solution indicates sites that complement the current network of protected areas in the Cerrado.

Finally, we sought for priority sites in which both biological and environmental governance dimensions are higher than socioeconomic constraints. We created one scenario to each dimension separately, in which we sought for priorities that maximize (positive weight) or minimize (negative weight) them, complementing the current network of protected areas. Our scenarios were: (1) a “human population density” scenario (in which site with high human

population density were avoided to minimize conservation conflicts with human settlements), (2) a “land cost” scenario (in which sites with high land cost were avoided to minimize the cost-inefficiency of conservation actions), (3) an “anthropogenic land use” scenario (in which sites with other types of land use other than natural vegetation cover were avoided to minimize conflicts with other land-use forms, such as agriculture or urbanization), (4) an “environmental governance” scenario (in which sites for which a high amount of monetary investments in environmental programs exist, maximizing opportunities for on-the-ground conservation actions), (5) a “biodiversity” scenario (in which only the modeled distribution of non-flying mammals were considered, without any socioeconomic or political constraint); and, lastly, (6) an “all-dimensions scenario” (in which all biological, socioeconomic and political dimensions were considered simultaneously).

We also quantified the spatial overlap at the top 17% sites of the landscape between each scenario and the all-dimensions scenario to test for the influence of each factor in the final optimal solution. We used the solution comparison tool in Zonation to measure the level of overlap between two solutions. The values of overlap ranging from 0%, when has not overlap, to 100%, when has complete overlap between the layers. Finally, we compared the performance of each scenario in minimizing the constraints and enhancing the benefits to mammal conservation. For practical purposes, here we show only the top 17% sites of landscape in all scenarios according to the target defined for terrestrial environment from Aichi Biodiversity Targets to 2020 (CBD, 2010). This target is a concrete political target assign by the Brazilian government to the biodiversity protection and our planning can help in the decision support.

RESULTS

Species distribution models had good predictive accuracies with TSS being always higher than 0.5 - most species (65% on average) with values higher than 0.7. In general, the average frequency of projection increases from north to south, with highest values found in the southeast part of the Cerrado (Fig. 1). However there were differences among sets of SDM, being DIST the most divergent one (Fig. 1B-D). In general, sites with the highest frequency of projections converge to regions with high population density, high land cost and high anthropogenic land use (Fig. 2A-C) and with diverse levels of environmental governance (Fig. 2D). These patterns result in positive correlation between frequency of projections and population density, high land cost and high anthropogenic land use, and next to zero for environmental governance (Table 1).

Table 1. Pearson's r Correlation Matrix of the biodiversity, socioeconomic and political variables used in the trade-offs analyses. Sets of SDMs were the distance set (DIST), the statistic set (STAT) and machine-learning set (ML).

	Land Cost	Environmental Governance	Population density	Anthropogenic Land Use	DIST	STAT	ML
Land Cost	1.00						
Environmental Governance	0.18	1.00					
Population density	0.47	0.00	1.00				
Anthropogenic Land Use	0.34	0.03	0.38	1.00			
DIST	0.24	0.05	-0.04	0.20	1.00		
STAT	0.24	0.07	0.11	0.29	0.63	1.00	
ML	0.23	0.07	0.11	0.30	0.65	0.98	1.00

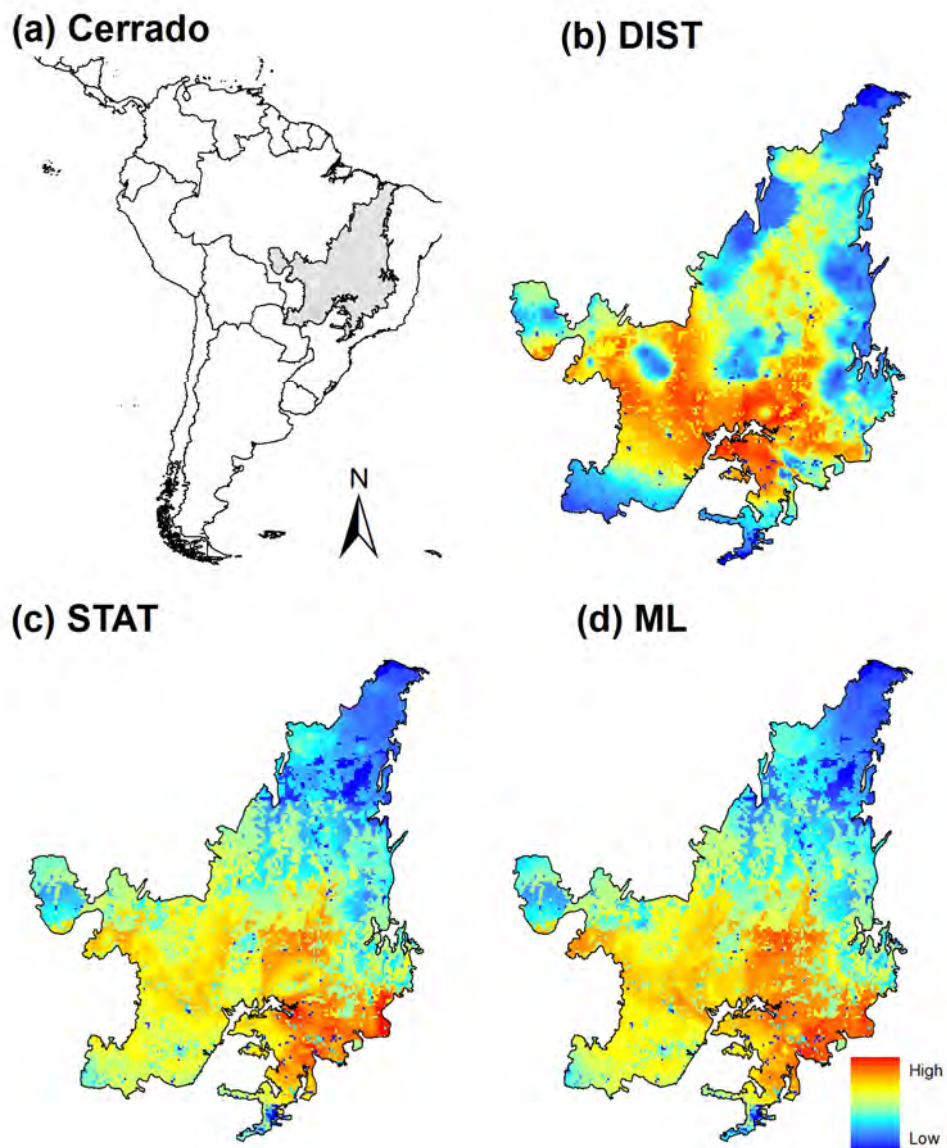
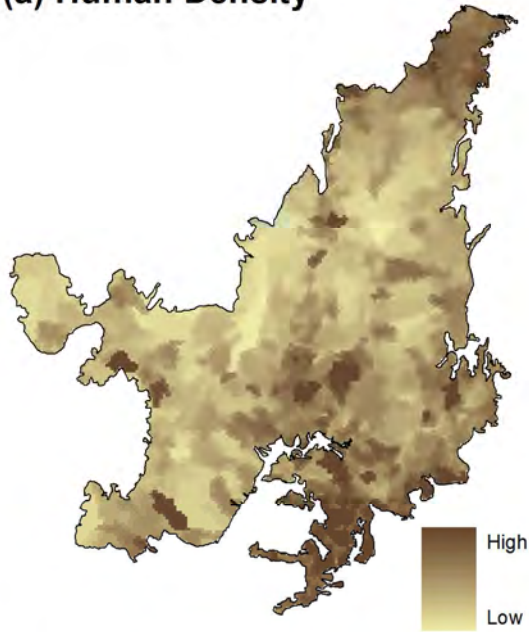
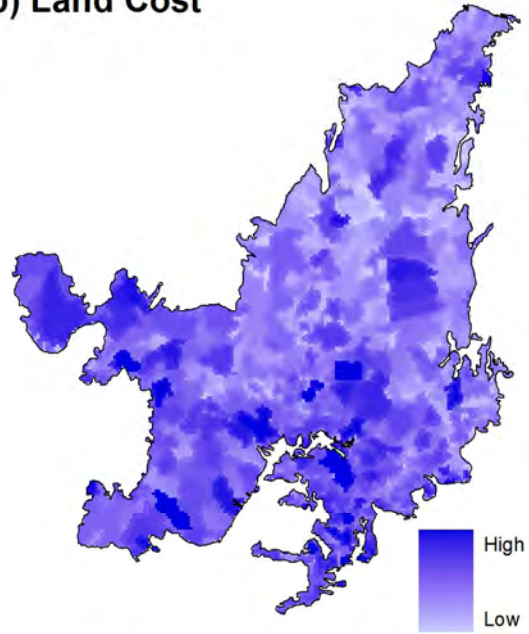


Figure 1. (a) The location of the Cerrado Biodiversity Hotspot, and the average frequency of projections of non-flying mammals delivered by consensus projections of species distribution model ensembles within three model-type sets: the distance set (DIST, b), the statistical set (STAT, c), and the machine learning set (ML, d).

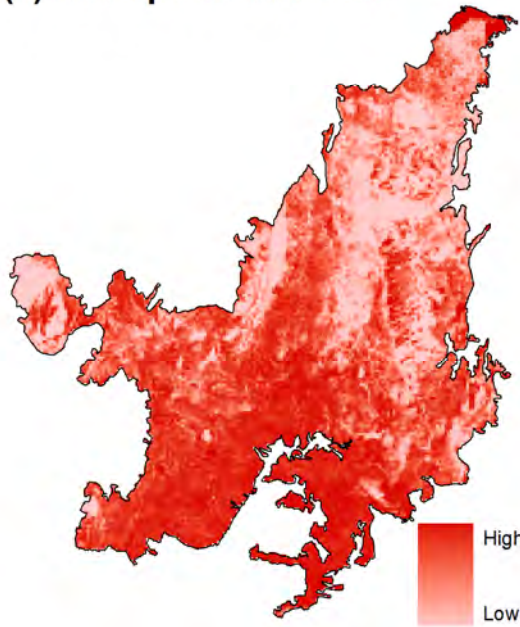
(a) Human Density



(b) Land Cost



(c) Anthropogenic Land Use



(d) Environmental Governance

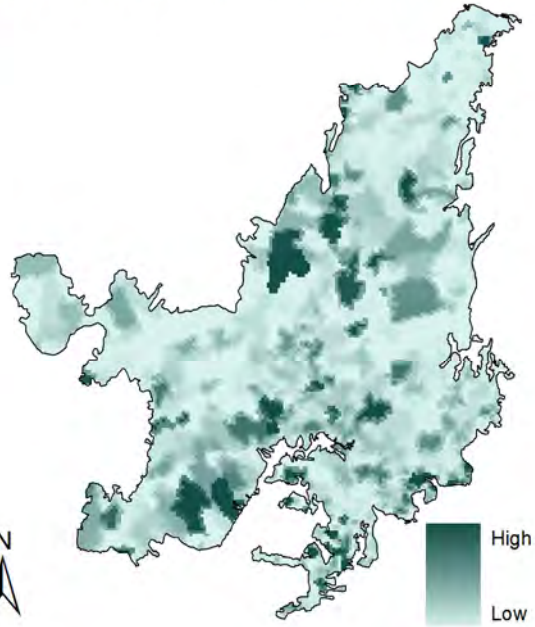


Figure 2. Spatial pattern of socioeconomic and political dimensions used in trade-offs analyses. Population density (a), land cost (b), anthropogenic land use (c), and environmental governance (d). We transformed each variables using the formula: $\text{Log}_{10}(\text{Variable}+1)$.

