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Biogeografia da Conservação frente à expansão agrícola: conflitos e prioridades

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Homenagem à Rosália.

"Na agricultura moderna, como na indústria urbana, o aumento da força produtiva e a maior mobilização do trabalho obtêm-se com a devastação e a ruína física da força de trabalho. E todo progresso da agricultura capitalista significa progresso da arte de despojar não só o trabalhador, mas também o solo; e todo aumento da fertilidade da terra num tempo dado significa esgotamento mais rápido das fontes duradouras dessa fertilidade. (...) A produção capitalista, portanto, só desenvolve a técnica e a combinação do processo social de produção, exaurindo as fontes originais de toda a riqueza: a terra e o trabalhador."

Karl Marx, O Capital, 1867.

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Pelas coisas bonitas, eu vou torcer, eu vou...

Resumo

Biogeografia da Conservação frente à expansão agrícola: conflitos e prioridades

A agricultura é a atividade humana com maior impacto sobre o ambiente. Particularmente, ela representa a maior ameaça à biodiversidade. No futuro, essa atividade deve expandir-se com o aumento populacional humano, o aumento do consumo e a produção de biocombustíveis a partir dos alimentos. Para entender os possíveis impactos dessa expansão sobre a biodiversidade, nós utilizamos cenários de mudança de uso do solo entre 2000 e 2100 do IMAGE (*Integrated Model to Access Global Environment*) para testar as seguintes hipóteses: (i) as áreas consideradas como prioridades globais de conservação pelas ONGs internacionais serão preferencialmente impactadas pela expansão agrícola no século XXI; (ii) há um conflito entre áreas prioritárias para a conservação de carnívoros e a expansão agrícola e esse conflito pode ser reduzido com a incorporação da informação sobre expansão agrícola no processo de priorização; (iii) a integração entre os países para o planejamento da conservação pode ser favorável à proteção da biodiversidade e à produção agrícola; (iv) no Brasil, as áreas protegidas serão impactadas pela expansão agrícola no futuro e esse impacto será diferente entre áreas de proteção integral e áreas de uso sustentável. Nós encontramos os seguintes resultados: (i) o impacto sobre as áreas prioritárias para a conservação depende dos critérios pelos quais elas foram definidas, assim, as áreas definidas por sua alta vulnerabilidade estão atualmente mais impactadas do que áreas de baixa vulnerabilidade. Ao longo do século XXI, o impacto geral da agricultura deve aumentar, mas a diferença entre os dois tipos de prioridades se mantém, exceto para as *High Biodiversity Wilderness Areas*, definidas por sua baixa vulnerabilidade, mas que nos cenários mais pessimistas podem ter um impacto agrícola semelhante ao das áreas de alta vulnerabilidade; (ii) há uma alta congruência espacial entre áreas com elevado uso agrícola no futuro e áreas prioritárias para a conservação de carnívoros; esse conflito pode ser reduzido se o processo de priorização incluir as informações sobre a expansão agrícola; a incorporação dessa informação, entretanto, provoca uma profunda alteração na distribuição das áreas prioritárias e reduz o número de populações de carnívoros protegidas; (iii) a integração entre os países para a criação de um conjunto de áreas prioritárias para conservação que represente 17% da superfície terrestre pode proteger 19%

mais populações de mamíferos sem reduzir a produção de alimentos, se comparada a uma estratégia em que cada país busque proteger seu território independentemente; (iv) o impacto da agricultura no Brasil deve aumentar até o fim do século XXI, ameaçando inclusive as áreas protegidas e o seu entorno. Esse impacto, porém, não deve ser diferente entre as áreas de uso sustentável e aquelas de proteção integral. Assim, a expansão agrícola deve continuar a ser uma importante ameaça à biodiversidade no futuro, atingindo inclusive áreas de especial interesse para a conservação. As ações de conservação devem ser planejadas levando em consideração essa ameaça, a fim de reduzir seus impactos potenciais. Para isso, países como o Brasil devem reforçar sua vigilância sobre a expansão agrícola e a maneira como essa atividade é desenvolvida. Além disso, a integração internacional dos esforços de conservação deve ser buscada, dados seus benefícios para a biodiversidade e para a produção de alimentos. E por fim, a humanidade deve optar por formas de produção agrícola que reduzam seus impactos, inclusive evitando sua expansão futura, mas que possam satisfazer as necessidades da população humana globalmente.

Palavras-chave: Agricultura; Mudança de uso e cobertura do solo; IMAGE; Conservação da Biodiversidade; Planejamento Sistemático de Conservação; Prioridades Globais de Conservação da Biodiversidade; *Hot spots* de Biodiversidade; Áreas Protegidas; Conservação de Mamíferos; Brasil.

Abstract

Conservation Biogeography faced with agricultural expansion: conflicts and priorities

Agriculture is the human activity with the greatest impact on the environment. Specifically, it represents the greatest threat to biodiversity. In the future, this activity should expand due to population growth, increased consumption and production of biofuels from food. To understand the possible impacts of this expansion on biodiversity, we used scenarios of land use change between 1970 and 2100 from IMAGE (Integrated Model to Access Global Environment) to test the following hypotheses: (i) areas considered as global priorities for conservation by international NGOs will be preferentially impacted by agricultural expansion in the XXI century, (ii) there is a conflict between the priority areas for carnivores conservation and agricultural expansion, and this conflict can be reduced by incorporating information on agricultural expansion in the prioritization process, (iii) the integration among countries for conservation planning may benefit both biodiversity and agricultural productivity, (iv) Brazilian protected areas will be impacted by agricultural expansion in the future and this impact will differ between protected areas of integral protection and those of sustainable use. We found that: (i) the impact on priority areas for conservation depends on the criteria by which they were set, so that areas defined by its high vulnerability are currently most affected than those of low vulnerability. Throughout the XXI century this impact is expected to increase, although the difference between the two types of priorities remains, except for High Biodiversity Wilderness Areas, defined by their low vulnerability in current time, but for which most pessimistic scenarios forecast an impact similar to priority areas of high vulnerability, (ii) there is a high spatial congruence between areas with high agricultural use in the future and priority areas for conservation of carnivores. This conflict can be reduced if the prioritization process include information on agricultural expansion; this incorporation, however, causes a profound change in the distribution of priority areas and reduces the number of protected carnivore populations, (iii) the integration of countries to create a set of priority areas for conservation that represents 17% of the land surface can protect 19% more mammal populations without reducing food production, compared to a strategy in which each country seeks to protect its territory independently, and (iv) the impact of agriculture in Brazil is expected to increase until the end of the century, threatening even the protected areas and their surroundings. This impact, however, should not be different between areas of sustainable use and those of integral protection. We conclude that agricultural expansion should remain a major threat to biodiversity in the future, even in areas of special interest for conservation. Conservation actions should be planned taking into account this threat in order to reduce their potential impacts. For this, countries like Brazil should strengthen its surveillance on agricultural expansion and on how this activity is developed. Furthermore, the integration of international conservation efforts should be pursued, given its benefits for biodiversity and food production. Finally, humanity must choose methods of agricultural production that reduce its impacts, including avoiding its future expansion, so as to meet the increasing needs of a human population globally.

Keywords: Agriculture; Land Use And Land Cover Change; IMAGE; Biodiversity Conservation; Systematic Conservation Planning; Global Biodiversity Conservation Priorities; Biodiversity Hotspots; Protected Areas; Mammals' Conservation; Brazil.

Conteúdo

Capítulo 1: Introdução Geral

A agricultura e a história humana

A chamada Revolução do Neolítico, representada pela domesticação de plantas e animais, foi a maior mudança na história da humanidade nos últimos 13 mil anos (Diamond, 2002). Essa revolução representa a adoção das atividades de criação de plantas e animais como a principal atividade de subsistência por populações humanas. A origem da agricultura se deu de maneira independente em diversas regiões do mundo: no Crescente Fértil, na Índia, em Nova Guiné, no Sahel, na Etiópia, no oeste da África, nos Andes, na Amazônia, na América Central e no leste dos Estados Unidos (Diamond, 2002). Tal mudança parece ter sido determinada por influências climáticas e pela disponibilidade de espécies passíveis de domesticação em certas regiões habitadas populações humanas que aproveitaram essa vantagem e adotaram a agricultura como modo de vida (Diamond, 1997).

A agricultura trouxe consigo uma série de modificações para os povos que a adotaram. Com o aumento do alimento disponível, houve um crescimento no tamanho dessas populações e a ocupação de sítios de maneira sedentária, abandonando o hábito nômade. Sem a necessidade do constante movimento em busca de comida, as pessoas puderam ter bens e objetos em quantidade e tamanho maior do que aquilo que podiam carregar. Por fim, o desenvolvimento da agricultura permitiu a produção de alimento excedente que pôde ser utilizado por indivíduos que não se dedicavam à atividade de produção do alimento e puderam, portanto, desenvolver outras funções, como as administrativas, que permitiram o desenvolvimento do Estado e atividade de produção de conhecimento e inovação tecnológica, como foi o caso da invenção da escrita e da metalurgia, além da atividade militar (Diamond, 1997).

Assim, as populações que dominaram a agricultura expandiram-se aumentando sua complexidade política e militar, competindo entre si e exterminando populações nômades em todos os continentes. Esse domínio é também representado pelo fato de que, embora existam cerca de 6500 linguagens, 88% da humanidade falam poucas dezenas de idiomas originados de duas regiões onde a agricultura se desenvolveu inicialmente (China e Crescente Fértil) e estimativas apontam que nas próximas duas gerações podem desaparecer outras 3000 línguas faladas por povos nômades (Pimm, 2000). Além disso, o arroz, o milho, o trigo e a batata, produtos oriundos dos primeiros centros de produção agrícola, são a principal fonte alimentar de calorias para a espécie humana (FAO, 2011).

Por outro lado, a atividade agrícola tem profundos efeitos sobre o ambiente. A alteração da cobertura do solo representada pela remoção da vegetação nativa seguida da atividade agrícola altera o regime de chuvas, reduz os nutrientes do solo, e tem efeito sobre a biodiversidade. Essas mudanças, por sua vez, podem afetar a própria atividade agrícola, alterando as condições ambientais necessárias para o cultivo e causando queda na produtividade. Os efeitos decorrentes da destruição ambiental tiveram importante impacto sobre a história humana, tendo um papel central no declínio e colapso de impérios dependentes da agricultura, como foi o caso dos Impérios Maia e do Império Romano (Diamond, 2005; Ponting, 2007).

Diversos avanços nas técnicas de produção agrícola ocorreram desde a invenção dessa atividade. A seguir, estão apresentadas de maneira resumida as principais mudanças ocorridas na agricultura, tendo como caso típico a região do Crescente Fértil e a Europa, a partir da síntese de Mazoyer & Roudart (2006). O primeiro sistema de cultivo existente foi baseado no sistema de coivara, no qual áreas de floresta eram derrubadas e queimadas, permitindo o cultivo por poucos anos. Em seguida essa área era abandonada por um longo período no qual a vegetação se regenerava enquanto outra área era cultivada. Nas planícies de inundação dos grandes rios, como é o caso do Nilo, sistemas de irrigação permitiram o cultivo mais intenso e em áreas mais amplas, gerando uma maior produção. O desenvolvimento de áreas agrícolas que já haviam sido degradadas pela agricultura de coivara na região do Mediterrâneo longe dos grandes rios, ainda na Antiguidade, foi possível com o uso de técnicas mais sofisticadas de cultivo, com o uso de arado e outras ferramentas, com uso de trabalho humano e animal mais intensivo e com a integração mais íntima entre a criação de animais e a agricultura. Nesse sistema de cultivo bianual, parcelas eram deixadas em pousio e recebiam adubação proveniente dos animais domesticados enquanto outras parcelas eram cultivadas para produção de cereal. Já na Idade Média, com a adoção de métodos de cultivo mais sofisticados como arados mais potentes, o uso mais intensivo do cavalo na tração e a criação de animais em estábulos durante o inverno, alimentados com feno, permitiu a disseminação da agricultura para regiões temperadas frias.