The planning scenario considering only the biodiversity value of the region (i.e. the biodiversity scenario) indicated priorities mainly in the central and southern portions of the biome (Fig. 3E; see also Fig.S1 to differences among the sets of SDMs). However, when socioeconomic and political dimensions were included in the analysis (i.e. the all-dimensions scenario) spatial priorities shifted to the north (Fig. 3F; see also Fig.S2 for differences among the sets of SDMs). Other scenarios provided somewhat similar solutions (Fig. 3A-D). This spatial change from the biodiversity scenario to the all-dimensions scenario at the top 17% of landscape to the ML set retained ca. 40% less than the average frequency of projections. However, at the same time, reduced by 68% the potential conservation conflicts with human population, by 72% the likely conflicts arising from land cost and by 68% anthropogenic land use (Table 2). It also increased by 81% the beneficial effect of environmental governance (Table 2; compare Fig. 3E and F). The principal constraint in trade-off analyses was the anthropogenic land use that decreased slowly its retention in the Cerrado (i.e. proportion of distribution remaining) whereas the population density and land cost had a fast decrease, mainly at 20% of landscape lost (Fig. 3F). At the 83% of landscape loss (i.e. top 17%) the anthropogenic land use was below of human population density and land cost whereas the species frequency of projection and environmental governance had higher representations (Fig. 3F).

Table 2. Comparison of the level of representation of each variable between the biodiversity scenario and all-dimension scenario for the top 17% of the landscape. The values represent the percentage of reduction (negative sign) or increase (positive sign) in the representation of each variable in the all-dimension scenario. Sets of SDMs were the distance set (DIST), the statistic set (STAT) and machine-learning set (ML).

Variables	DIST	STAT	ML
Biodiversity	-37%	-40%	-40%
Population density	-69%	-66%	-68%
Land Cost	-72%	-72%	-72%
Anthropogenic Land Use	-69%	-69%	-68%
Environmental Governance	51%	63%	81%

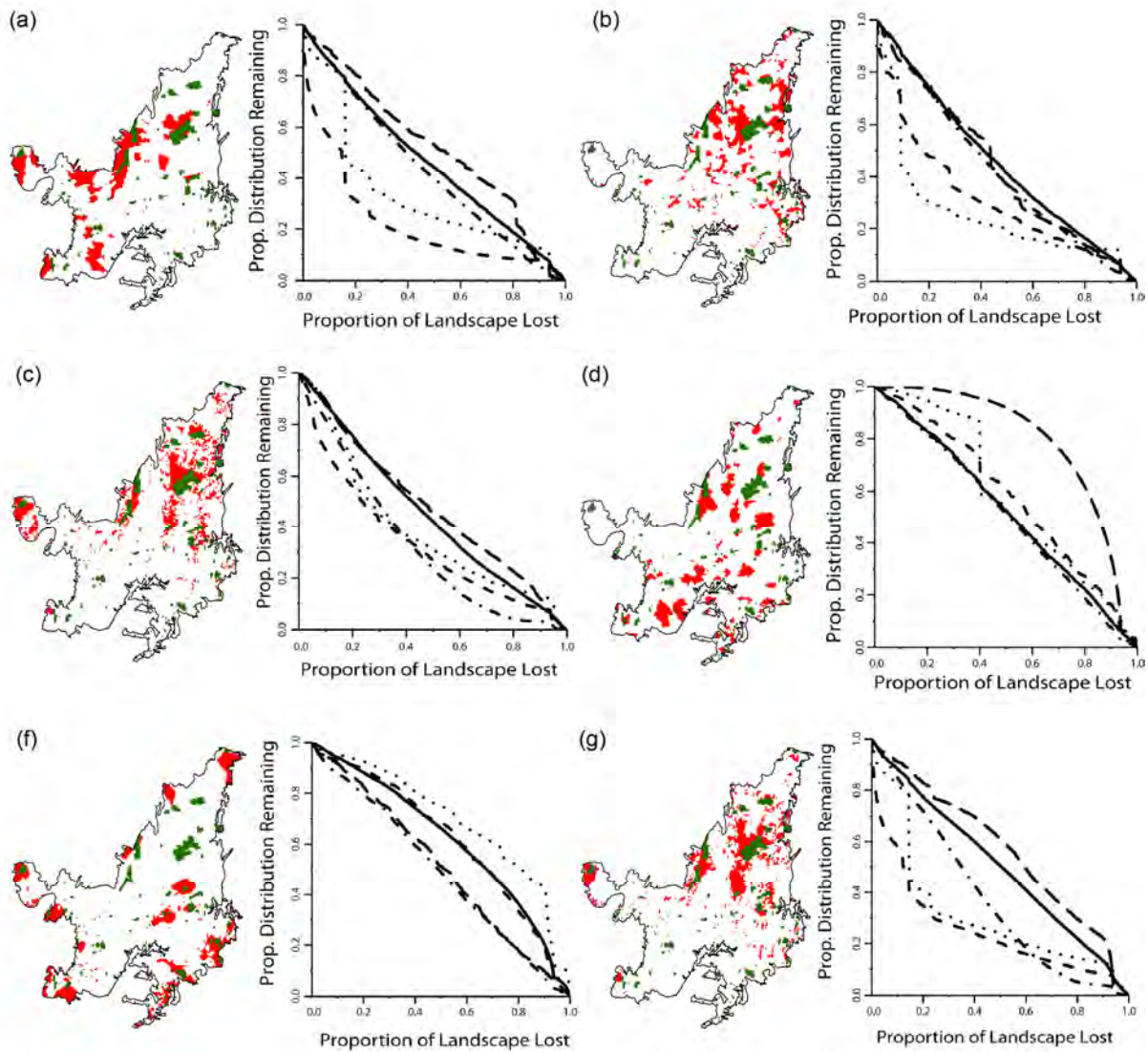


Figure 3. Spatial distribution of priority sites for the conservation of non-flying mammals (black) and the currently established network of protected areas (gray) according to data delivered by the machine learning set of species distribution models (ML), and its respective performance graph. The full line stands for the average frequency of projection to non-flying mammals (i.e. species richness); dashed line = human population density, dotted line = land cost, dot-dash line = anthropogenic land-use, and long dashed line = environmental governance. Spatial conservation planning scenarios were (a) human population density scenario, (b) land cost scenario, (c) anthropogenic land use scenario, (d) environmental governance scenario, (e) biodiversity scenario, and (f) all-dimensions scenario (all biodiversity, socioeconomic and political dimensions included).

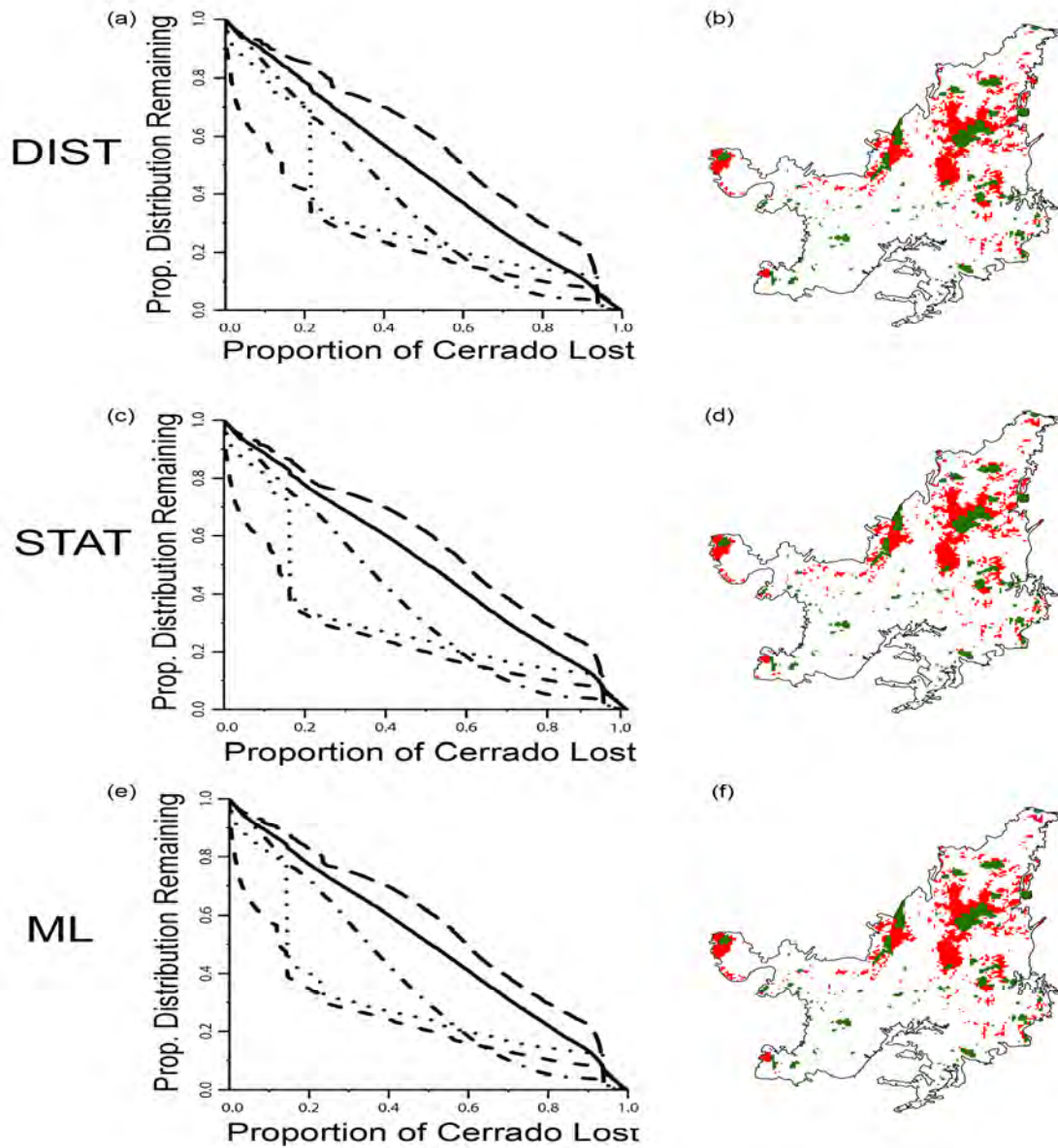


Figure S1. Spatial distribution of priority sites for non-flying mammal conservation (black) and the currently established network of protected areas (gray) according to spatial data delivered by each set of species distribution models (SDMs), and its respective performance graph for the biodiversity scenario. The full line stands for the average frequency of projection to non-flying mammals (i.e. species richness); dashed line = human population density, dotted line = land cost, dot-dash line = anthropogenic land-use, and long dashed line = environmental governance. Sets of SDMs were (a-b) the distance set (DIST), (c-d) the statistic set (STAT), (e-f) the machine-learning set (ML).

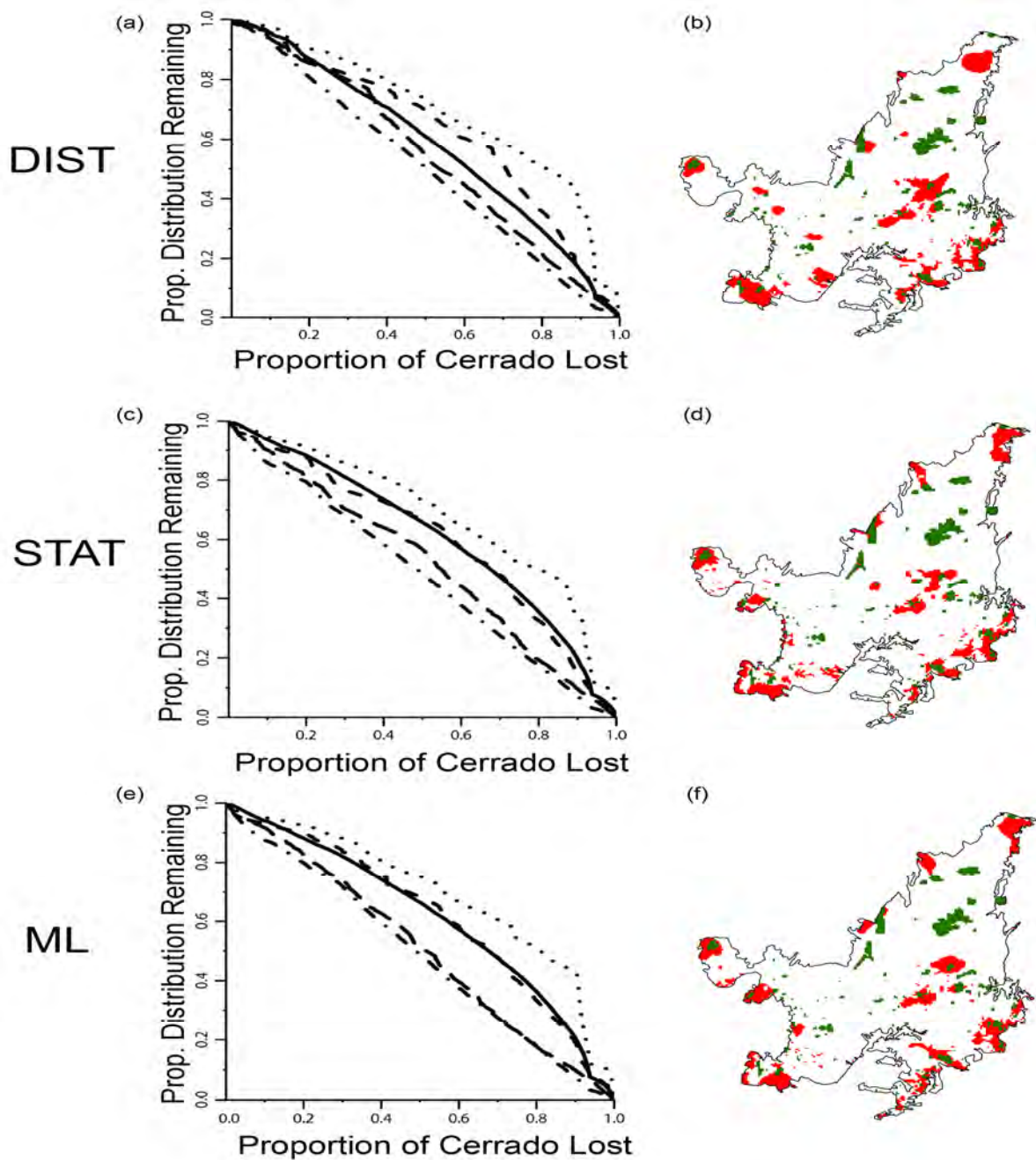


Figure S2. Spatial distribution of priority sites for non-flying mammal conservation (black) and the currently established network of protected areas (gray) according to spatial data delivered by each set of species distribution models (SDMs), and its respective performance graph for the all-dimensions scenario. The full line stands for the average frequency of projection to non-flying mammals (i.e. species richness); dashed line = human population density, dotted line = land cost, dot-dash line = anthropogenic land-use, and long dashed line

= environmental governance. Sets of SDMs were (a-b) the distance set (DIST), (c-d) the statistic set (STAT), (e-f) the machine-learning set (ML).

The percentage of overlap between each individual scenario with the all-dimensions scenario for the top 17% of the landscape was the highest to anthropogenic land use, followed by human population density, land cost, environmental governance, and biodiversity scenario respectively (Table 3). Individual scenarios always were less effective in balancing the constraints and opportunities of conservation (Fig. 3 A-D), but they help us to understand the influence of each dimension in the final spatial solution given by the all-dimensions scenario.

Table 3. The percentage of spatial overlap between each individual scenario with the all-dimensions scenario for the top 17% of the landscape. Sets of SDMs were the distance set (DIST), the statistic set (STAT) and machine-learning set (ML).

Scenario	All-dimensions scenario (DIST)	All-dimensions scenario (STAT)	All-dimensions scenario (ML)
Anthropogenic Land Use	83.28%	82.66%	82.59%
Population density	56.35%	56.39%	58.28%
Land Cost	54.05%	53.81%	53.67%
Environmental Governance	50.62%	50.62%	50.65%
Biodiversity	45.64%	47.66%	48.01%

DISCUSSION

Our results reinforce that using only the biological criterion for the proposition of spatial conservation priorities can undermine conservation plans given the complex nature of conflicts among socioeconomic and political dimensions of the conservation problem. Further, although the use of environmental governance coupled with others criteria has been poorly explored in previous studies, it helped us identify sites where conservation investment can provide greatest return given (1) the current political priorities for environmental conservation applied by decision makers, and (2) because they impose, at the same time, fewer socioeconomic conflicts. Our trade-off analyses figure as a methodological prospect supporting the decision-make process and the consequent translation of conservation planning outcomes into conservations actions – especially in regions where the identification of the stakeholders is puzzling.

Spatial conservation priorities changed from sites with high to low average frequency of species projections (a proxy to the niche of the species), but entailing fewer socioeconomic and political conflicts when these factors were considered in the analysis. On the one hand, this imposes hard choices from the biological point of view mainly when we do not know exactly what are the consequences of these choices in the long term viability to a wide range of species (Sarkar *et al.*, 2006). On the other hand, the development of conservation plans that do not consider the likely high conflicts between humans and biodiversity may increase species extinction risk when (and if) applied (Gaston, 2005; Gibson *et al.*, 2011; Phalan *et al.*, 2011). Actually, conservation plans not framed within a human context are not of much help for the implementation of on-the-ground conservation actions (Knight *et al.*, 2008).

Land-use change is one of the greatest threats to biodiversity (Sala *et al.*, 2000; Pereira *et al.*, 2010;). We found that anthropogenic land use was the major constraint for the selection of priority sites; and the conversion of native areas in the Cerrado probably will intensify (Dobrovolski *et al.*, 2011). Interestingly, the spatial distribution of species had the lowest influence in our trade-off analyses possibly because of the flexibility in species representation at different sites. A similar pattern was found at the global scale, in which the outcomes of different conservation planning scenarios were more sensitive to socioeconomic constraints than to biological taxonomy (Bode *et al.*, 2008).

The political dimension of biodiversity conservation has been a recurrent theme of debate in the literature (Ferraro, 2005; Katzner, 2005; Smith & Walpole, 2005; Walpole & Smith, 2005) and several analyses have been undertaken especially at the national level. These analyses usually consider the level of political corruption or fraudulent conduct as a constraint to conservation (Eklund *et al.*, 2011; Garnett *et al.*, 2011), although empirical tests failed to find support to this assumption (Barrett *et al.*, 2006). Here we used a simple environmental governance measure that still need a better understand and whose behavior should be tested in future analyses.

We showed that the socioeconomic and political dimensions of the conservation problem had more importance in determining spatial conservation priorities than the spatial distribution of species in the Cerrado Biodiversity Hotspot. Moreover, the inclusion of these criteria

increased the performance of conservation plans with some loss in the biodiversity value but with great changes in the spatial pattern of the priority areas given socioeconomic and political constraints. We hope our results could act as a first step in a complex conservation planning process needed to safeguard non-flying mammals from the Cerrado, adding also to burgeoning initiatives to protected biodiversity and solve other conservation problems in other regions of world.

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CAPÍTULO II

Submetemos este capítulo para a revista “Biological Conservation”

Defining spatial conservation priorities in the face of land-use and climate change

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HIGHLIGHTS

1. Land-use and climate changes challenge the way spatial conservation planning is done.
2. Species distribution models are useful for such plans, but carry uncertainty.
3. We included species range shifts and land-use changes in mammal conservation planning.
4. Our spatial plans were improved by the inclusion of dynamics threats and uncertainty.
5. We offer a methodological way to consider these threats in spatial planning.

ABSTRACT

Creating and managing protected areas is critical to ensure the persistence of species but dynamic threats like land-use and climate change may jeopardize the effectiveness of reserves planned under a static approach. Here we defined spatial priorities for the conservation of non-flying mammals inhabiting the Cerrado Biodiversity Hotspot, Brazil, that overcome the likely impacts of land-use and climate change to this imperiled fauna. We used cutting-edge methods of species distribution models combining thousands of model projections to generate a complete and comprehensive ensemble of forecasts that shows the likely impacts of climate change in mammal distribution. We also generate a future land-use model that indicates how the region would be fragmented in the future. We then used our models to run optimization procedures and propose priority sites for mammal conservation minimizing species climate-forced dispersal distance as well as the mean uncertainty associated to species distribution models and climate models. At the same time, our proposal maximizes complementary species representation across the existing network of protected areas. Including land-use changes and model uncertainties in the planning process changed significantly the spatial distribution of priority sites in the region. While the inclusion of land-use models altered the spatial location of priority sites at the regional scale, the effects of climate change tended to take place at the local scale. Given that, our solutions already include possible dispersal corridors linking current and future priority sites for mammal conservation, as well as a formal risk analysis based on planning uncertainties. We built spatial conservation plans at a spatial resolution that provides decision makers a portfolio of spatial solutions that could be negotiated at the decision level.

Keywords: Brazilian savanna; Convention on Biological Diversity, global warming, systematic conservation planning; species distribution models, uncertainty analysis.

INTRODUCTION

Humans have triggered many threats to biodiversity like land-use and climate changes, overexploitation, pollution, and introduction of invasive species (Brook et al., 2008; Schipper et al., 2008; Hoffmann et al., 2010; Maclean and Wilson, 2011; Mantyka-Pringle et al., 2011). Among these threats, land-use change and climate change are considered the worst (Sala et al., 2000; Thomas et al., 2004; Pereira et al., 2010) and they have a great synergistic action (Brook et al., 2008; Asner et al., 2010; Mantyka-Pringle et al., 2011). Therefore, assessments of future global changes predict that biodiversity will continue to decline (Sala et al., 2000; Pereira et al., 2010).

Climate change causes selective micro-evolutionary pressures in species, favoring individuals capable of dispersing either locally or regionally to track more suitable habitats (Holt, 1990; Parmesan and Yohe, 2003; Parmesan, 2006; Dawson et al., 2011). Given the proper timeframe, the dispersal process can result in range shifts that have been of great importance for species dealing with past and current climate change and it likely will have great importance in the future (Graham and Grimm, 1990; Lyons, 2003; Parmesan and Yohe, 2003). However, human modification of the landscape may block the dispersal from current to the future suitable habitat and increase species extinction risk by its synergistic effect with changing climates (Brook et al., 2008; Asner et al., 2010; Hof et al., 2011; Mantyka-Pringle et al., 2011).