Outra revolução agrícola é representada pela associação da agricultura com outra atividade humana surgida no século XVIII, a indústria. A partir daí a agricultura teve de satisfazer a demanda de matérias primas para a indústria e alimentar uma população urbana crescente que abandonara a atividade agrícola. Nessa nova forma de cultivo mais intensiva, o prática do pousio foi abandonada, e substituída pelo cultivo de vegetais específicos para alimentação animal. Tal mudança gerou por um lado um grande crescimento na produção, mas por outro uma nova onda de crise agrícola, especialmente na Europa. Os solos europeus sobre-explorados tiveram uma redução de produtividade que passou a ser suprimida com a importação de fertilizantes, tais como guano e salitre. A importância desses insumos estrangeiros provocou inclusive, na América do Sul, a disputa pelas minas de nitrato, o que culminou com a Guerra do Pacífico entre Bolívia, Paraguai e Chile, aliado da Inglaterra. Como resultado, Chile incorporou territórios dos outros dois países (nessa oportunidade, a Bolívia perdeu seu acesso ao Oceano Pacífico) (Foster, 2004).

Tal busca internacional por compostos ricos em nutrientes necessários à produção agrícola, especialmente o nitrogênio, só foi reduzida com a invenção da fixação artificial do nitrogênio pelo químico alemão Fritz Haber, em 1909 (Foster, 2004). O uso desses novos nutrientes e técnicas agrícolas, porém, limitou-se principalmente aos países centrais do capitalismo, i.e. Europa e América do Norte, enquanto os países periféricos mantiveram sistemas agrícolas tradicionais.

Num novo ciclo de crescimento agrícola, a chamada Revolução Verde expandiu para países periféricos novas tecnologias de cultivo, gerando um aumento da produção agrícola capaz de satisfazer as necessidades de alimentação decorrentes do grande crescimento populacional seguido à Segunda Guerra Mundial (Tilman *et al.*, 2002). Como nas demais mudanças tecnológicas da agricultura, as novas tecnologias difundidas pela Revolução Verde tiveram impactos sobre o ambiente. Entre esses impactos destacam-se a eutrofização dos corpos d'água, a compactação do solo pelo maquinário agrícola e a alteração das comunidades de plantas e animais alvos dos chamados defensivos agrícolas (Tilman *et al.*, 2002).

O estado da agricultura no presente

A agricultura passa, no presente, por uma grave crise representada pela crescente insegurança alimentar entre os seres humanos e pelos seus impactos ambientais sem precedentes (Mazoyer e Roudart, 2006; Rosset, 2011). Induzida pela Revolução Verde e outros avanços agrícolas em termos de área e de produtividade, a produção agrícola mundial vem crescendo de maneira constante até os dias atuais desde, pelo menos, 1960 (Earth Policy Insitute, 2012). Apesar disso, cerca de 1 bilhão de pessoas passam fome no mundo (FAO, 2011).

Essa situação foi bastante piorada na chamada crise alimentar de 2006-2008 (FAO, 2011) quando ocorreu um aumento de cerca de 30% no preço do milho, cresceu em 115 milhões o número de pessoas famintas no mundo e protestos contra a alta dos alimentos ocorreram em 35 países (Rosset, 2011; Sheeran, 2011). Entre os fatores que contribuíram para essa crise dos alimentos estão a crise financeira e o direcionamento dos investimentos para o setor de alimentos e o aumento do uso de alimentos para a fabricação de biocombustíveis (Earth Policy Institute, 2012). Tal valorização do mercado de alimentos tem levado à compra de terras agricultáveis por empresas estrangeiras em países em desenvolvimento (De Schutter, 2011).

Do ponto de vista ambiental, a agricultura é a maior fonte de impactos da humanidade atualmente (Foley *et al.*, 2011): o ser humano ocupa 38% da superfície terrestre livre de gelo para essa atividade. Além disso, 70% da água potável são utilizados para a irrigação agrícola. As emissões de gases estufa decorrentes da agricultura representam 30-35% das emissões totais das atividades humanas. A perda de hábitat, principal ameaça à biodiversidade, é motivada principalmente pela expansão agrícola (Foley *et al.*, 2005).

O caso do Brasil

O Brasil foi um país que historicamente teve, no contexto da divisão internacional do trabalho, um papel de exportador de produtos primários com baixo valor agregado, entre os quais se destacam os produtos agrícolas. Com efeito, ao longo de sua história, por dois momentos o Brasil teve sua economia baseada em um produto agrícola de exportação único: a cana-de-açúcar nos séculos XVI e XVII e o café no século XIX e início do século XX. Na segunda metade do século XX, o Brasil passou por uma diversificação da produção. Sendo um dos alvos da Revolução Verde, a agricultura no Brasil também se modernizou como consequência do processo de industrialização do país a partir da década de 1950. A população urbana, que representava 31% do total do país, atingiu uma proporção de 84% em 2010 (IBGE, 2012). Essa demanda urbana crescente representou um estímulo para agricultura brasileira – especialmente para as culturas de milho, soja, trigo e algodão (Alves, 2005) – que se expandiu em termos de área e de produtividade. Entre 1975 e 2010, a área de cultivo de grãos aumentou em 45,6%, enquanto a produção cresceu 268%.

Apesar desse crescimento de produtividade, a expansão agrícola teve um profundo impacto sobre os ecossistemas naturais do Brasil. A Mata Atlântica, localizada junto à costa e, portanto, mais sensível à exploração desde o período colonial, apresenta atualmente cerca de 14% de cobertura vegetal remanescente (Ribeiro *et al.*, 2009). O Cerrado, por sua vez, teve 50% da sua cobertura alterada e a Amazônia teve uma porcentagem de 15% de destruição da cobertura vegetal original. A área média desmatada anualmente tem sido de mais de 14 mil km^2 desde 1988 para o Cerrado (MMA, 2010) e de 18 mil km^2, desde 1977, para a Amazônia (INPE, 2011).

A agricultura mundial tem tido uma expansão da produção principalmente pelo aumento da produtividade. Nas últimas décadas, a expansão da área agrícola tem sido pequena, no entanto, ela tem ocorrido principalmente nas regiões tropicais, detentoras de uma parcela importante da biodiversidade global. Dado que a produtividade agrícola mundial pode ser aumentada com a redução das lacunas de produtividade (*yield gaps*) e a otimização dos meios de produção, a destruição das áreas tropicais pode ser interrompida sem a redução da produção agrícola. O Brasil, no entanto, parece estar em oposição a esse entendimento. O principal instrumento legal para proteção da biodiversidade nas áreas rurais, o Código Florestal (Lei 4771 de 1965), tem sido ameaçado por propostas de flexibilização (Metzger, 2010). Os instrumentos previstos nessa lei, como é o caso da reserva legal e das áreas de preservação permanente, têm um papel fundamental na manutenção da biodiversidade e dos serviços ecossistêmicos nas áreas agrícolas.

O Brasil é um país especialmente vulnerável aos efeitos da expansão agrícola devido à sua ligação histórica com essa atividade, ao papel central que a agricultura ocupa na economia brasileira e à presença de uma importante parcela da biodiversidade global em seu território. Além disso, alterações recentes em leis ambientais evidenciam a existência de uma complacência com a degradação ambiental no país. Assim, a avaliação dos impactos da expansão agrícola no contexto específico do Brasil passa a ter uma relevância e uma urgência especiais.

O papel das áreas agrícolas para a biodiversidade

O real valor da agricultura para a biodiversidade é uma questão em disputa na literatura científica. Alguns autores têm destacado o papel das áreas agrícolas como hábitats capazes de sustentar uma importante parcela da biodiversidade (Daily *et al.*, 2003; Perfecto & Vandermeer, 2010; Wright *et al.*, 2012). No entanto, essa visão está associada ao entendimento de que diferentes tipos de agricultura desempenham papéis diferentes na manutenção da biodiversidade.

O debate sobre o papel das áreas agrícolas está diretamente associado ao entendimento de quais são as estratégias de conservação da biodiversidade mais adequadas em relação à agricultura. Esse debate tem se concentrado principalmente na dicotomia entre "terras exclusivas" (do inglês, *land sparing*) e "terras compartilhadas" (*land sharing*) (Balmford *et al.*, 2005; Green *et al.*, 2005; Ewers *et al.*, 2009; Phalan, 2011). A estratégia das terras exclusivas consiste em cultivar de maneira intensiva as terras agrícolas, de maneira a obter o máximo de produção nessas áreas, satisfazendo à demanda humana de produtos agrícolas e permitindo que outras áreas sejam reservadas para a proteção da biodiversidade de maneira exclusiva. Já a abordagem das terras compartilhadas é definida pelo uso de técnicas agrícolas com menor impacto sobre a biodiversidade, de maneira a tornar as áreas de cultivo mais "permeáveis" à biodiversidade, ainda que isso signifique uma redução da produtividade.

Desse contexto, emergem algumas conclusões que orientam nossa posição, com consequências sobre os métodos que utilizamos nos artigos aqui apresentados. As áreas de vegetação original têm um valor único para a biodiversidade (Barlow *et al.*, 2007; Gibson, 2011) e para os serviços ecossistêmicos, sendo que algumas espécies vivem apenas em áreas não cultivadas. Áreas protegidas de qualquer tipo de cultivo agrícola são, portanto, imprescindíveis para a proteção da biodiversidade. Porém, algumas técnicas agrícolas associadas a uma alta produtividade têm impacto não apenas sobre a biodiversidade, mas sobre outras bases da agricultura como a água e o solo. Desta maneira, torna-se necessário o desenvolvimento e a difusão de técnicas que beneficiem a biodiversidade, mas que possam também beneficiar a produção agrícola. Por fim, o entendimento de que certas abordagens consideradas como tendo um potencial maior de manter uma proporção mais elevada da biodiversidade, como são aquelas associadas à produção orgânica, não tem uma produtividade menor necessariamente (Drinkwater *et al.*, 1998; Reganold *et al.*, 2001; Badgley *et al.*, 2007), pressuposto da dicotomia entre terras exclusivas e terras compartilhadas.

Os cenários de expansão agrícola para o futuro

Deste complexo sistema de produção agrícola brevemente descrito acima emergem uma série de incertezas a respeito do futuro. A estratégia disponível para lidar com as incertezas sobre os rumos das sociedades humanas e seu consequente impacto é a construção de cenários. Para a construção desses cenários são identificados aspectos socioeconômicos centrais na organização humana, como tamanho populacional, consumo per capita, integração e avanço tecnológico. Para cada um desses aspectos são definidas possíveis trajetórias, bem como os resultados da interação entre os mesmos.