The main issue here is that climate change, as well as other dynamic threats, poses a new challenge to the static way conservation planning is usually done forcing it to become

dynamic (Hannah, 2010). Conservation biology has proposed creative solutions to deal with these threats, most focusing on the establishment of protected areas (Williams et al., 2005; Lawler, 2009; Mawdsley et al., 2009; Hannah, 2010; Dawson et al., 2011; Mawdsley, 2011). Creating and managing protected areas is critical to ensure the persistence of species but these dynamic threats may jeopardize the effectiveness of protected areas planned under a static approach (Araújo et al. 2004; Hannah 2010; Dobrovolski et al. 2011a, b). Therefore it is necessary to incorporate species' range shifts in spatial conservation planning to ensure its effectiveness in the future (Araújo et al., 2004; Hannah et al., 2007; Hannah, 2010). Some recent studies did have included the effects of the future climate change aiming to deliver more effective conservation plans, but they usually ignore land-use changes (e.g. Hannah et al. 2007; Carroll et al. 2010) and considered subjective values or unrealistic species' dispersal capacity (e.g. Carroll et al. 2010).

Species distribution models (SDMs) have been used to predict the present and future species' distributions (Lawler et al. 2012). However, different methods for modeling species distribution and different climate models (i.e. the coupled Atmosphere-Ocean General Circulation Models, AOGCMs) may produce very distinct results increasing the uncertainties among the predictions and their applicability to conservation (Araújo and New, 2007; Diniz-Filho et al., 2009). Consequently, a clear reduction of uncertainties in conservation planning is also necessary to increase the quality of spatial solutions (Regan et al., 2009; Wilson, 2010).

Here we developed spatial conservation plans that accommodate species' range shifts induced by climate change as well as landscape change predicted by a land-use model. Further, we quantified and reduced uncertainties associated with SMDs, and modeled the dispersal capacity of each species aiming at minimizing the distance between their current and future distributions along priority areas for conservation. We used mammals and the Brazilian Cerrado (a tropical woodland savanna) as our case study for several reasons. First, the Cerrado has an enormous vegetation complexity that includes grassland, savanna and forest, harboring a highly threatened biodiversity (Myers et al., 2000; Klink and Machado, 2005; Ribeiro and Walter, 2008). Second, high rates of land conversion have already transformed more than half of its two million km² in anthropogenic land use (Klink and Machado, 2005). Although this region has been included in previous conservation schemes (see Brooks et al. 2006 for a review), currently only 2.2% of its area is under strictly protection (IUCN I-IV categories, see Klink & Machado 2005). Third, mammals are under many threats from local to global scale, which is resulting in a faster extinction rate than those recorded by background extinction (Schipper et al., 2008; Barnosky et al., 2011). It is also a well-known group both in terms of their natural history and evolution, making the access to biological traits easier than in other groups. Finally, planning for the conservation in the Neotropics in the face of climate and land-use changes are among the most cutting-edge and important topics in the science of spatial conservation prioritization (Moilanen et al., 2009a).

METHODS

2.1. Land use model

We modeled land use changes with variables from different sources. We compared the Cerrado land use between 2002 and 2008 (data available at <http://siscom.ibama.gov.br/monitorabiomas/index.htm>) to generate a matrix of transition

probability between native areas to anthropic areas. We modeled the land use with the module Land Change Modeler - LCM, available in Idrisi Taiga Version (Eastman, 2009), using the following explanatory variables: digital elevation model and annual accumulated precipitation (data available at www.worldclim.org), proximity to roads, proximity to recent deforested areas and proximity to cities (data available at <http://mapas.mma.gov.br/i3geo/datadownload.htm>). LCM is a machine learning procedure that uses Markov Chains to project future land-use conditions. In order to evaluate model precision, we inverted the maps from 2002 and 2008 and the expected land-use was projected back into 1990. Then we generated a total of 458 control points to cover the entire Cerrado by doing a visual inspection of MrSID images from 1990 (data available at <https://zulu.ssc.nasa.gov/mrsid>). Finally, we predicted the land use in 2050 with a spatial resolution close to 500x500 m.

1.2. *Species distribution models*

We updated previous lists of the Cerrado's non-flying mammals (Marinho-Filho and Juarez, 2002; Marinho-Filho et al., 2007) and obtained 154 species range maps (Table S1) from International Union for Conservation of Nature and Natural Resources (IUCN version 2010; www.iucnredlist.org). We mapped the extent of occurrence of each species at the resolution of 0.1° x 0.1° of latitude/longitude in an equal-area grid that covered the full extent of the Cerrado. Therefore we obtained the species presences and absences considering that all grid cells inside the limits of range maps are presences and those outside are absences.

We used the current climatic variables (annual mean temperature, mean diurnal range in temperature, temperature seasonality, annual precipitation, precipitation seasonality and precipitation of coldest quarter) from WorldClim (data available at www.worldclim.org/current), which were generated by interpolated climate data from 1950-2000 periods (Hijmans et al., 2005). We used the future climate variables (year 2050) from three Atmosphere-Ocean General Circulation Models (AOGCMs) of the B2a emission scenario (CCCMA_CGCM2, CSIRO-MK2.0 and UKMO_HADCM3) that were generated by application of delta downscaling method on the original data from Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (provided by International Centre for Tropical Agriculture at <http://ccafs-climate.org/>). This method assumes changes in climates only over large distances and the relationships between variables are maintained from current towards the future (see <http://ccafs-climate.org/> for more details). We re-scaled both current and future climate variables to our grid resolution.

We used the presence and absence derived from species range maps and the climatic variables to model species distributions (see Fig. 1). The use of these presence and absence data is still incipient in the SDM literature (but see Lawler et al. 2009; Diniz-Filho et al. 2009 for recent examples). Although in regions with poor knowledge about the species distribution and under high threat such as the Cerrado such approach may be a first assessment to identify general priorities that can be revised after data improvement (Lemes et al., 2011). Actually, this hierarchical approach is one of the proposals of conservation biogeography (Whittaker et al., 2005).

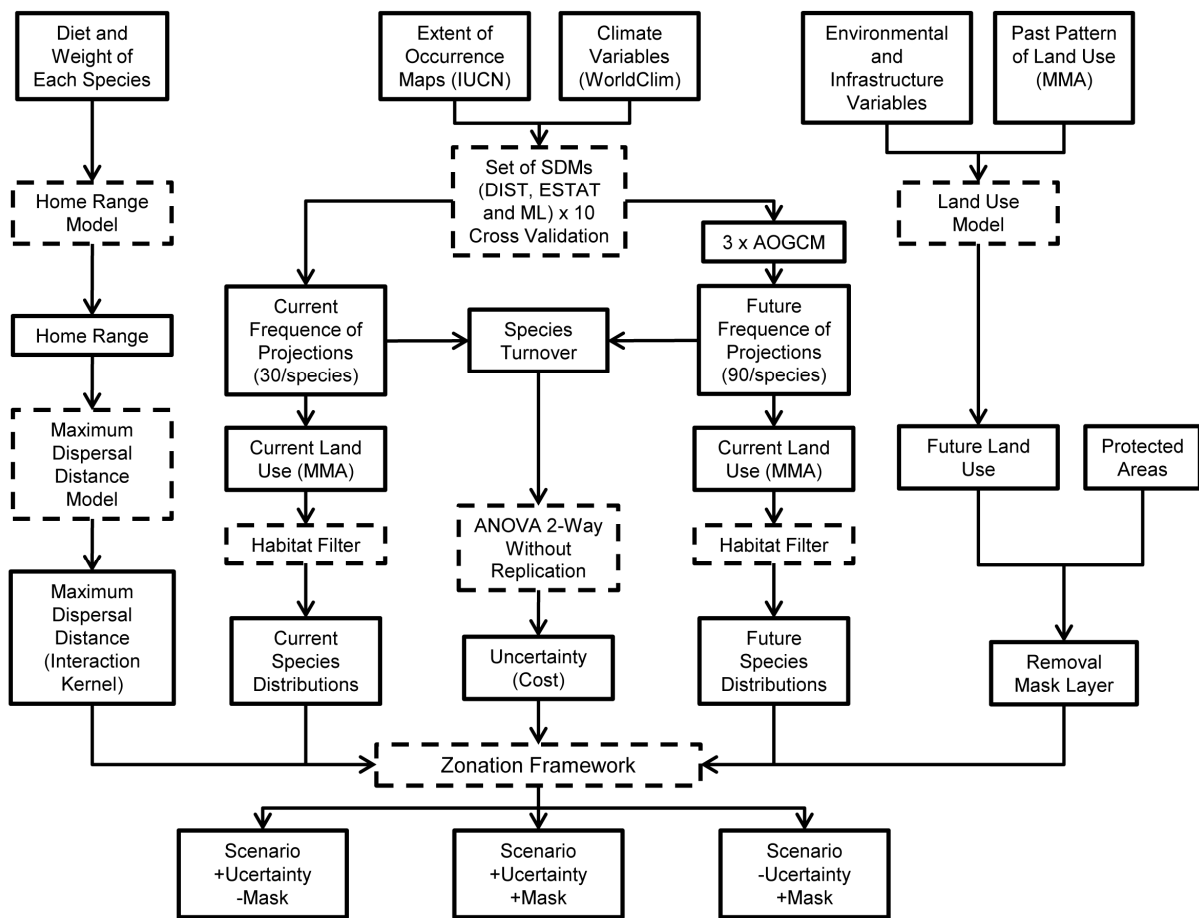


Figure 1. A schematic representation of the methods used to generate the spatial conservation planning scenarios for non-flying mammals in the face of land-use and climate changes expected for the Cerrado. We ensemble species distribution models (SDMs) of three different types (distance models, DIST; statistical models, STAT; and machine learning models, ML), projected these models into the future (2050) based on three climate global circulation models (AOGCMs), and produced a consensus map among the projections within each set. We then clipped the predicted distribution of each species by the habitat in which species occur to obtain the current and future distribution maps of each species. We quantified the uncertainty associated to SDMs and AOGCMs for each site and modeled the maximum species dispersal distance as proportional to the diet and body weight of species. We also modeled future land-use changes in the Cerrado. Finally, we used the distributions maps, the dispersal distance, model uncertainty, future landscape and the current network of protected areas to generate spatial prioritization scenarios. See text for further explanations.

We fitted nine modeling methods, which differ both conceptually and statistically (Franklin, 2009), grouped them into three separate sets (distance, statistical and machine-learning methods), and applied the ensemble forecasting approach within each set (see Fig. 1 and text below). Distance methods (henceforth, DIST) were BIOCLIM (Busby, 1991), Euclidian and Gower distances (Carpenter et al., 1993). Statistical methods (STAT) were Generalized Linear Models (GLM; Guisan et al. 2002), Generalized Additive Models (GAM; Hastie & Tibshirani 1986) and Multivariate Adaptive Regression Splines (MARS; Friedman 1991) that were represented by the inherent statistical methods of modern regressions (Franklin, 2009). Finally, machine-learning methods (ML) were Maximum Entropy (MaxEnt; Phillips et al. 2006; Phillips & Dudík 2008), Random Forest (Breiman, 2001), and Genetic Algorithm for Rule Set Production (GARP; Stockwell & Noble 1992).

We partitioned randomly the data of presence and absence of each species in 75% to calibration (or train) and 25% to validation (or test) and repeated this process 10 times (i.e. a cross-validation) maintaining the observed prevalence of species. We converted the continuous predictions in presence and absences finding the threshold with maximum sensitivity and specificity values (actually minimum 1-specificity value) in the ROC curve and after we calculated the True Skill Statistics (TSS) to evaluate model performance (Allouche et al., 2006). The TSS range from -1 to +1, where values equal +1 is a perfect prediction and values equal or less of zero is a prediction no better than random (Allouche et al., 2006).

We did the ensembles of forecasts to produce more robust predictions and reduce the uncertainties owing to the modeling process (Araújo and New, 2007; Marmion et al., 2009). We projected distributions to future climate and obtained 90 projections per species within each set of methods (3 modeling methods x 3 AOGCMs x 10 randomly partitioned data) and 30 projections per species for the current time (3 modeling methods x 10 randomly partitioned data) – this allowed us to generate a frequency of projections in the ensemble. We then generated the frequency of projections weighted by the TSS statistics for each species and timeframe within each set of methods (Fig. 1). We considered the presence of a species only in cells with 50% or more of frequency of projections, but we hold a continuous value when this occurred.

We also reclassified land-use classes in 2008 (our “current landscape”) to forest, savanna, grassland and anthropic (e.g. agriculture, pasture, urban influence) and quantified the proportion of each class in each grid cell. We compiled habitat (forest, savanna and grassland), body weight and food habits (carnivorous, herbivorous and omnivorous) for each species from the literature (papers, books and theses).

Finally, we clipped each frequency of projection map based on the presence of the species’ preferential habitat (i.e type of vegetation cover) in the cell – a process we called habitat filtering (Fig. 1). Thus, we let the value in frequency of projection only in cells in which the species’ habitat was present, based in the current landscape. We used this procedure to reduce the commission errors (false positive) inherent to the extent of occurrence data (following the suggestions of Lemes et al. 2011; Rondinini et al. 2011). Note that we could have used the

habitat as a predictor in the SDM if we had local species' occurrence and land use map at the same resolution. However in lack of these data we used the SDM in a first step and the habitat filter in a second step to obtain the final species' distributions that have frequency of projection for each cell (Fig. 1). The habitat filtering works like a second "security system" adding the ensembles of model projection, which also reduces commission and omission errors.

Quantifying and mapping uncertainties

We calculated species turnover between current and future species distributions in each cell as $(G + L) / (SR + G)$, where "G" was the number of species gained, "L" the number of species lost and "SR" is the current species richness found in the cell (Fig. 1). Then we used the total sum of squares from a two-way Analysis of Variance (ANOVA) without replication (Sokal and Rohlf, 1995) to calculate the uncertainties of each cell following the protocol recently proposed by Diniz-Filho et al. (2009) (Fig. 1). We performed the ANOVA using species turnover as the response variable, and modeling methods and AOGCMs as factors. Finally we calculated the percent of variation found in each cell relative to the total uncertainty found in all cells.

1.3. Spatial conservation planning

We used the Zonation framework and software (Moilanen et al., 2005) to rank and select the best sites for conservation investment in the Cerrado aiming at safeguarding all species of non-flying mammals. We also minimized SDM uncertainties and the geographic distance

between the centroids of the current and future species distribution induced by climate change and land-use change.

We set spatial priorities using the Zonation reverse heuristic algorithm and calculated the marginal loss of a cell (i.e. the relative contribution of the cell to achieve the conservation goal) using the original core-area cell removal rule (Moilanen et al. 2009b for details). The Zonation algorithm generates a nested hierarchical ranking of the landscape maximizing the highest occurrence level (in our case, the frequency of current and future projections of each species) divided by the cost of the cell (here, the uncertainty value associated to the modeling methods and AOGCMs sing to produce the ensembles of forecasts) and accounting for complementarity (see Moilanen et al. 2009b).

Additionally the algorithm can minimize the distance between current and future species distributions according to its dispersal distance (Rayfield et al., 2009; Carroll et al., 2010). Here we estimated the home range of each species as being proportional to its diet and body weight according to the model proposed by Kelt & Van Vuren (2001). Then we assumed that the maximum dispersal distance of a species was proportional to its home range according to Bowman et al. (2002) (Fig. 1). We modulated the importance of some sites using a mask layer that forced the inclusion of the current established protected areas in the analyses, thus indicating areas that complement the current network of protected areas in the Cerrado. We also forced the exclusion of sites with little vegetation cover in 2050 (i.e. first quartile of the frequency of vegetation cover distribution) to measure the influence of land-use change in the

definition of spatial priorities. This also avoids regions with little conservation value to be selected, threatening the persistence of species (Fahrig, 2001).

We sought for priority sites to reduce the impact of land-use and climate change in the species distribution considering the species dispersal distance and the uncertainty arising from SDMs. In addition, we created three different conservation-planning scenarios by varying some components of the above full scenario (Fig. 1) to test the influence of SDM uncertainty and the land-use change in the spatial plans. The scenarios were: 1) a conservation plan considering only SDM uncertainty costs; 2) a scenario considering only land-use change (using the vegetation mask layer), and 3) a last scenario taking into consideration both SDM uncertainty and land-use change (the full scenario). For practical purposes, here we show only the top 17% sites of landscape in all scenarios according to the target defined for terrestrial environment from Aichi Biodiversity Targets to 2020 (Convention on Biological Diversity, 2010).

RESULTS

The land-use model classified correctly 83.1% of native or anthropic areas predicted in 1990 and projected loss mainly in central and southern regions of the Cerrado in 2050 (Fig. 2).

Species distribution models had good predictive accuracies with TSS values being always higher than 0.495 - most species (65% on average) with values higher than 0.7. Our models predicted that some species would be extinct in 2050 (6.4% in STAT and 8.4% in DIST and ML). In general, the current patterns of average frequency of projection and species richness

increased from north to south, with highest values in the southeast (Fig. 3 A-C). Species range shifts induced by climate change intensified these patterns (Fig. 3 D-F). Yet, there were differences among sets of SDM, being DIST the most divergent one (Fig. 3 A-F).

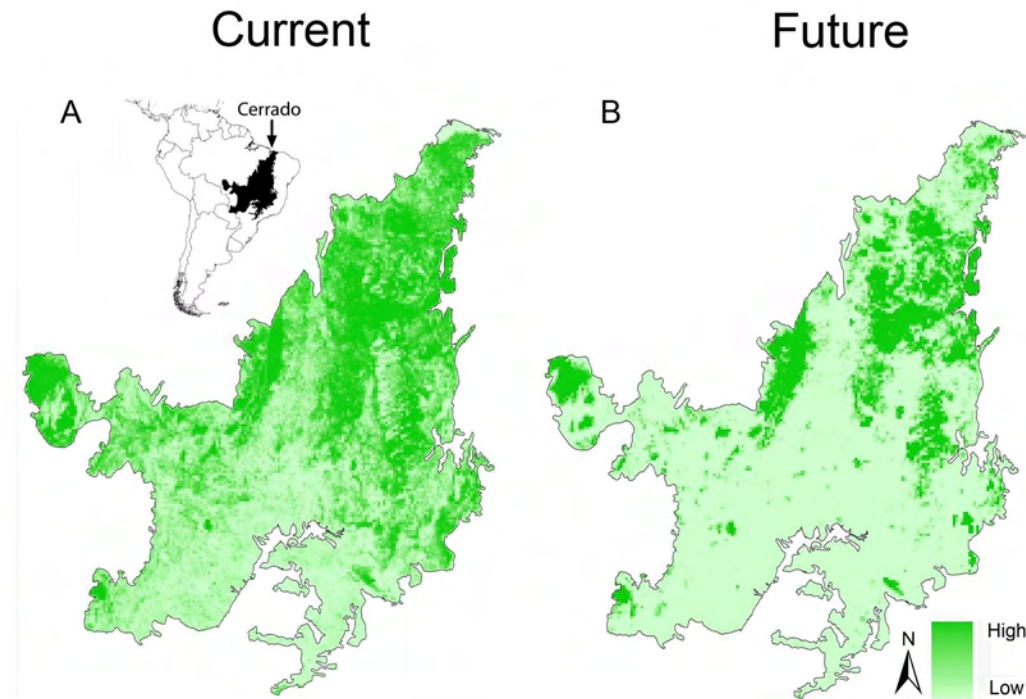


Figure 2. Maps showing the proportion of native vegetation currently found in the Cerrado (A) and that predicted for 2050 (B), according to our land-use model.

Habitat filtering reduced on average 7.7% and 7.3% the current and future occurrences of species respectively with variation among SDM set and species IUCN status (Table S2).

Places with little uncertainty (Fig. 3 G-I) concentrate in regions with high frequency of projections in the future (Fig. 3 D-F) although with little or no vegetation cover in current time; which probably will lose more vegetation in the future (Fig. 2).

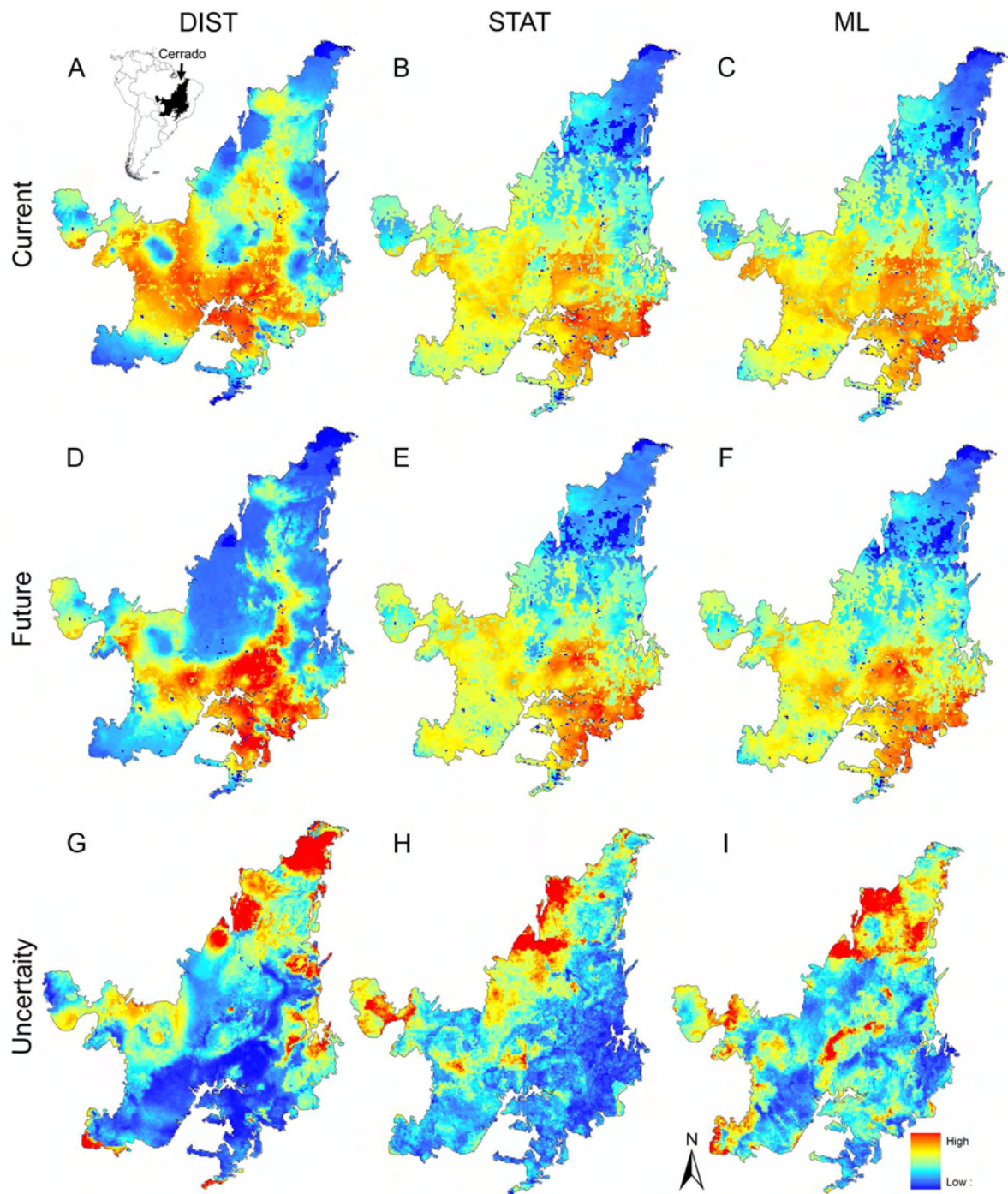


Figure 3. Average frequency of projections of mammal distribution in the Cerrado, both for current time (A-C) and for 2050 (D-F). Uncertainties associated to different modeling

methods – the distance set (DIST), statistical set (STAT) and machine learning set (ML) – are also shown in G-I.