Pelo menos desde 1972, quando foi publicado o livro *Limits to Growth* (Meadows *et al.* 1972), um marco da discussão ambiental, existe uma demanda para cientistas abordarem prováveis consequências futuras do modo de vida da humanidade no presente a fim de orientar tomadas de decisão baseadas no conhecimento científico disponível. Entre os documentos mais recentes que fazem uso dos cenários futuros a fim de contribuir para a tomada de decisões que reduzam os impactos negativos das ações humanas estão o relatório do *Intergovernmental Panel on Climate Change* (IPCC) de 2007 (Pachauri *et al.*, 2007), voltado para as mudanças climáticas, e o *Millenium Ecossystem Assessment* (MEA, 2003), voltado para os serviços ecossistêmicos ligados ao bem-estar humano.

Um dos modelos que subsidia as discussões sobre as mudanças ambientais globais é o IMAGE, *Integrated Model to Access the Global Environment*. O IMAGE simula interações entre a população humana, os ambientes terrestres e os marinhos e a atmosfera, com o fim de avaliar os possíveis resultados dessas dinâmicas. Entre os componentes do IMAGE, encontra-se um modelo de uso do solo, no qual informações de demanda e potencial produtivo são conciliadas para gerar mapas globais de cobertura da terra para o século XXI. Esses mapas têm resolução espacial de 0,5° x 0,5° de latitude/longitude e cobrem o período de 1970 a 2100 a partir dos cenários SRES (IPCC, 2000).

Os cenários de expansão agrícola e a biodiversidade

As informações sobre alterações de uso do solo para o futuro podem ser utilizadas para o entendimento dos possíveis impactos dessas mudanças sobre a biodiversidade. Essas informações podem ser aplicadas em modelos pertencentes aos dois arcabouços teóricos vigentes na Ecologia e na Biogeografia: aquele que utiliza modelos nos quais a identidade e as características particulares das espécies são ignoradas ("neutros") e aqueles nos quais essas características são incorporadas de maneira explícita ("baseados em nicho").

Entre os modelos neutros que podem fazer uso dos dados sobre alterações do uso do solo destacam-se os modelos de relação espécie-área. Esses modelos preveem o incremento de número de espécies com o aumento da área disponível, geralmente com o uso da versão função de potência $S = cA^z$, onde S é o número de espécies, A é a área disponível, e c e z são constantes, embora essa relação possa variar de acordo com a região de estudo e com o grupo taxonômico (Guilhaumon *et al.*, 2008). Esses modelos têm sido utilizados para predizer o número de extinções locais em resposta à perda de habitat por mudança de uso do solo (Pimm & Askins, 1995; Brooks *et al.*, 2002; He & Hubbell, 2010).

Entre os modelos que fazem uso as características das espécies, dados sobre expansão agrícola podem ser incorporados quando estes incluírem o espaço entre as suas variáveis, sejam, por exemplo, modelos baseados em indivíduo, modelos de viabilidade populacional e modelos de comunidades. Além disso, as análises de risco de extinção das espécies (Purvis *et al.*, 2000) têm feito o uso simultâneo da suscetibilidade intrínseca das espécies, dada pelas características ecológicas e de história de vida das espécies, e ameaças externas, das quais a agricultura é um exemplo.

No contexto mais aplicado da biogeografia da conservação (Whittaker *et al.*, 2005), duas linhas de investigação podem ser abordadas com o uso de dados sobre expansão agrícola: os estudos sobre conflitos de conservação (Balmford *et al.*, 2001) e os estudos sobre planejamento sistemático (Margules & Pressey, 2000). Os conflitos de conservação ocorrem quando áreas com especial interesse biológico coincidem espacialmente com as ameaças à biodiversidade. A maior parte dos estudos de conflito de conservação avaliou a convergência entre riqueza de espécies e densidade populacional humana (e.g. Araújo *et al.*, 2003; Balmford *et al.*, 2001; revisado em Luck *et al.*, 2007). O planejamento sistemático é uma abordagem objetiva, com critérios explícitos para orientar os investimentos em conservação. Essa busca pode focar em indicadores de biodiversidade, como riqueza e complementaridade de grupos taxonômicos alvo ou ainda incorporar informações socioeconômicas que representem ameaças à conservação (Margules & Pressey, 2000).

A estrutura da tese

Os trabalhos a seguir tratam especialmente dos temas associados à biogeografia da conservação do ponto de vista dos conflitos de conservação (capítulos 2 e 5) e do ponto de vista do planejamento sistemático (capítulos 3 e 4).

O capítulo 2, "Agricultural expansion and the fate of global conservation priorities", testa se as áreas consideradas como prioridades globais de conservação (revisadas em Brooks et. al, 2006 – e.g. *Biodiversity Hotspots* e *Last of the Wild*) serão preferencialmente impactadas pela expansão agrícola no século XXI.

O capítulo 3, "*Carnivore conservation biogeography and the conflicting global expansion of agricultural areas*", aborda conflitos de conservação entre expansão agrícola e áreas prioritárias para a conservação de carnívoros, no nível global, escolhidas de acordos com princípios de planejamento sistemático. Além disso, foi testado se a incorporação da informação sobre a expansão agrícola no planejamento sistemático resolve esses conflitos de conservação, bem como o impacto dessa incorporação em termos de distribuição espacial e benefício das áreas prioritárias escolhidas para a biodiversidade.

O capítulo 4, "*Globalization of conservation efforts helps saving species and feeding the world*", testa o efeito da integração dos esforços de conservação entre países na priorização para a conservação. Nesse capítulo, tanto os benefícios para conservação quanto a capacidade de produção agrícola são levados em conta no estabelecimento de uma rede global para a conservação de mamíferos, uma vez que existe uma crescente de alimentos.

O capítulo 5, "*Agricultural Expansion Can Menace Brazilian Protected Areas During the 21st Century*" testa se as áreas protegidas de uso sustentável diferem das áreas protegidas de uso restrito quanto ao impacto da expansão agrícola.

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Capítulo 2: Agricultural expansion and the fate of global conservation priorities[1]

Abstract

Non-governmental organizations have proposed nine different global prioritization schemes, some of them focusing on areas with low vulnerability (a proactive reasoning) and some others targeting areas with high vulnerability (a reactive reasoning). The main threat to the remaining natural habitats of these areas is the expansion of agriculture. We evaluated the spatial congruence between agricultural land cover and global conservation priority areas in the present and in the future using a spatial model of land use coverchange from 2000 to 2100. We showed that by the year 2000, the extent of agriculture was larger in reactive priority areas than in the rest of the world, while it was smaller in areas highlighted as important under proactive approaches. During the twenty-first century, we found a general increase in agriculture area and the difference between the approaches of conservation schemes is expected to hold true, although we found that high-biodiversity wilderness areas (HBWA), a proactive scheme, may be specially affected in certain scenarios of future change. These results suggest an increase in conservation conflicts over this century. In face of agricultural expansion, both kinds of prioritization approaches are important, but different strategies of protection are necessary (e.g., reactive approaches need the urgent protection of remnant habitats, while proactive ones have space to create megareserves). Further, conservation organizations must include agriculture expansion data and their uncertainty in conservation planning in order to be more successful in biological conservation.

Keywords

Agriculture; Conservation conflict; Global biodiversity conservation priorities; Land use and land cover change; Biodiversity hotspots; High-biodiversity wilderness areas; Endemic bird areas; Crisis ecoregions; Megadiversity countries; Last of the wild

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Introduction

Conflicts between biodiversity conservation and human development may threaten the livelihood of species worldwide. The world is faced by an astonishing increase in the number of species considered to be threatened (IUCN 2009) in response to growth of human population (United Nations Population Division 2008) and per capita consumption (Myers and Kent 2003) that generates an increasing pressure on natural resources. The biodiversity we are losing is important for ecological processes, human economy, and human leisure (Millenium Ecosystem Assessment 2005). Here, we assessed if agricultural expansion up to 2100 will threat biodiversity inhabiting priority areas for conservation worldwide scaling up conservation conflicts in the future.

Throughout the world, there are places with special biological features (i.e., high diversity or high levels of endemism) that arouse the attention of conservation scientists, practitioners and planners. When these places are also subject to human development activities, a conservation conflict emerges. Such congruencies have been measured in different ways, including the correlation between the human population and species richness (Balmford et al. 2001; Araújo 2003; see Luck 2007 for a recent review), the comparison of human population inside and outside Biodiversity Hotspots (Cincotta et al. 2000), the correlation between avian endemism and deforestation (Balmford and Long 1994), the correlation between biodiversity and agricultural productivity (Huston 1993) and the extent of agriculture within the Endemic Bird Areas (Scharlemann et al. 2004). However, we are still in need of a proper evaluation of the different global conservation priority schemes versus agriculture expansion, both in the present and in the context of future changes. Such assessment may inform the conservation practitioners and scientists about foreseeable risks to biodiversity and conservation opportunities as well.

There is growing evidence that habitat loss is the main threat to biodiversity (Vitousek et al. 1997; Sala et al. 2000; Green et al. 2005). Humans destroy natural habitats through changes in land cover and land use mostly in order to expand agriculture areas that feed human populations and livestock (Tilman et al. 2001; Foley et al. 2005; Green et al. 2005). With the increase of human populations and their consumption per capita, it is expected that the area devoted to agriculture is going to increase worldwide (Tilman et al. 2001). Beyond habitat destruction, agriculture is related to other impacts, such as biological invasion, eutrophication, chemical contamination, and greenhouse gases emissions (Tilman et al. 2001). To understand the dynamics of land cover and land use change and its associated impacts on biodiversity and ecosystem services, a land change science has emerged (Sala et al. 2000; Turner et al. 2007). One of the tools used by this interdisciplinary field is the development of spatially explicit models, such as the Integrated Model to Assess the Global Environment (IMAGE), capable of forecasting land use change based on the joint modeling of human activities and environmental processes. To anticipate the consequences of different socioeconomic pathways that human societies can follow, different scenarios of land use change have been proposed (IPCC 2000; UNEP 2002; Millenium Ecosystem Assessment 2005; Pereira et al. 2010).

Since the foundation of the systematic conservation planning framework—epitomized by Myers' (1983) seminal paper—the conservation community has been looking for a "silver bullet" and seeking a way to get the "biggest bang for the buck". However, even considering the existence of objective methods for analyzing data and establishing priorities, it is important to note that conservation strategies in a changing world can be done using different and alternative principles (Fonseca et al. 2000; Redford et al. 2003). Thus, important non-governmental organizations have proposed nine schemes during the last two decades, which can be interpreted as nine major institutional templates for global conservation priorities (e.g., Stattersfield et al. 1998; Myers et al. 2000; Sanderson et al. 2002). These templates were revised and classified according to the conservation planning theoretical principles of irreplaceability and vulnerability (Brooks et al. 2006). Six of them incorporate irreplaceability by means of endemism of plants (WWF and IUCN 1994–1997; Mittermeier et al. 1997; Olson and Dinerstein 1998; Myers et al. 2000; Mittermeier et al. 2003) or terrestrial vertebrates (Stattersfield et al. 1998). Five templates take into account vulnerability that has been measured as a proportion of habitat loss (Myers et al. 2000; Mittermeier et al. 2003; Hoekstra et al. 2005), forest cover (Bryant et al. 1997), protected area coverage (Hoekstra et al. 2005) or human population growth and density (Sanderson et al. 2002; Mittermeier et al. 2003). As later suggested by Brooks et al. (2006), these prioritization schemes can be classified as reactive (i.e., those highlighting areas with high vulnerability, e.g., Biodiversity Hotspots), proactive (i.e., those that prioritize areas with low vulnerability, e.g., Last of the Wild) and approaches that do not incorporate vulnerability as a criterion (neutral approaches, e.g., Endemic Bird Areas).