These patterns were reflected in our spatial plans. The scenario that considered only SDM uncertainties indicates priorities mainly in the central and southern regions of the Cerrado (Fig. 4 A-C), where there are high average proportion of species range projections (Fig. 5 A-C) and little uncertainty (Fig. 5 D-F). On the other hand, scenarios considering land-use change indicated priorities mainly in the central and northern regions (Fig. 4 D-I). Based on current human pressures, these regions would hold native vegetation in the future, as well as little average proportion of range projections (Fig. 5 A-C), and high uncertainty (Fig. 5 D-F). Differences in uncertainty and species projections between scenarios with or without the vegetation cover increased from DIST to ML (Fig. 5).

Note that performance curves measuring the effectiveness of spatial plans and that did not consider the land-use changes decreased proportionally while those solutions accounting for land-use changes had some deviations (Fig. 5). These deviations were caused by the forced exclusion of sites with high frequency of projection (but little vegetation cover in the future) and by the inclusion of sites with low frequency of distribution (some current established reserves) in the top 17% fraction sites of landscape. Therefore at the same proportion of landscape and with the same amount of uncertainty, the scenarios that did not consider land-use changes had higher average proportion of species distribution than when land-use changes were taken into account (Fig. 5).

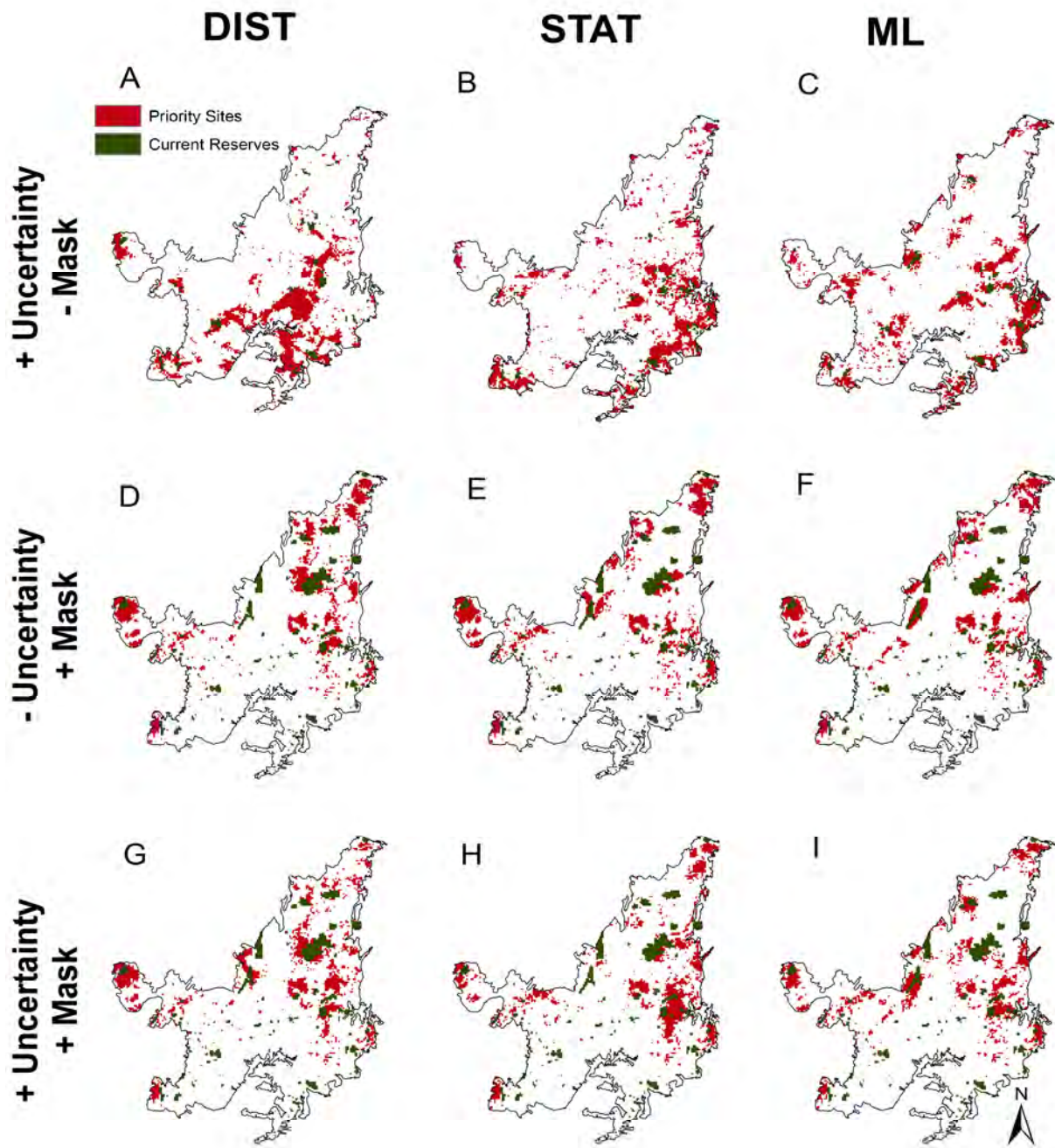


Figure 4. Spatial distribution of priority sites (black) and the currently established protected areas (gray) to reduce the impacts of land-use and climate change on non-flying mammals of the Cerrado. A-C shows the uncertainty scenario; D-F the land-use change scenario; and the uncertainty plus land-use change scenario. Spatial solutions are separated according to the distance set (DIST), statistical set (STAT) and machine learning set (ML) of modeling methods.

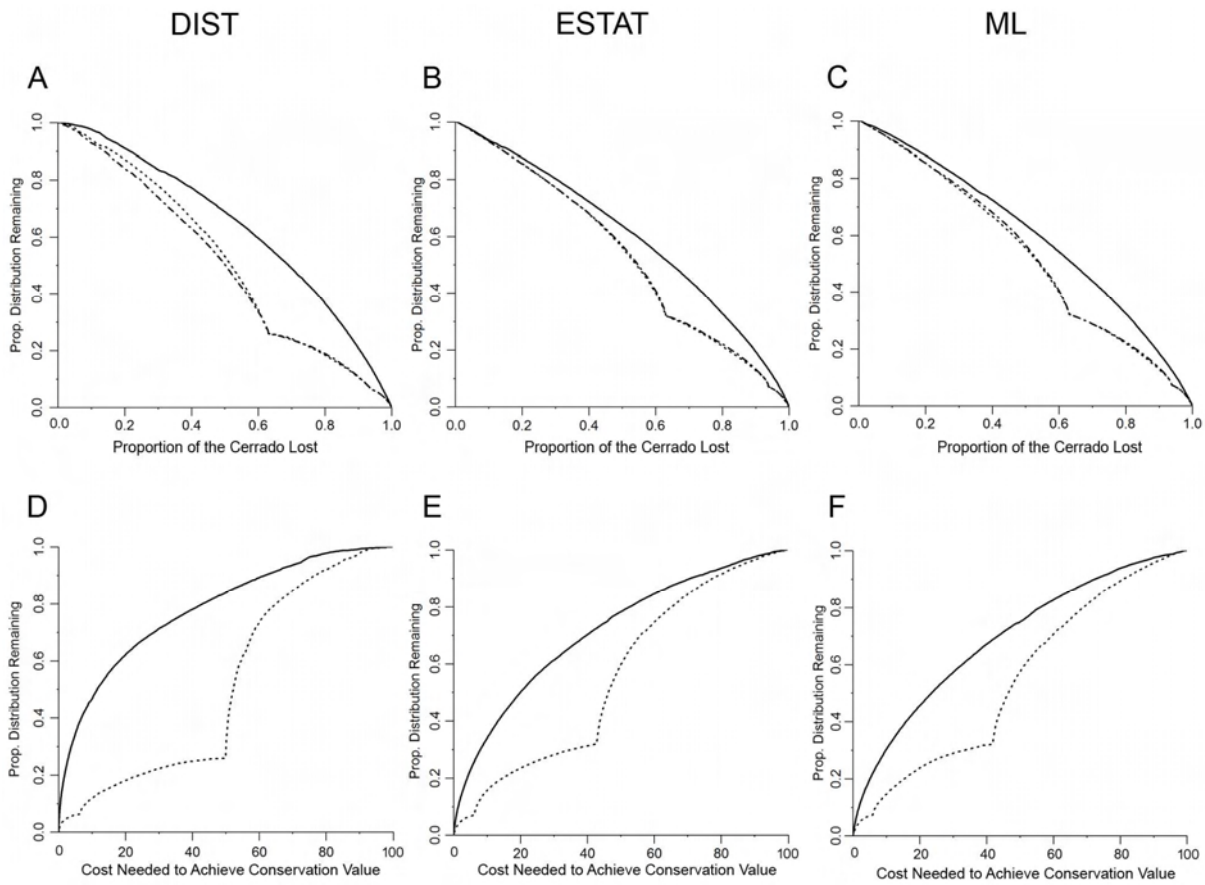


Figure 5. Proportion of landscape and their correspondent average proportion of species distribution remaining (frequency of projections) (A-C). Uncertainty (used as a cost) and its correspondent average proportion of distribution remaining are shown in D-F. The full line stands for the uncertainty scenario; dot-dash line stands for land-use change scenario; and the dotted line represents the uncertainty plus land-use change scenario. Results are shown for distance set (DIST), statistical set (STAT) and machine learning set (ML) of modeling methods.

Scenarios without land-use projections highlighted sites that are important both in current time and in the future. However, they did not force the inclusion of protected areas in top priority sites, or the exclusion of sites with little native vegetation in the future (Fig A-C). Therefore, we tested the importance of current protected areas and which are the best sites for conservation investment if current landscape remains unchanged or the implementation of new reserves occurs before land-use changes in the landscape. Moreover the last view neglects the minimization of future conflicts. In contrast, the other scenarios are complementary to the current protected areas and will avoid future conflicts between anthropic and conservation land-uses (*sensu* Balmford et al., 2001) (Fig. 4 D-I). Despite of the differences among the SDM sets there were 71.22 % of average spatial overlap among the full scenarios with only local scale differences (Fig. 4 G-I).

DISCUSSION

Our analyses suggest methodological and possible spatial solutions to face the interaction between land-use change and climate change accounting for the dispersal distance of species and uncertainty in SDMs that can be applied to others regions and taxa. So far, few studies offered solutions to lead with the synergistic effects of these global changes in conservation planning (but see Araújo 2009; Possingham et al. 2009).

In general, the spatial priorities in the Cerrado changed at the regional scale (toward the northern part of the biome) when land-use changes are included in conservation planning

scenarios, whereas uncertainty in SDM produced marked differences only at the local scale. Further, land-use change scenarios had less average proportion of species distribution than in scenarios considering with only SMD uncertainties. This finding indicate a difficult choice between minimizing the future conflict between the anthropic and conservation land uses or maximizing the proportion of distribution measured as the frequency of projections as a proxy to the niche of the species.

Our finds agree with Pearson et al. (2006) that found similar accuracy among SDM, however the spatial pattern in the predictions was different. The DIST is a set of simple methods that does not consider complex relationship between species occurrence and predictors, presence-only methods and tend underestimate the distribution in novel conditions like in climate change (Pearson et al., 2006; Franklin, 2009). Alternatively, the STAT and ML sets are very complex, assume different relationships, and presence-absence of presence pseudo-absence methods and can underestimate or overestimate the distribution in novel conditions (Pearson et al., 2006; Franklin, 2009). These features explain the strong difference of the DIST set when compared with other sets and this pattern holds in conservation planning scenarios.

The establishment of protected areas still figures as the best conservation action to protect biodiversity. Mammals are a highly threatened group (Schipper et al., 2008; Barnosky et al., 2011; Hoffmann et al., 2011) and the consequences of mammal extinctions can spread through networks of interaction causing extinction cascades and consequent disrupted ecological functions in ecosystems (Cardinale et al., 2006; Nichols et al., 2009). The Cerrado have been pinpointed as priority by world conservation schemes that meet different criteria

(Brooks et al., 2006; Loyola et al. 2009) and conservation planning at the biome scale has been formulated with different scenarios and for different taxonomic groups (see Diniz-Filho et al., 2008 for an example). Our approach has the advantage of incorporating future threats in the choice of priorities.

The impossibility of validate the future predictions of the species distribution (Araújo and Guisan, 2006) leads us to accounting for SDM uncertainty in spatial conservation plans. Model uncertainty is an important issue in the choice of priorities areas and can be minimized by quantification of the uncertainties in the model process and by application of the ensemble of forecasting approach (Wilson et al., 2005; Araújo and New, 2007; Diniz-Filho et al., 2009; Marmion et al., 2009). Moreover working on a consensus distribution model is an important step to avoid problems with false positive and negative in the species distribution, range shift and range expansion or contraction that can affect the conservation priorities (Araújo and New, 2007). Here we included the uncertainty in conservation planning with little impact in the proportion of distribution remaining represented in the solutions, but with a considerable local scale changes in spatial location of the priorities areas.

The SDM literature usually does not consider the dispersal capacity of species or make simple assumptions about dispersion (unlimited or no dispersal) without relevance to species (see Garcia et al., 2012, for a recent example). However the dispersal distance is a species-specific trait that has great variation across species being related to home range, diet and body weight in mammals (Kelt and Van Vuren, 2001; Bowman et al., 2002). This is an important trait determining if a given species can overcome land-use and climate changes by dispersing to

future available suitable areas (Parmesan, 2006) and it is possible to take advantage of this species-specific trait during the conservation planning, as shown here (see also Dawson et al. 2011). Hence, proper conservation plans can facilitate range shift considering the dispersal abilities of each species (Williams et al., 2005; Phillips et al., 2008; Dawson et al., 2011). The pattern of priority sites showed in our scenarios favored the expansion, formation of corridors and stepping-stones between protected areas depending on their spatial location and surrounding matrix. All this will be ultimately a consequence of the tradeoffs among the variables used to build the spatial plan (i.e. species distribution, uncertainty, dispersal distance, land-use change and SDM set).

Our study contributes to advances in dynamic prioritization approach principally in cope future threats to biodiversity (Hannah, 2010). Our results highlight the importance of anticipating these human impacts to implement cost-effective and proactive management with low-intensity intervention (e.g. *in-situ* conservation) instead of waiting for the consequences to make an expensive reactive solution that need intensive intervention (e.g. *ex-situ* conservation) (Dawson et al., 2011). These spatial plans have the important function to avoid current and future extinctions by human impacts, but others actions like landscape management, assisted migration, population management also should be considered to achieve effective conservation (Dawson et al., 2011; Redford et al., 2011).

Although our approach copes with the interaction between land use and climate changes in spatial conservation, our findings have some caveats. Firstly, we used extent of occurrence maps to model the species' distribution and this data overestimate the distribution of species

and increase the false positive rate (Rondinini et al., 2006) and likely the same error will be in the predictions of the SDM. Most of these errors could be reduced by producing ensembles of species distribution (Araújo and New, 2007; Lawler et al. 2012), like we did. Further, we also applied a habitat filtering approach that removed unsuitable sites from distribution of species and have likely reduced even more the number of false positive (see also Rondinini et al., 2011). We could have used points of occurrence from museums, but the sampling bias (e.g. collected along roads, proximity of cities), purposive sample (sampling based in expert knowledge) and little sample size of these data really underestimate the real species occurrences and have serious consequences to the model accuracy and interpretation (Rondinini et al., 2006; Loiselle et al., 2008; Franklin, 2009). Moreover, the lack of occurrence data for many species (like in our case here) or very little sample size for most species prevents the use of SDMs.

Secondly, we predicted the future land use changes assuming that the vegetation types and the biome Cerrado will remain in the same regions of the current distribution, but these changes can occur (Salazar et al., 2007). This assumption can affect our habitat filtering and SDM predictions. The species' range shift outside of the current limitation of Cerrado or the preferential habitat cannot be measure by our methods. Yet, we believe that this assumption will have little effect in our predictions because these changes would be a real problem only for narrow ranged species that are habitat specialists what is not the case of mammals of Cerrado (Marinho-Filho and Juarez, 2002).

In conclusion, we highlight the possibilities of using reasoned spatial conservation plans to reduce the impacts of land-use and climate changes upon non-flying mammals inhabiting the Cerrado. The future land-use had great decrease of proportion of distribution and in the spatial location of reserves while the uncertainty cost had inconsiderable effect in the proportion of distribution and little spatial effect. Our scenarios are a scientific support to the planning and decision-making process, nevertheless it is obviously necessary to account for other socioeconomic and cultural forces and the process of negotiation with all stakeholders to implement on-the-ground conservation actions (Margules and Pressey, 2000; Ferrier and Wintle, 2009). Equally the coordination of global efforts is necessary considering that the changes in environmental are global, although better solutions would be found across the national borders.

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APPENDIX A

Table A1. The list of non-flying mammals of the Brazilian Cerrado considered in our spatial conservation plans. The table contains taxonomic classification and threat status found in the IUCN Red List. Codes as follow: Data Deficient (DD), Least Concern (LC), Near Threatened (NT), Vulnerable (VU) and Endangered (EN).

Order	Family	Species	Red List Status (IUCN)
CARNIVORA	CANIDAE	<i>Cerdocyon thous</i>	LC
CARNIVORA	CANIDAE	<i>Chrysocyon brachyurus</i>	NT
CARNIVORA	CANIDAE	<i>Pseudalopex vetulus</i>	LC
CARNIVORA	CANIDAE	<i>Speothos venaticus</i>	NT
CARNIVORA	FELIDAE	<i>Leopardus colocolo</i>	NT
CARNIVORA	FELIDAE	<i>Leopardus pardalis</i>	LC
CARNIVORA	FELIDAE	<i>Leopardus tigrinus</i>	VU
CARNIVORA	FELIDAE	<i>Leopardus wiedii</i>	NT
CARNIVORA	FELIDAE	<i>Panthera onca</i>	NT
CARNIVORA	FELIDAE	<i>Puma concolor</i>	LC
CARNIVORA	FELIDAE	<i>Puma yagouaroundi</i>	LC
CARNIVORA	MEPHITIDAE	<i>Conepatus semistriatus</i>	LC
CARNIVORA	MUSTELIDAE	<i>Eira barbara</i>	LC
CARNIVORA	MUSTELIDAE	<i>Galictis cuja</i>	LC
CARNIVORA	MUSTELIDAE	<i>Galictis vittata</i>	LC
CARNIVORA	MUSTELIDAE	<i>Lontra longicaudis</i>	DD
CARNIVORA	MUSTELIDAE	<i>Pteronura brasiliensis</i>	EN
CARNIVORA	PROCYONIDAE	<i>Nasua nasua</i>	LC
CARNIVORA	PROCYONIDAE	<i>Potos flavus</i>	LC
CARNIVORA	PROCYONIDAE	<i>Procyon cancrivorus</i>	LC
CETARTIODACTYLA	CERVIDAE	<i>Blastocerus dichotomus</i>	VU
CETARTIODACTYLA	CERVIDAE	<i>Mazama americana</i>	DD
CETARTIODACTYLA	CERVIDAE	<i>Mazama gouazoubira</i>	LC
CETARTIODACTYLA	CERVIDAE	<i>Ozotoceros bezoarticus</i>	NT
CETARTIODACTYLA	TAYASSUIDAE	<i>Pecari tajacu</i>	LC
CETARTIODACTYLA	TAYASSUIDAE	<i>Tayassu pecari</i>	NT
CINGULATA	DASYPODIDAE	<i>Cabassous tatouay</i>	LC
CINGULATA	DASYPODIDAE	<i>Cabassous unicinctus</i>	LC
CINGULATA	DASYPODIDAE	<i>Dasypus novemcinctus</i>	LC
CINGULATA	DASYPODIDAE	<i>Dasypus septemcinctus</i>	LC
CINGULATA	DASYPODIDAE	<i>Euphractus sexcinctus</i>	LC
CINGULATA	DASYPODIDAE	<i>Priodontes maximus</i>	VU
CINGULATA	DASYPODIDAE	<i>Tolypeutes matacus</i>	NT
CINGULATA	DASYPODIDAE	<i>Tolypeutes tricinctus</i>	VU
DIDELPHIMORPHIA	DIDELPHIDAE	<i>Caluromys lanatus</i>	LC
DIDELPHIMORPHIA	DIDELPHIDAE	<i>Caluromys philander</i>	LC