Here, we asked if areas highlighted as priority under reactive or neutral approaches are likely to be more affected by agriculture than non-priority areas. We also investigate if areas included in proactive schemes, in contrast, are less affected than the rest of the world; i.e. the presence of agriculture reproduces the pattern of vulnerability that would be predicted by the conservation templates' design. Moreover, we evaluated whether agriculture expansion throughout the twenty-first century is more likely to occur inside global conservation priority areas than outside them, suggesting an increase in conservation conflict. We also assessed whether there will be a convergence in the proportion of the areas affected in each conservation template regardless of approach (reactive, neutral or proactive). Finally, we tested if the uncertainty regarding land use model scenarios was higher in these priority conservation areas.

Materials and methods

Land use data

We used the Integrated Model to Assess the Global Environment (IMAGE, version 2.2) (IMAGE Team 2001) to map agricultural land. This model is an "integrated assessment model" that is used to describe the environmental consequences of human activities. The objective of IMAGE is to explore the long-term dynamics of global environmental change, taking many feedback mechanisms within the society–biosphere–climate system into account (IMAGE Team 2001). It is also a spatially explicit model that analyzes the trends found in global land cover/land use and in the variables that influence its change. Global land use was mapped by IMAGE 2.2 on a 0.5 × 0.5 latitude–longitude grid. IMAGE 2.2 does not model land use in the Antarctic and in some oceanic islands; hence, we excluded these areas from our analyses. We defined agricultural land as cropland, fallow land, and grassland (excluding extensive grassland) (IMAGE 2.2 class one). To map the extent of agricultural land, IMAGE considers variables such as previous land cover, potential vegetation cover, crop productivity, management factors, human population density, and demand for food, biofuel and timber products (IMAGE Team 2001). The model's temporal span starts in 1970 and goes up to 2100, with maps for every 10 years, providing alternative pathways of future land use change based on six scenarios (A1B, A1F, A1T, A2, B1, B2) developed by IPCC in the Special Report on Emissions Scenarios (SRES) (IPCC 2000; IMAGE Team 2001) (Fig. 1).

Briefly, the IPCC (SRES) scenarios are based on two axes: the degree of globalization versus regionalization and the level of orientation on material versus social and ecological values (IMAGE Team 2001). The A1 scenario family assumes a continuing globalization, very rapid econ omic growth, low population growth, and rapid introduction of new and more efficient technologies. This process results in convergence among regions due to increased cultural and social interactions and to a substantial reduction in regional differences in per capita income. The A1 scenario is divided into three possibilities, in accordance with their technological emphasis: fossil intensive (A1F), non-fossil energy sources (A1T), and balanced across all sources (A1B) (IPCC 2000).

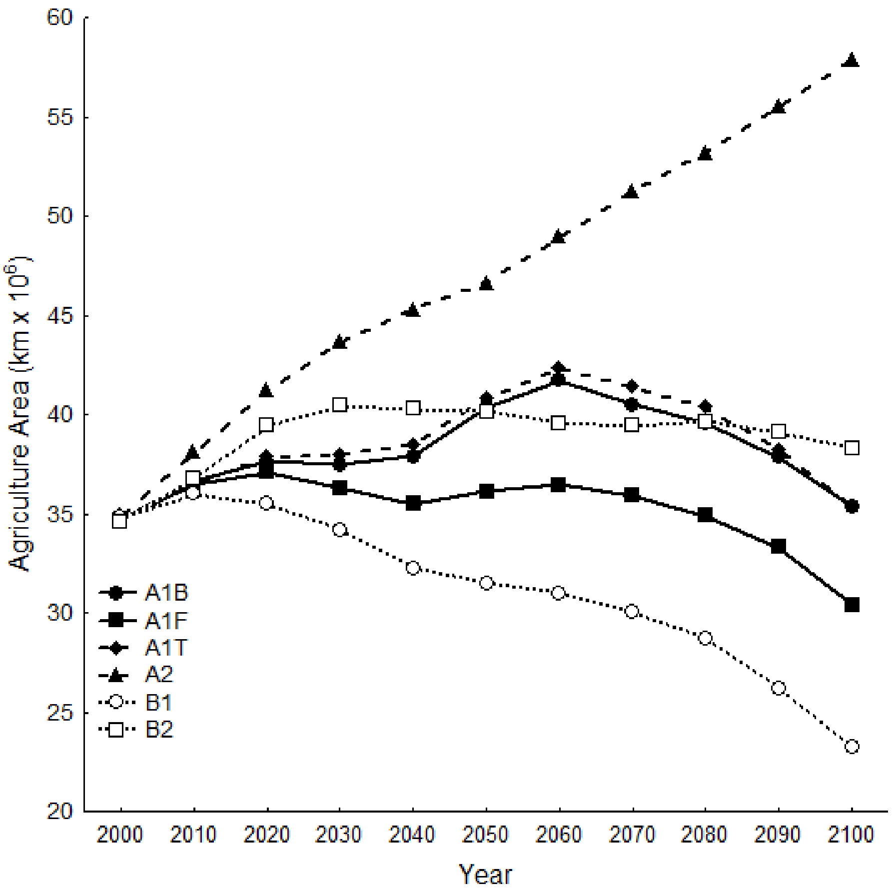


Fig. 1 Change in global extent of agriculture from 2000 to 2100 according to the Integrated Model to Assess the Global Environment version 2.2 under six SRES scenarios (A1B, A1F, A1T, A2, B1, B2).

In the A2 scenario, globalization slows down, generating a very heterogeneous world as nations and governments focus on cultural identity and traditional values and leading to slower economic growth, technological change, and fertility reduction. The other scenario used herein (B1), also starts from the same low population growth rate as A1, but it assumes important changes in economic structures toward a service and information economy, which represents a human focus on the environmental and social or immaterial aspects of life, and the introduction of clean and resource-efficient technologies. In this scenario, the emphasis is placed on global solutions to economic, social, and environmental sustainability, including improved equity (IPCC 2000). In scenario B2, people are organized to find solutions to economic, social, and environmental sustainability issues in the same way as in B1, except that they are focused on local and regional solutions. Thus, there is significant heterogeneity between regions. All these scenarios do not include explicit climate policy interventions (IPCC 2000). Further details about each scenario are described by IPCC (2000) (see Millenium Ecosystem Assessment 2005 for a comparison with other proposed scenarios).

Intersection of global biodiversity conservation priorities and land use maps

We used the nine major templates for Global Biodiversity Conservation Priorities (GBCP) (see Brooks et al. 2006). We also evaluated the conservation schemes resulted from overlaying reactive (Crisis Ecoregions, CE; and Biodiversity Hotspots, BH) and proactive conservation approaches (high-biodiversity wilderness areas, HBWA; Frontier Forests, FF; and Last of the Wild, LW) as proposed by Brooks et al. (2006). Conservation schemes that do not consider vulnerability, i.e., neutral approaches, are Endemic Bird Areas (EBA), Megadiversity Countries (MC), Centers of Plant Diversity (CPD), and Global 200 Ecoregions (G200) (Brooks et al. 2006). Template polygons were converted to a raster image with 0.58 9 0.58 resolution, which is compatible with those from IMAGE 2.2 land use maps. The cells whose area was covered in a proportion higher than 50% by the template polygon were considered part of the template. The reference coordination system of all spatial data was WGS 84.

Maps of agricultural extent and GBCP were overlaid using the Idrisi Kilimanjaro GIS software (Eastman 2003). We calculated the proportion of global agriculture cover as the area affected by this land cover type divided by the total terrestrial area mapped by the IMAGE. The same was repeated for each conservation template. The agriculture area in 2000 was defined by the overlay of the maps of this land cover type in the world in the six scenarios, given that we found a great congruence among them (84.4%).

For predictions about the future, we performed two analyzes. Firstly, we choose a particular future scenario to help to envisage a specific future scenario for world agriculture.In this simpler analysis, we summed the 10 images of the scenario A1B and assigned value one to any cell converted to agriculture anytime during the twenty first century. This approach was based on two assumptions: (i) the A1B is a plausible scenario, since the world nowadays can be classified as economically driven (A), we are under a process of international integration through globalization (1), and the non-fossil fuels have been gaining importance, so we seem to be going to a world of balanced use of fossil and non-fossil fuels (B). Also, A1B has an intermediate level of agriculture impact (Fig. 1); (ii) the areas once affected by agriculture will be permanently altered, since the secondary habitats do not have the same value for biological conservation than original ones (Barlow et al. 2007). In the second approach, that preserves all the complexity of the model, in terms of time and scenarios, the expansion of agriculture during the twenty-first century was defined by the overlay of the 60 maps available for the years between 2010 and 2100 for all six scenarios. This procedure resulted in an agriculture-proneness-score (APS) for each cell, which varied between zero (no agriculture at any date of any scenario) and 60 (presence of permanent agriculture in all scenarios). This second approach, which maintains all uncertainties, is important because it can help to understand key uncertainties in the future, can be used to incorporate alternative perspectives in conservation planning and probably can provide more resilience to decisions in response to changes (Peterson et al. 2003).

To evaluate if the proportion of agricultural land in 2,000 was randomly distributed between each conservation template and the rest of the world, we designed a randomization test. Initially, we defined the cells prone to agriculture conversion as any cell that was affected by agriculture any time in any SRES scenario during the twenty first century (APS equal or higher than one). Then, we took the cells considered above as a constraint and, inside them, we randomized the position of the cells that were known to have agriculture in 2000. Finally, we calculated the number of cells with agriculture in this null model for each conservation template. The whole process was repeated 1,000 times.

Since we have different alternative hypothesis for reactive plus neutral in comparison to proactive templates, we used different one-tailed randomization tests in each case. For reactive and neutral templates, the proportion of randomized values equal or higher than the observed number of cells with agriculture (P value) was used to test if the observed value could be explained by chance alone ($\alpha > 0.05$). For proactive templates, we did the same, but took into account the values equal to, or lower than, the observed number of cells. For the twenty-first century map, we followed the same general randomization procedure for the analysis of the A1B scenario, but multiplied the number of cells by their respective APS for the analysis that combined all scenarios. We estimated the p-value for significant tests by the proportion of APS calculated from random assignments of cells for each conservation template that was equal to or higher than the observed values. In all cases, the number of cells was corrected by cell area. All randomization procedures were done using R (R Development Core Team 2008).

Scenario uncertainty evaluation

In our analysis, we had two main sources of uncertainty, particularly for the future, i.e., time and scenario. Scenario could be considered hierarchically more important than time in those analysis because, for conservation purposes, it is more important to know if an area will be or not affected by agriculture than when or for how many years. Thus, we performed an analysis of the uncertainty related to the difference among scenarios to clarify the source of uncertainty.

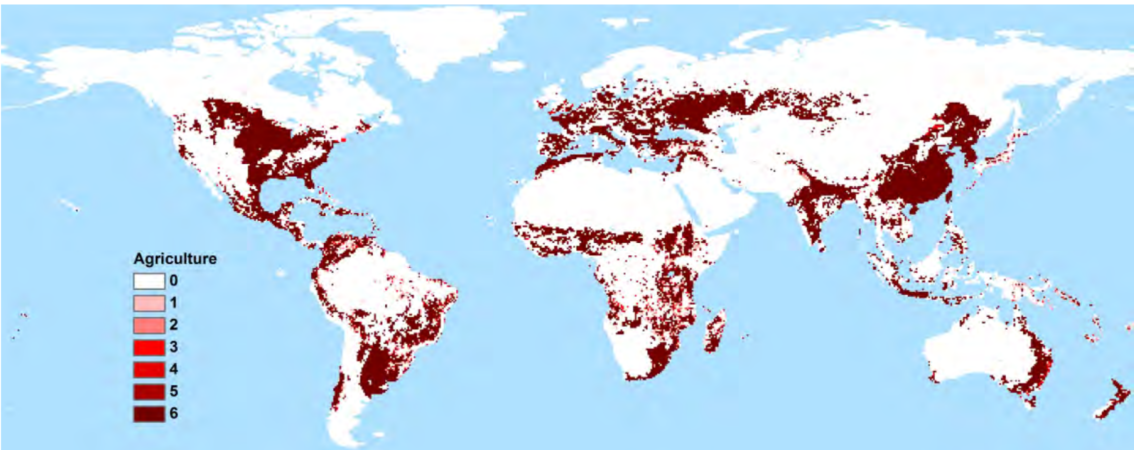
To perform this analysis, we summed all maps of the ten dates of each six scenarios. With this procedure, we managed to depict the areas that will be affected by agriculture anytime in the twenty-first century in each scenario. This procedure annulled the importance of time as a source of variation. The remaining differences among maps are derived only from the distinctions in the scenarios. To quantify this uncertainty score (US), we first added the six scenarios' maps of agriculture distribution. For areas that were affected by agricultural expansion in every scenario, uncertainty is zero. The same holds true for those areas not affected in any scenario. On the other hand, a cell affected by only one scenario has an US of five. Cells affected by two scenarios have US of four, and so on. We evaluated the probability of the sum of uncertainty score found in each conservation template through a randomization test as we have done for the presence of agriculture (see above). This procedure was done for the uncertainty of the areas of agriculture in 2000 and in the twenty-first century. The estimated the P value was the number of times that the sum of the uncertainty scores obtained through randomization was equal or lower than the observed value.

Results

Current land use

In 2000, 26.5% of the world's land surface was converted to agricultural land (Fig. 2a; Table 1). The only reactive template significantly more affected by agriculture than the rest of the world was CE (52.3%; P = 0.001) (Table 1). All proactive schemes were less affected than the outside areas. For instance, LW had only 3.0% of its area affected and was 11 times less affected than the rest of the world (P = 0.001) (Table 1).

The comparison of reactive and proactive approaches showed that the former (48.6%; P = 0.001) are much more affected by agriculture than the latter (5.2%; P = 0.001). For the approaches that did not consider vulnerability, we found different results. For example, EBA were 83% more affected than the rest of the world (P = 0.001) (Table 1). Other neutral templates (MC, CPD, and G200) had proportions of agricultural land similar to those found in areas outside of them.



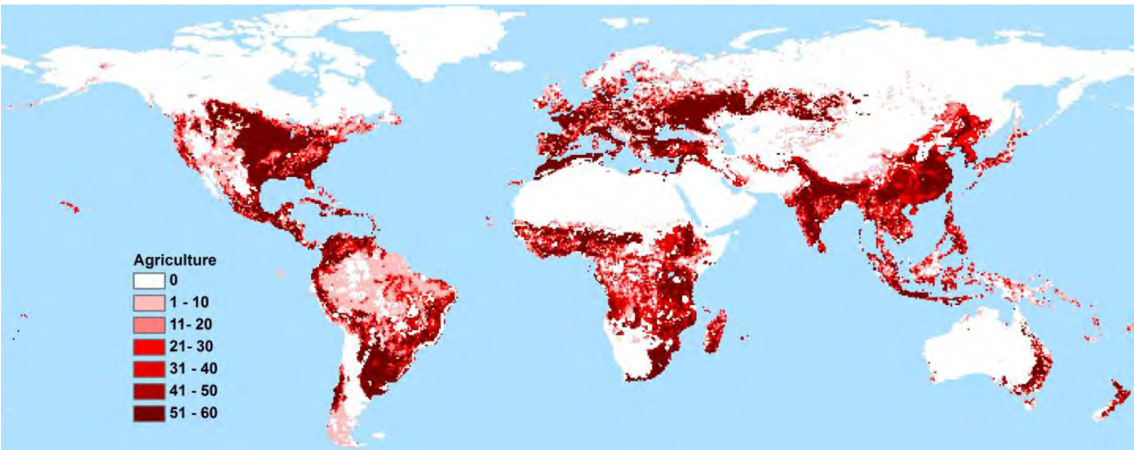


Fig. 2 Map composed by the sum of the maps of the global extent of agriculture in 2000, simulated by the Integrated Model to Assess the Global Environment version 2.2 with six SRES scenarios (a). In b, there is the sum of the 60 maps of the global extent of agriculture for six future scenarios of 10 time periods from 2010 to 2100 reaching 47.7% of global land cells (Fig. 2b; Table 1). In our analyses these cells were affected, on average, by 34 out of the 60 possible combinations of scenarios each year (SD = 22.1).

Agricultural expansion in the twenty first century

Agriculture in the world will reach 34.3% of the analyzed land surface during the twenty first century according to the scenario A1B, which means an increase of 29.6% in relation to the agriculture extent in 2000. Reactive approaches whether combined (60.1%;

P<0.001) or separately (CE = 63.9%; P<0.001 and BH = 56.7; P<0.001) besides EBA (53.8%; P<0.001) were particularly affected.

Our analyses of the 6 models and 10 dates combined (APS) reveal that there will be an increase of 80% of the world area affected by agriculture during the twenty-first century, reaching 47.7% of global land cells (Fig. 2b; Table 1). In our analyses these cells were affected, on average, by 34 out of the 60 possible combinations of scenarios each year (SD = 22.1).

Table 1 Agriculture intersection with global conservation priority schemes

Priority Scheme	*In/Out*	*All models 2000 (%)*	*p-value*	*(A1B) 2100 (%)*	*p-value*	*All models 2100 (%)*	*2100 (S)*	*p-value*
BH(R)	In	42.5	N.S.	56.7	<0.001	75.7	36	<0.001
	Out	22.6		29.0		41.0	32	
CE (R)	In	52.3	<0.001	63.9	<0.001	76.8	41	<0.001
	Out	15.5		21.7		35.2	27	
CPD (P)	In	29.5	N.S.	39.8	N.S.	60.9	29	N.S.
	Out	26.2		33.8		46.4	34	
EBA (N)	In	44.9	<0.001	53.8	<0.001	73.7	35	<0.001
	Out	24.5		32.2		44.9	33	
G200 (N)	In	26.8	N.S.	35.2	N.S.	52.9	31	N.S.
	Out	26.3		33.8		44.5	36	
MC (N)	In	35.3	N.S.	44.5	N.S.	64.0	32	N.S.
	Out	21.8		28.9		38.9	35	
HBWA (P)	In	11.3	<0.001*	25.9	N.S.	73.5	14	N.S.
	Out	27.9		35.1		45.3	36	
FF (P)	In	4.5	<0.001*	10.5	N.S.	34.2	12	N.S.
	Out	28.7		36.8		49.1	35	
LW (P)	In	3.0	<0.001*	5.7	N.S.	17.9	12	N.S.
	Out	34.1		43.7		57.4	36	
Reactive	In	48.6	<0.001	60.1	<0.001	74.7	39	<0.001
	Out	12.1		17.5		30.1	24	
Proactive	In	5.2	<0.001*	10.3	N.S.	26.1	15	N.S.
	Out	35.9		44.9		57.2	37	
Mundo	In	26.5		34.3		47.7	34	

Percentage (%) of the area of each global biodiversity conservation priority scheme that was covered by agriculture in 2000, and its coverage prediction in 2010–2100 according to the Integrated Model to Assess the Global Environment version 2.2. Value of the agriculture-proneness-score (APS) mean of the cells of each conservation scheme resulted from the sum of the 60 maps (possible values = 0–60). Value of probability (P value) that the priority template area was more affected than the portion of the world that was convertible to agriculture (see text) (* For proactive schemes in 2000, we tested the probability that the scheme was less affected).
Global conservation priority schemes and their respective authors are as follows: BH biodiversity hotspots, Myers et al. (2000), updated in Mittermeier et al. (2004); CE crisis ecoregions, Hoekstra et al. (2005); CPD centers of plant diversity, WWF AND IUCN (1994–1997); EBA endemic bird areas, Stattersfield et al. (1998); G200 global 200 ecoregions, Olson and Dinerstein (1998), updated in Olson and Dinerstein (2002); MC megadiversity countries, Mittermeier et al. (1997); HBWA high-biodiversity wilderness areas, Mittermeier et al. (2003); FF frontier forests, Bryant et al. (1997); LW last of the wild, Sanderson et al. (2002). R reactive schemes; P proactive schemes; N neutral schemes
In inside the global biological conservation priority template area; Out outside of it. NS not significant; a = 0.05.

Reactive templates, when analyzed separately or coupled, had about 75% of their area affected by agriculture; a higher proportion when compared to the global average. For example, BH was found to be 75.7% covered by agriculture during the twenty-first century ($P<0.001$) (Table 1). The APS of their cells were also higher. In contrast, proactive templates, when taken together, had a smaller proportion and scores of affected area. However, when examined separately, HBWA had 73% of its area affected by agriculture, although it had a lower score, which means that it was reached by agriculture only in a few scenarios and for a short period of time (P value not significant); this proportion is similar to that of reactive templates.

With regard to neutral templates, only Endemic Bird Areas were significantly more affected by agriculture than expected by chance (73.7%; $P<0.001$).

Scenario uncertainties

Uncertainty about the expansion of agriculture according to different scenarios also depends on the conservation approach. For 2000, although there was only 15.6% uncertainty, this uncertainty was not equally distributed among the conservation schemes. Only in CE (9.1%; $P<0.001$), MC (12.5%; $P<0.001$) and in the reactive approaches summed (12.4%; $P<0.001$) (Table 2; Fig. 3a) the agriculture presence was significantly less uncertain than for the rest of the world. The other templates had more uncertainty than the rest of the world. The proactive areas had more uncertainties when taken separately (HBWA = 424% higher; FF = 270% higher; LW = 261% higher; Table 2) or together (Proactive = 330% higher; Table 2).

In the future, the analysis of uncertainty becomes more important, as 50.6% of the area expected to be covered by agriculture in the future has some degree of uncertainty (Table 2; Fig. 3b). We found an opposite trend of agriculture uncertainty in relation to agriculture amount. The bigger agriculture extent is inside each conservation template, the smaller the uncertainty is. Therefore, in BH (51.4%; $P<0.001$), CE (36.3%; $P<0.001$), EBA (47.5%; $P<0.001$) and reactive approaches (12.4; $P<0.001$), our uncertainty was smaller than for the rest of the world. For proactive approaches, taken together or separately, the uncertainty was bigger inside them than for the rest of the world (e.g. the agriculture uncertainty in the sum of proactive approaches area was 96% higher than in the rest of the world).

Table 2. Uncertainty of global conservation priority schemes.