DIDELPHIMORPHIA	DIDELPHIDAE	Chironectes minimus	LC
DIDELPHIMORPHIA	DIDELPHIDAE	Cryptonanus agricolai	DD
DIDELPHIMORPHIA	DIDELPHIDAE	Didelphis albiventris	LC
DIDELPHIMORPHIA	DIDELPHIDAE	Didelphis aurita	LC
DIDELPHIMORPHIA	DIDELPHIDAE	Didelphis marsupialis	LC
DIDELPHIMORPHIA	DIDELPHIDAE	Gracilinanus agilis	LC
DIDELPHIMORPHIA	DIDELPHIDAE	Gracilinanus microtarsus	LC
DIDELPHIMORPHIA	DIDELPHIDAE	Lutreolina crassicaudata	LC
DIDELPHIMORPHIA	DIDELPHIDAE	Marmosa murina	LC
DIDELPHIMORPHIA	DIDELPHIDAE	Marmosops incanus	LC
DIDELPHIMORPHIA	DIDELPHIDAE	Metachirus nudicaudatus	LC
DIDELPHIMORPHIA	DIDELPHIDAE	Micoureus constantiae	LC
DIDELPHIMORPHIA	DIDELPHIDAE	Micoureus demerarae	LC
DIDELPHIMORPHIA	DIDELPHIDAE	Monodelphis americana	LC
DIDELPHIMORPHIA	DIDELPHIDAE	Monodelphis domestica	LC
DIDELPHIMORPHIA	DIDELPHIDAE	Monodelphis kunsii	LC
DIDELPHIMORPHIA	DIDELPHIDAE	Monodelphis rubida	DD
DIDELPHIMORPHIA	DIDELPHIDAE	Monodelphis umbristriata	VU
DIDELPHIMORPHIA	DIDELPHIDAE	Philander frenatus	LC
DIDELPHIMORPHIA	DIDELPHIDAE	Philander opossum	LC
DIDELPHIMORPHIA	DIDELPHIDAE	Thylamys karimii	VU
DIDELPHIMORPHIA	DIDELPHIDAE	Thylamys macrurus	NT
DIDELPHIMORPHIA	DIDELPHIDAE	Thylamys velutinus	LC
LAGOMORPHA	LEPORIDAE	Sylvilagus brasiliensis	LC
PERISSODACTYLA	TAPIRIDAE	Tapirus terrestris	VU
PILOSA	BRADYPODIDAE	Bradypus variegatus	LC
PILOSA	MYRMECOPHAGIDAE	Myrmecophaga tridactyla	VU
PILOSA	MYRMECOPHAGIDAE	Tamandua tetradactyla	LC
PRIMATES	AOTIDAE	Aotus azarae	LC
PRIMATES	ATELIDAE	Alouatta caraya	LC
PRIMATES	ATELIDAE	Alouatta ululata	EN
PRIMATES	CALLITRICHIDAE	Callithrix geoffroyi	LC
PRIMATES	CALLITRICHIDAE	Callithrix jacchus	LC
PRIMATES	CALLITRICHIDAE	Callithrix penicillata	LC
PRIMATES	CALLITRICHIDAE	Mico melanurus	LC
PRIMATES	CEBIDAE	Cebus apella	LC
PRIMATES	CEBIDAE	Cebus cay	LC
PRIMATES	CEBIDAE	Cebus libidinosus	LC
PRIMATES	CEBIDAE	Cebus robustus	EN
PRIMATES	PITHECIIDAE	Callicebus nigrifrons	NT
PRIMATES	PITHECIIDAE	Callicebus personatus	VU
RODENTIA	CAVIIDAE	Cavia aperea	LC
RODENTIA	CAVIIDAE	Galea flavidens	LC
RODENTIA	CAVIIDAE	Galea spixii	LC

RODENTIA	CAVIIDAE	Hydrochoerus hydrochaeris	LC
RODENTIA	CAVIIDAE	Kerodon acrobata	DD
RODENTIA	CAVIIDAE	Kerodon rupestris	LC
RODENTIA	CRICETIDAE	Akodon cursor	LC
RODENTIA	CRICETIDAE	Akodon lindberghi	DD
RODENTIA	CRICETIDAE	Akodon montensis	LC
RODENTIA	CRICETIDAE	Bibimys labiosus	LC
RODENTIA	CRICETIDAE	Calomys callosus	LC
RODENTIA	CRICETIDAE	Calomys expulsus	LC
RODENTIA	CRICETIDAE	Calomys tener	LC
RODENTIA	CRICETIDAE	Calomys tocantinsi	LC
RODENTIA	CRICETIDAE	Cerradomys maracajuensis	LC
RODENTIA	CRICETIDAE	Cerradomys marinhui	DD
RODENTIA	CRICETIDAE	Cerradomys scotti	LC
RODENTIA	CRICETIDAE	Cerradomys subflavus	LC
RODENTIA	CRICETIDAE	Euryoryzomys lamia	EN
RODENTIA	CRICETIDAE	Euryoryzomys russatus	LC
RODENTIA	CRICETIDAE	Holochilus brasiliensis	LC
RODENTIA	CRICETIDAE	Holochilus sciureus	LC
RODENTIA	CRICETIDAE	Hylaeamys megacephalus	LC
RODENTIA	CRICETIDAE	Kunsia fronto	EN
RODENTIA	CRICETIDAE	Kunsia tomentosus	LC
RODENTIA	CRICETIDAE	Microakodontomys transitorius	EN
RODENTIA	CRICETIDAE	Neacomys spinosus	LC
RODENTIA	CRICETIDAE	Necomys lasiurus	LC
RODENTIA	CRICETIDAE	Necomys rattus	LC
RODENTIA	CRICETIDAE	Necomys squamipes	LC
RODENTIA	CRICETIDAE	Oecomys bicolor	LC
RODENTIA	CRICETIDAE	Oecomys catherinae	LC
RODENTIA	CRICETIDAE	Oecomys cleberi	DD
RODENTIA	CRICETIDAE	Oecomys concolor	LC
RODENTIA	CRICETIDAE	Oecomys mamorae	LC
RODENTIA	CRICETIDAE	Oecomys paricola	DD
RODENTIA	CRICETIDAE	Oecomys trinitatis	LC
RODENTIA	CRICETIDAE	Oligoryzomys chacoensis	LC
RODENTIA	CRICETIDAE	Oligoryzomys eliurus	LC
RODENTIA	CRICETIDAE	Oligoryzomys flavescens	LC
RODENTIA	CRICETIDAE	Oligoryzomys fornesi	LC
RODENTIA	CRICETIDAE	Oligoryzomys microtis	LC
RODENTIA	CRICETIDAE	Oligoryzomys moojeni	DD
RODENTIA	CRICETIDAE	Oligoryzomys nigripes	LC
RODENTIA	CRICETIDAE	Oligoryzomys rupestris	DD
RODENTIA	CRICETIDAE	Oligoryzomys stramineus	LC
RODENTIA	CRICETIDAE	Oxymycterus delator	LC

RODENTIA	CRICETIDAE	<i>Oxymycterus roberti</i>	LC
RODENTIA	CRICETIDAE	<i>Pseudoryzomys simplex</i>	LC
RODENTIA	CRICETIDAE	<i>Rhipidomys emiliae</i>	LC
RODENTIA	CRICETIDAE	<i>Rhipidomys macrurus</i>	LC
RODENTIA	CRICETIDAE	<i>Rhipidomys mastacalis</i>	LC
RODENTIA	CRICETIDAE	<i>Sooretamys angouya</i>	LC
RODENTIA	CRICETIDAE	<i>Thalpomys cerradensis</i>	LC
RODENTIA	CRICETIDAE	<i>Thalpomys lasiotis</i>	LC
RODENTIA	CRICETIDAE	<i>Wiedomys cerradensis</i>	DD
RODENTIA	CRICETIDAE	<i>Wiedomys pyrrhorhinos</i>	LC
RODENTIA	CTENOMYIDAE	<i>Ctenomys boliviensis</i>	LC
RODENTIA	CUNICULIDAE	<i>Cuniculus paca</i>	LC
RODENTIA	DASYPROCTIDAE	<i>Dasyprocta azarae</i>	DD
RODENTIA	ECHIMYIDAE	<i>Carterodon sulcidens</i>	DD
RODENTIA	ECHIMYIDAE	<i>Clyomys bishopi</i>	DD
RODENTIA	ECHIMYIDAE	<i>Clyomys laticeps</i>	LC
RODENTIA	ECHIMYIDAE	<i>Dactylomys dactylinus</i>	LC
RODENTIA	ECHIMYIDAE	<i>Euryzygomatomys spinosus</i>	LC
RODENTIA	ECHIMYIDAE	<i>Isothrix bistrata</i>	LC
RODENTIA	ECHIMYIDAE	<i>Phyllomys brasiliensis</i>	EN
RODENTIA	ECHIMYIDAE	<i>Proechimys longicaudatus</i>	LC
RODENTIA	ECHIMYIDAE	<i>Proechimys roberti</i>	LC
RODENTIA	ECHIMYIDAE	<i>Thrichomys apereoides</i>	LC
RODENTIA	ECHIMYIDAE	<i>Thrichomys inermis</i>	LC
RODENTIA	ECHIMYIDAE	<i>Thrichomys pachyurus</i>	LC
RODENTIA	ECHIMYIDAE	<i>Trinomys moojeni</i>	EN
RODENTIA	ECHIMYIDAE	<i>Trinomys setosus</i>	LC
RODENTIA	ERETHIZONTIDAE	<i>Coendou prehensilis</i>	LC
RODENTIA	ERETHIZONTIDAE	<i>Sphiggurus spinosus</i>	LC
RODENTIA	SCIURIDAE	<i>Sciurus aestuans</i>	LC

Table A2. Range size (measured in number of cells) before (SDM set) and after (SDM set filtered) the use of habitat filtering approach for the non-flying mammals of the Brazilian Cerrado, followed by the average proportion of reduction using of habitat filtering. Codes as follow: Data Deficient (DD), Least Concern (LC), Near Threatened (NT), Vulnerable (VU) and Endangered (EN). The analyses are separated according to the distance set (DIST), statistical set (STAT) and machine learning set (ML) of methods and the time period (present, future and both periods).

Time Frame	SDM set	DD	LC	NT	VU	EN	All species
Present	DIST	4854.0	7223.3	6789.2	6543.4	6756.9	6900.4
	DIST filtered	4546.3	6554.7	6667.2	6316.9	6395.1	6344.2
	% Reduced	6.3%	9.3%	1.8%	3.5%	5.4%	8.1%
	STAT	4707.0	7393.2	6320.4	6306.1	7170.6	6986.8
	STAT filtered	4513.5	6725.2	6192.0	6101.6	6900.6	6447.8
	% Reduced	4.1%	9.0%	2.0%	3.2%	3.8%	7.7%
	ML	4895.4	7476.7	6221.5	6276.1	7281.0	7063.4
	ML filtered	4693.3	6822.0	6092.6	6108.3	7008.4	6535.2
	% Reduced	4.1%	8.8%	2.1%	2.7%	3.7%	7.5%
	All SDM	4818.8	7364.4	6443.7	6375.2	7069.5	6983.5
	All SDM filtered	4584.4	6559.0	6317.3	6175.6	6768.0	6442.4
	% Reduced	4.9%	10.9%	2.0%	3.1%	4.3%	7.7%
Future	DIST	2651.9	5043.7	4981.1	5796.6	4295.6	4811.8
	DIST filtered	2502.1	4642.5	4888.0	5682.9	4088.5	4482.0
	% Reduced	5.6%	8.0%	1.9%	2.0%	4.8%	6.9%
	STAT	4573.2	7074.9	6365.3	6132.6	7961.3	6776.1
	STAT filtered	4366.3	6452.5	6238.6	5865.3	7549.1	6258.0
	% Reduced	4.5%	8.8%	2.0%	4.4%	5.2%	7.6%
	ML	4331.5	6953.2	5815.7	6199.9	7448.1	6605.7
	ML filtered	4151.3	6367.8	5699.3	5973.6	7111.3	6124.1
	% Reduced	4.2%	8.4%	2.0%	3.7%	4.5%	7.3%
	All SDM	3852.2	6357.3	5720.7	6043.0	6568.3	6064.5
	All SDM filtered	3673.2	5820.9	5608.6	5840.6	6249.6	5621.4
	% Reduced	4.6%	8.4%	2.0%	3.3%	4.9%	7.3%
Both periods	All SDMs	4335.5	6900.3	6082.2	6209.1	6818.9	6524.0
	All SDMs filtered	4128.8	6302.4	5963.0	6008.1	6508.8	6031.9
	%Reduced	4.8%	8.7%	2.0%	3.2%	4.5%	7.5%