Priority Scheme	*In/Out*	*2000 (%)*	*2000 (US)*	*p-value*	*2100 (%)*	*2100 (US)*	*p-value*
BH (R)	In	21.7	0.43	N.S.	51.4	1.53	<0.001
	Out	12.7	0.25		50.3	1.77	
CE (R)	In	9.1	0.21	<0.001	36.3	1.11	<0.001
	Out	24.7	0.40		63.9	2.24	
CPD (N)	In	19.4	0.33	N.S.	59.0	2.12	N.S.
	Out	15.0	0.30		49.5	1.64	
EBA (N)	In	18.1	0.38	N.S.	47.5	1.56	<0.001
	Out	15.0	0.29		51.2	1.72	
G200 (N)	In	20.1	0.35	N.S.	56.2	1.93	N.S.
	Out	12.7	0.27		46.5	1.53	
MC (N)	In	12.5	0.24	<0.001	51.2	1.79	N.S.
	Out	18.0	0.37		50.1	1.62	
HBWA (P)	In	58.9	0.35	N.S.	89.3	3.57	N.S.
	Out	13.9	0.30		44.9	1.42	
FF (P)	In	40.7	0.21	N.S.	91.0	3.82	N.S.
	Out	15.1	0.31		47.7	1.55	
LW (P)	In	38.7	0.25	N.S.	88.3	3.73	N.S.
	Out	14.8	0.31		46.8	1.49	
Reactive	In	12.4	0.28	<0.001	40.7	1.25	<0.001
	Out	23.5	0.35		66.7	2.42	
Proactive	In	45.0	0.29	N.S.	85.4	3.37	N.S.
	Out	13.6	0.30		43.6	1.36	
World	In	15.6	0.30		50.6	1.70	

Percentage (%) of the area of each global biodiversity conservation priority schemes that was affected by uncertainty about the area covered by agriculture in 2000 and from 2010 to 2100 according to the Integrated Model to Assess the Global Environment version 2.2. Value of uncertainty mean score (US) of the cells of each conservation scheme resulted from the sum of the 6 maps (possible value = 0–6). Value of probability (P value) that the priority area was more affected by uncertainty than the portion of the world that was convertible to agriculture (see text). See abbreviations and references in Table 1.

Discussion

Several authors have portrayed a spatial conflict between biodiversity conservation and human development (reviewed in Luck 2007). We analyzed the conflict between global conservation priorities and agriculture in current time and in the future. We found that the magnitude of the conflict depends on how the conservation priority was defined.

Reactive approaches, defined by high vulnerability, were strongly affected. This result was in concordance with the design of the Biodiversity Hotspots (BH), for example, which were defined by areas that had more than 70% of their natural vegetation cover destroyed (Myers et al. 2000), and the Crisis Ecoregions (CE), which were composed by ecoregions that had less than 50% of their natural areas preserved (Hoekstra et al. 2005). Our study shows that 42 and 52% of these areas, respectively, were already converted to agricultural land in 2000. However, by 2100, these areas may have about 60%, if we analyze only the A1B scenario and almost three-quarters of their total area impacted by agriculture, when combining all possible future scenarios.

Proactive approaches that take into account only wilderness (i.e., the lack of human presence), such as Last of the Wild (LW) and Frontier Forests (FF), were virtually unaffected in 2000 and during the twenty-first century were likely to have just relatively small increases, reaching about 18 and 34%, respectively, of agriculture extent inside their area when all scenario were combined. The other approaches (Global 200 ecoregions, G200; Megadiversity Countries, MC; Endemic Bird Areas, EBA; and Centers of Plant Diversity, CPD) showed different results, ranging from proactive to reactive approaches. As shown in previous research (Scharlemann et al. 2004), EBA was also highly affected, similarly to a reactive approach.

Since an effective conservation priority scheme should be able to anticipate threats for the foreseeable future, one of the most interesting findings of our analyses was the results obtained for HBWA. This is a proactive approach whose areas were affected in only 11% of their extension in 2000, but which could see up to 75% used by 2100 under certain land use scenarios, as if it were a reactive approach. This assumes great importance given that HBWA is the only proactive scheme that considers irreplaceability, defined by high levels of plant endemism (Mittermeier et al. 2003). HBWA are composed of North American deserts, savannas of Miombo-Mapone and the tropical forests of Amazonia, Congo and Indonesia. Tropical forests are regions that contain most of the global biological diversity, play a vital role in providing ecosystem goods and services and have been under intensive destruction over the last decades (Laurance 1999). Further, they encompass most of the tropical ecosystems still offering significant options for successful broad-scale conservation action (Loyola et al. 2009a).

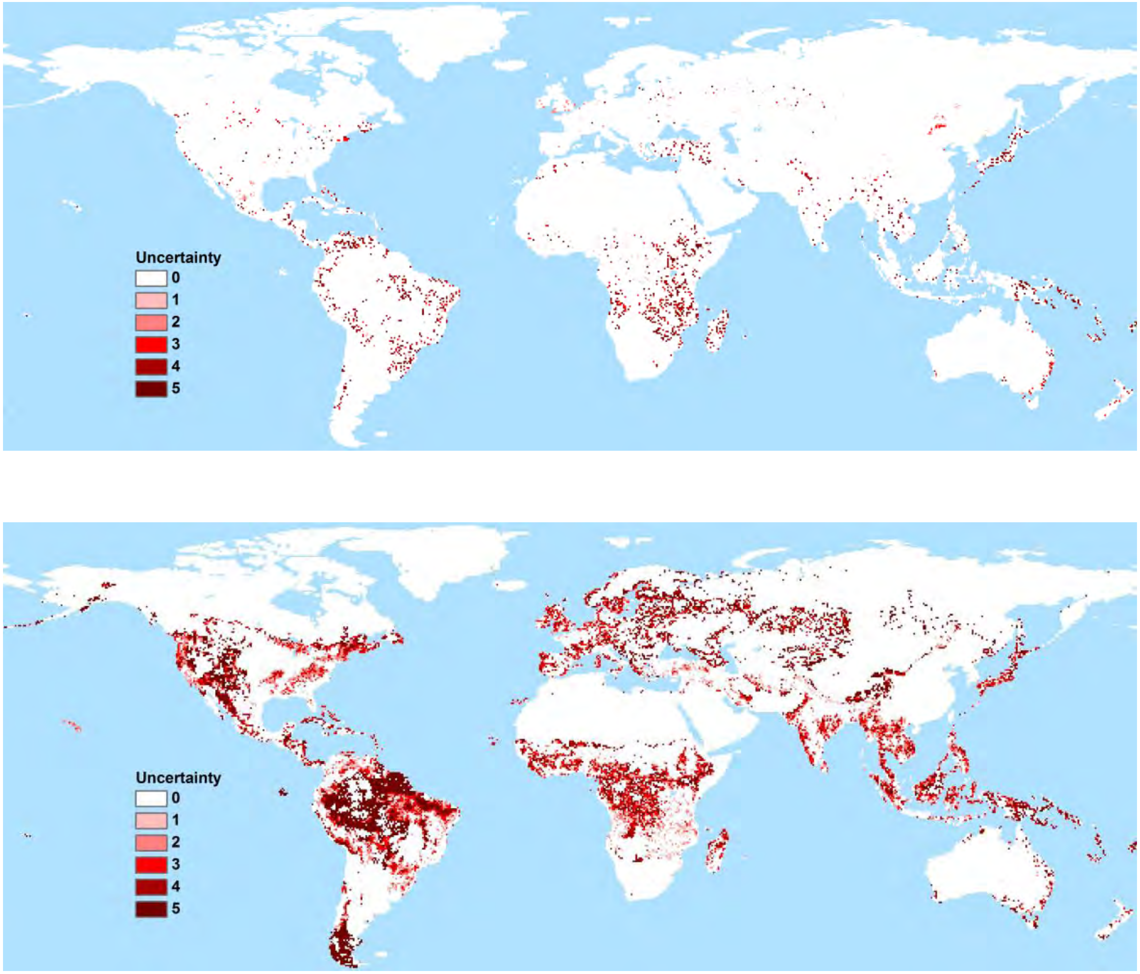


Fig. 3 Map of uncertainty value in the global extent of agriculture in 2000 (a) and from 2010 to 2100 (b) simulated by the Integrated Model to Assess the Global Environment version 2.2 with six SRES scenarios.

Agricultural expansion has been encouraged in these regions, which aims at local development and generation of capital for national industrialization, although such processes do not guarantee sustainable development (Rodrigues et al. 2009). Our projections show that a less vulnerable region today may not be so in the foreseeable future, and modeling future trends of land use/land cover change can help to anticipate threats to species and ecosystem. A good (or bad) example of this assumption was observed in the Islands of Eastern Melanesia. These islands have seen their land surface converted from an almost pristine environment to a situation in which less than 30% of its natural vegetation cover remains intact, in less than 10 years. The region ended up being classified as a Biodiversity Hotspot in 2004 (Mittermeier et al. 2004).

But what are the benefits of our approach? Human population density, the ultimate cause of species extinction worldwide, has been shown to be positively correlated to pressures on biodiversity, such as habitat alteration (Thompson and Jones 1999), over-harvesting (Brashares et al. 2001) and biological invasion (McKinney 2001). However, Rangel et al. (2007) have shown that agriculture can represent a threat to biodiversity that is independent of the human population, as was found in the Brazilian "Cerrado" (the open savannas in the central part of the country), where species richness and complementarity is coincident with indicators of agriculture and cattle ranching, but not with human population per se. This pattern is explained by the increase in technology applied to agriculture in the Cerrado region of Central Brazil (Klink and Moreira 2002). To illustrate the implications of this process, in Brazil (one of the 16 megadiversity countries that also harbors two Biodiversity Hotspots), the cropland and the number of bovine heads doubled, while the number of people in agriculture reduced 6% and the number of tractors increased 475% from 1970 to 2006 (IBGE 2010). Associated with this process, there was a huge destruction in two Brazilian biomes prone to agricultural expansion: the Cerrado, where only 20% of the original vegetation remains intact (Myers et al. 2000), and the Amazon rainforest, which has been losing an average of 1.8 million hectares of forest per year during 1988–2008 period (INPE 2010). Moreover, 70% of Brazil's population is concentrated in another biome, the Atlantic Forest (Metzger 2009). Therefore, we suggest that the agriculture area, the principal driving force of habitat destruction, should be investigated as an important indicator of the human impact for evaluating conservation conflicts, as shown by the Brazilian examples above. Also, as we found here, agriculture was capable of capturing differences among the prioritization approaches (reactive versus proactive schemes).

In addition, the use of the Global Biodiversity Conservation Priorities can be reasoned by the fact that these priorities represent large areas of the world that have directed conservation funds and efforts for on-the-ground conservation actions (Brooks et al. 2006). These several conservation schemes have been criticized as been developed due to a lack of agreement about the global conservation priorities at international level and as a cause of duplicate effort that difficult the rational application of conservation resources (Mace et al. 2000). However, our work helps demonstrate that once 74% of the world's land area is covered by some biodiversity conservation priority templates, these schemes could play an important role as part of an effective conservation strategy against agricultural expansion. Some areas highlighted in these templates are, and certainly will be even more, put in jeopardy under different intensities of destruction if society does not take action.

Like other authors (Balmford et al. 2001; Dobson et al. 2001; Luck 2007), our work suggest that these different places need different conservation strategies. For example, reactive approaches need intensive and continuous conservation actions, like the identification at higher spatial resolution, and protection of the remnants of natural areas in landscapes dominated by agriculture and other human uses, which implies in higher costs. Areas included in reactive approaches need strategies of coexistence of agriculture and biodiversity conservation, including the so-called conservation agriculture (Baudron et al. 2009) and the conservation of wildlife on private lands (Main et al. 1999). The systematic conservation planning in these areas can also be improved by strategies in which the economic costs of land acquisition are considered (e.g. Loyola et al. 2009a). Conversely, to conserve proactive areas, it is crucial (and still possible) to protect large areas (Peres 2005) because the land considered under such approaches is available and tends to be cheaper.

Assuming the agriculture data of IMAGE is correct, it remains at least three sources of uncertainty: (i) future scenarios; (ii) time and (iii) the ability of agriculture areas for maintain biodiversity. Conservation community should take advantage of this uncertainty since it could mean just lack of knowledge or a possible "leeway". In the case of scenarios, our analysis shows that the uncertainty in future land use change related to agriculture is higher under proactive approaches, which means that regions indicated as priorities under these schemes are likely to be affected only under certain future scenarios. Thus, the conservation community must pay attention to factors that influence the outcome of future scenarios, such as human population density (Cincotta et al. 2000), technological development (Reganold et al. 2001; Balmford et al. 2005; Ewers et al. 2009) and human per capita consumption (Myers and Kent 2003). However, the conservation community is not limited by the scenarios above, and people are free to build a future reality better than those suggested by available scenarios. In relation to time, the conservation actions may use the data about agriculture dynamic in an adaptive management (Salafsky et al. 2002) and conservation planning (see Pressey et al. 2007 for a review) to anticipate actions needed to choose areas less prone to be converted to agriculture, to work in agricultural areas, making it less harmful (uncertainty iii above), and planning the restoration actions to be implemented immediately after the agriculture areas are abandoned.

Conservation organizations must work together (Redford et al. 2003) in order to replace those unrelated initiatives that means duplicate efforts with an orchestrated mosaic of conservation strategies in which international efforts will be complementary (Loyola et al. 2009b). This cooperative work can be improved by the forecast of threats to biodiversity, such as agriculture, and its uncertainties. It seems that instead of a "silver bullet" (Myers 1983), the international conservation community needs a "utility belt" to deal with this changing world.

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Capítulo 3: Carnivore conservation biogeography and the conflicting global agricultural expansion[2]

Abstract

Aim Global conservation prioritization must deal with conflicting land uses. We tested the spatial congruence between agricultural expansion for the 21st century and important areas for carnivore conservation. We evaluated whether accounting for projected agricultural expansion in spatial conservation planning can alleviate conservation conflicts and estimated the consequences of such approach for the performance of the resulting networks of priority areas.

Location Global.

Methods We investigated the correlation between spatially explicit projections of agricultural expansion and the outcomes of global spatial prioritizations for carnivore conservation implementing different objectives: (1) maximizing species richness, (2) maximize species representation, and (3) representing species while avoiding areas under pressure for agriculture expansion. We evaluated the performance of conservation plans based on number of protected populations, their spatial congruence with established global prioritization schemes and spatial overlap with the current network of protected areas.

Results Priority areas for carnivore conservation were spatially correlated with future agricultural distribution. This correlation was substantially reduced by constraining the site selection using future agricultural expansion data. This resulted in a spatial solution that meets proactive global conservation schemes. When agriculture was not accounted for in the analysis, the solution converged to a reactive conservation schemes. Accounting for future agriculture distribution also resulted in less protected populations, especially for rare species. The current global network of protected areas had little overlap with the spatial solutions we found.

Main conclusions A strong conservation conflict exists between agricultural expansion and carnivore conservation, which can be alleviated by accounting for future agricultural

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[2] [2] Esse capítulo é um manuscrito inédito de autoria de Dobrovolski, R., Loyola, R.D., Guilhaumon, F., Gouveia, S.G., Diniz-Filho, J.A.F.

expansion in the prioritization process. However, this decreases the performance of the network of priority areas. We propose that priority areas highlighted by contrasting conservation planning approaches could be integrated in a strategy that directs different conservations actions to areas where they are likely to be more effective regarding agricultural expansion.

Keywords

Agriculture, Biodiversity Hotspots, endemic species, extinction risk, global biodiversity conservation priorities, IMAGE, mammal conservation, protected areas, spatial prioritization, Zonation.

Introduction

Threats to biodiversity (e.g. habitat destruction, over-exploitation, introduction of alien species and climate change) are unevenly distributed around the globe – some areas being highly vulnerable, while others remaining relatively safe (Sanderson et al., 2002). This has prompted two main research agendas in conservation biology at broad geographical scales: conservation conflicts (sensu Balmford et al., 2001) and systematic conservation planning (Margules & Pressey 2000).

Broad-scale studies focusing on conservation conflicts seek to answer if geographical patterns in human development coincide with areas harboring special biological features such as high levels of biological diversity. Most of these studies found that such conflicts are widespread worldwide (e.g. Balmford et al., 2001; Araújo, 2003; Luck, 2007a) and can emerge by distinct forms of anthropogenic spatial colonization and economic expansion within a region (Diniz-Filho et al., 2005). Systematic conservation planning, in turn, has incorporated different biological and socioeconomic information to propose sets of priority areas for conservation investment. Such information included human land use (Visconti et al., 2011); land costs (Ando et al., 1998; Underwood et al., 2008; Loyola et al., 2009, see also Naidoo et al. 2006 for a review); opportunity costs (Carwardine et al., 2008) and synthetic data such as human footprint (e.g. Loyola et al., 2008; Terribile et al., 2009).

Global strategies for biodiversity conservation have historically dealt with these conflicts under two opposing (but complementary) conceptual and philosophical approaches: the reactive and the proactive ones (see Brooks et al., 2006 for a review). The purpose of the reactive approach is to confront threats by prioritizing highly vulnerable areas, e.g. the Biodiversity Hotspots (Myers et al., 2000), whereas the less impacted areas are prioritized in proactive approaches such as the Last of the Wild (Sanderson et al., 2002), aiming to avoid conservation conflicts.

More recent prioritization approaches may or may not take into account socioeconomic information (Moilanen et al., 2009). In the former case, they implicitly sought to alleviate conservation conflicts and can be considered as analogous to proactive approaches. Conversely, those approaches that do not incorporate socioeconomic information will likely lead to conservation conflicts and consequently can be related to reactive approaches.

One of the main threats to biodiversity is the destruction of natural habitats resulting from anthropogenic land conversion (Foley et al., 2005; Schipper et al., 2008), mainly propelled by ground opening for agriculture (Tilman et al., 2001; Foley et al., 2005; 2011). Indeed, the increase in human population and human consumption of resources – including meat and agrofuel (Hill et al., 2006) – has caused a constant expansion of the area destined for agricultural production. The need for understanding these patterns of land use change has yielded many models of agricultural extent, both for the past (Goldewijk et al., 2011) and the future (IMAGE Team, 2001). These models are used to anticipate the consequences of this expansion for biodiversity and to devise conservation strategies that could avoid conservation conflicts (Sala et al., 2000; Scharlemann et al. 2004; Dobrovolski et al., 2011a; b).

Mammals have been routinely used as a target group for conservation applications, such as the definition of spatial conservation priorities, and are considered a flagship taxonomic group (e.g. Ceballos et al., 2005; Cardillo et al., 2006; Schipper et al., 2008; Rondinini et al., 2011). Among mammals, however, the carnivores are of particular interest for conservation applications (Loyola et al, 2008; 2009; Valenzuela-Galván et al, 2007). This is because they occupy a high trophic position, constraining them to live at low population densities and are particularly prone to extinction in response to agriculture and other threats (Woodroffe & Ginsberg, 1998). They are "the flagship among flagships", and as such, there is much biological information available about this group (Bininda-Emonds et al., 1999; Purvis et al., 2000; Diniz-Filho & Tôrres, 2002; Valenzuela-Galván et al., 2007; Cardillo et al., 2004; Loyola et al., 2008; 2009; Diniz-Filho et al., 2009;) and low uncertainty about their geographical distribution, when compared to other mammals. Further, as predators, carnivores play a key role in ecosystem dynamics as they operate top-down regulation (Terborgh et al., 2001; Williams et al., 2004).

Here, we tested the following hypotheses: (i) there is a conflict between the forecasted agricultural impacts for the 21st century and the best areas for investment in carnivore conservation; (ii) these conflicts can be alleviated when systematic conservation planning accounts for land use change forecast, (iii) the conservation solution obtained by unconstrained systematic conservation planning overlaps with reactive global priorities; while the conservation solution obtained when future land use information is accounted for matches proactive global priorities, (iv) there is an overlap between the spatial distribution of the current global protected areas and the carnivore conservation solutions we found. Additionally, we evaluated if the solutions obtained by both prioritization approaches (constrained and unconstrained) differ with respect to their performance in protecting carnivores populations.

Methods

Data

We overlaid the geographic ranges of 245 carnivores (Mammalia: Carnivora) obtained from the Global Mammal Assessment (IUCN, 2011) onto a grid of 2° × 2° spatial resolution. We considered a species to be present in a cell if any extent of its mapped distribution occurred in the focal grid cell. We generated a map of species richness (number of species present) by overlapping these presence/absence maps. We obtained the conservation status of all species from the IUCN red list (IUCN, 2011) and converted them into numerical values of increasing extinction risk following Purvis et al. (2000): 0 (least concern), 1 (near threatened), 2 vulnerable, 3 (endangered), 4 (critically endangered), and 5 (extinct in the wild/extinct). We attributed the value of zero (corresponding to a least concern IUCN status) to data deficient species to avoid overestimation of extinction risk. We used the above information to get the minimum range size and the maximum value of extinction risk across the species constituting the assemblage in each grid cell. The reference coordinate system of all spatial data was WGS-84.

We mapped agricultural land use forecasts for the 21st century using the land cover map produced by the Integrated Model to Assess the Global Environment (IMAGE, version 2.2) (IMAGE Team, 2001). The resulting map summarized at a resolution of 2° the number of years that each grid cell is cultivated during the 21st century (agricultural impact, hereafter) according to 6 SRES scenarios (IPCC, 2000) used by IMAGE.

For comparison with other global prioritization strategies, we obtained maps for five prioritization schemes (Brooks et al., 2006): Biodiversity Hotspots (Mittermeier et al., 2004) and Crisis Ecoregions (Hoekstra et al., 2005) – reactive approaches; and Frontier Forests (Bryant et al.; 1997), Last of the Wild (Sanderson et al., 2002) and High Biodiversity Wilderness Areas (Mittermeier et al., 2003) – proactive approaches.

To investigate the overlap between the best areas for carnivore conservation and the current global conservation efforts, we obtained the spatial distribution of the protected areas – categories I-IV of IUCN (Dudley, 2008) – from the World Database on Protected Areas (WDPA, 2009).

Spatial prioritization analyses

We used the Zonation framework and software (version 2.0; Moilanen & Kujala, 2008) to derive global priorities for carnivore conservation. Zonation provides maximum utility conservation solutions in accordance with the core principles of systematic conservation planning known as C.A.R.E. (comprehensiveness, adequacy, representativeness, and efficiency; Possingham et al., 2000). The main output of Zonation is a ranking of conservation priority through space (Moilanen et al., 2009). It has been used to solve different conservation problems in different environmental contexts, for various focal taxonomic groups and at several spatial extents, and has the advantage of allowing the integration of various costs (e.g. monetary cost) in the prioritization process (Kremen et al., 2008; Moilanen & Kujala, 2008 ; Moilanen et al., 2008; Eklund et al., 2011).

Here, we obtained two different conservation solutions using the Zonation's original core-area removal rule (see Moilanen & Kujala, 2008), which considers sites gathering higher proportion of species geographical distribution as more valuable, thus favoring the rarest species in the final solution. The first solution was obtained without imposing any land cost constraint, and solely promoted the maximum possible protection of carnivore biodiversity (biosolution, hereafter). The second solution was obtained by constraining the prioritization process by agricultural land use forecasts for the 21st century, considering the agricultural impact along the 21st century as a cost layer (agrosolution, hereafter). Following the Strategic Plan 2011-2020 of the Convention on Biological Diversity (CBD, 2011) we used a cutoff of 17% to define the spatial extent of our conservation plans.

Agricultural Conservation Conflict Analysis

We evaluated the potential ongoing conflicts between agricultural demand and biodiversity conservation using spatial correlation analyses between the projected agriculture impact and global carnivores' conservation value. We performed analyses for three measures of importance for carnivores' conservation: (i) species richness; (ii) the ranking of grid cells according to the biosolution; and (iii) according to the agrosolution.

Comparing solutions

We evaluated the overall cost of each conservation solution in terms of proneness to agricultural conversion by summing the values of agricultural impact (see Methods - Data) across the set of 17% grid cells included in each conservation solution.

To characterize the performance of conservation solutions (biosolution vs. agrosolution) in terms of carnivores conservation, we used the following statistics: (i) number of species' presences protected (a proxy for the number of populations protected – sensu Ceballos et al., 2005); (ii) spatial correlation between the rankings of cells provided by the focal solution and the minimum range size among the species present in each grid cell; and (iii) the maximum extinction risk among the species present in each grid cell. Additionally, for each conservation solution, we investigated (using species as statistical units) the relationship between the proportion of species' range under protection and (i) the overall size of their geographical range and (ii) their extinction risk.

We tested for the significance of spatial congruences between the biosolution and the agrosolution and existing global biodiversity conservation priorities schemes (e.g. Biodiversity Hotspots and Last of the Wild) using randomization tests. We first quantified the observed spatial overlaps by counting the number of grid cells (containing at least one carnivore occurrence) that were both included in our conservation solutions and in the focal global prioritization schemes (i.e. observed value). We estimated the significance of these spatial overlap by randomizing over the global grid (1000 times) the position of the cells included in our conservation solutions and calculating the proportion of spatial overlap between them and the global prioritization schemes as above. The proportion of randomized values equal or superior to the observed value was considered as the P-value of the randomization test. The null hypothesis that the observed overlap was lower than expected by chance was tested with at the level α of 5%.

Finally, we investigated the spatial congruence between the current global network of protected areas and the two conservation solutions we obtained. Using the polygons of protected areas (WDPA, 2009), we calculated the correlation between the proportion of each grid cell currently under protection and the ranking of the grid cell according to the two conservation solutions.

Because geographical data are often spatially autocorrelated, we used Clifford et al.'s (1989) method to find the correct the degrees of freedom for the statistical tests of all correlation analyses. These analyses were performed using the software SAM (Spatial Analysis in Macroecology, v. 4.0; Rangel et al., 2010; freely available at www.ecoevol.ufg.br/sam).

Results

The total number of carnivore occurrences was 46,892. The highest carnivore species richness – up to 37 species per cell – concentrated in southeastern Asia, southern side of the Plateau of Tibet, the Indochina Peninsula and Malaysia; tropical Africa, especially in the Savannas; and Colombian Andes (Fig. 1A). These areas also concentrated species with the smallest ranges, as shown by the map of minimum range and overlap with well known biodiversity centers of endemism such as Central America, Chile, California, Madagascar, Central Brazil, Iberian Peninsula and Japan (Fig. 1B). These areas also harbored the most threatened species (Fig. 1C).

The IMAGE projections for agricultural expansion during the 21st century forecasted more intense agricultural land cover (through time and scenarios) in areas currently under intensive use such as the Uruguayan savanna ecoregion in South America, the Corn Belt in United States, the Southern and Eastern Africa, Europe and Southeastern Asia. Moreover, agricultural extent can spread into most of the Amazonian region, the western part of Africa and North America, as well as increase the extent in Europe and Asia (Fig. 2).

According to the unconstrained conservation solution (biosolution) as given by Zonation, the 848 best grid cells (17%) for carnivore protection were distributed in Africa (278), Asia (223), South America (166), North America (140), and Europe (41) (Fig. 3A). The ranking of the grid cells according to this solution is highly negatively correlated with minimum range size ($r = -0.806$; $P < 0.001$; Table 1) and moderately positively correlated with maximum threat ($r = 0.474$; $P < 0.001$; Table 1). This solution comprised 13,700 (29.2%) carnivore presences. The average proportion of species range protected was 55.5% (±31.7 sd), ranging from 100% for all species with range size smaller than 30 grid cells to 3% for Alopex lagopus, the arctic fox (range = 1035 cells, threat category = least concern), which had 26 populations under protection. Twelve species were protected in less than

10% of their range, the minimum number of presences protected among this group of species is 24 and the species' smallest range was 332 grid cells.

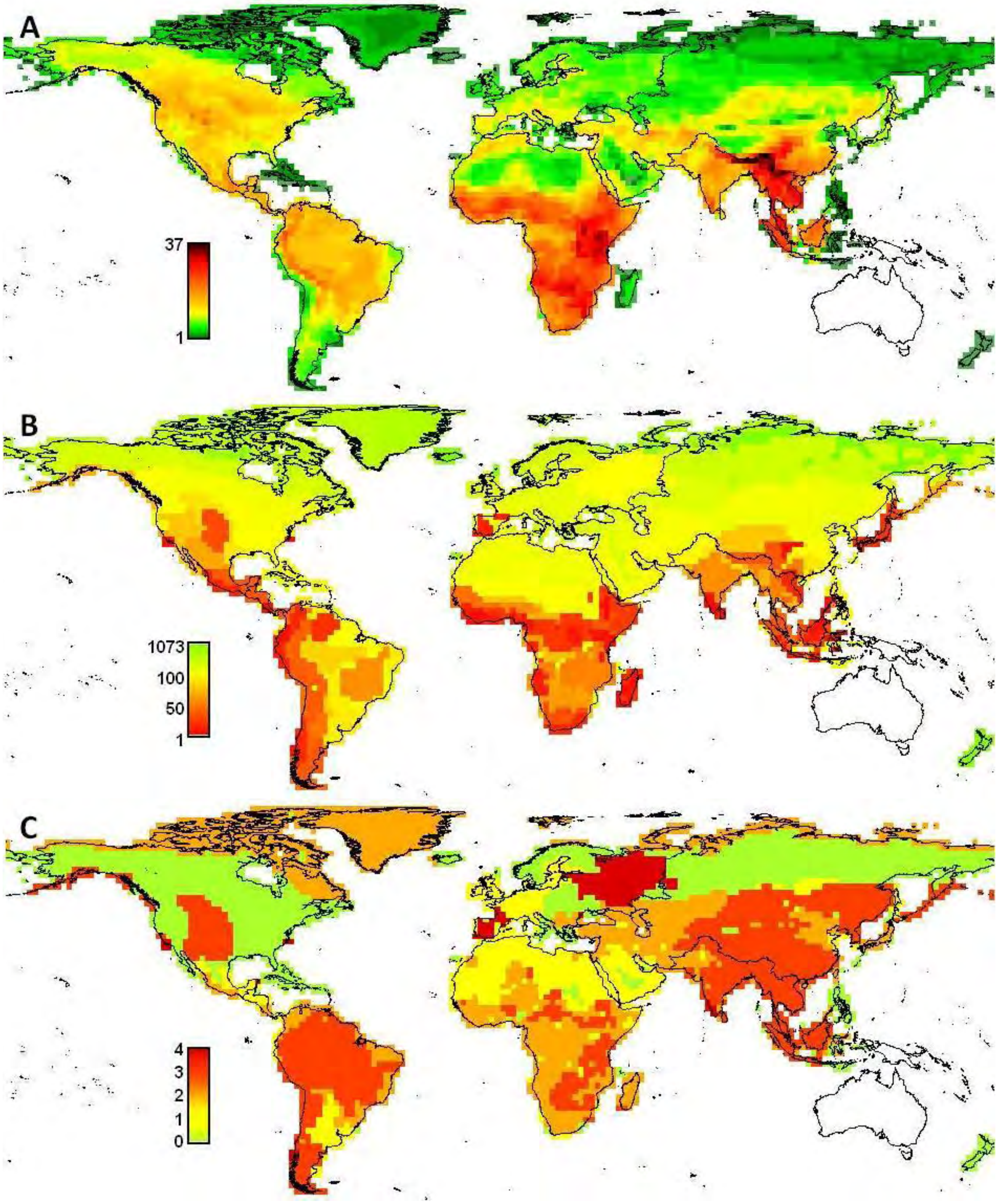

Figure 1. Geographical patterns of global carnivore species richness (A), minimum geographic range observed in the assemblage (B) and the maximum threat level of the species (C) present in each grid cell resolved at a 2° × 2° grain size.

Accounting for agricultural distribution (agrosolution), only 255 (30%) of the cells matched those from the biosolution. According to the agrosolution, the best 848 cells for protection of carnivores were distributed in Africa (239), Asia (259), North America (191), South America (114), and Europe (45) (Fig. 3B). A large proportion of these cells were located in areas of very low value for agriculture, such as tropical forests (e.g. South America, Africa and Malaysia), deserts (e.g. Sahara, Kalahari and Gobi deserts, Arabic Peninsula), or situated at high latitudes (e.g. Greenland, Northern North America, Europe and Southern South America).

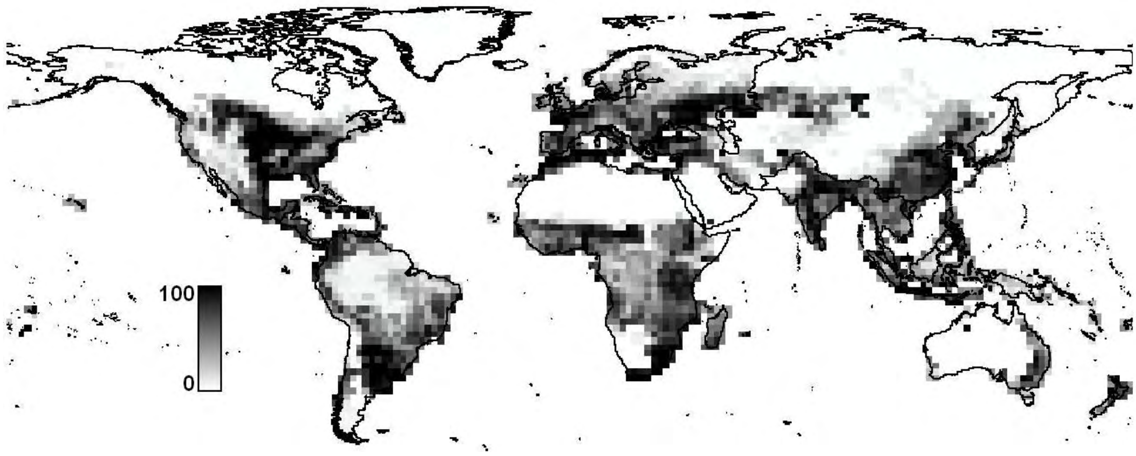

Figure 2. Geographical pattern of agriculture distribution simulated by the Integrated Model to Assess the Global Environment version 2.2 derived from the sum of the 60 maps of the global extent of agriculture for six future scenarios of 10 dates 2010 to 2100, resolved at a 2° × 2° grain size. Values represent the number of years that each grid cell will be cultivated according to an average among all six scenarios.

In contrast to biosolution, the ranking of grid cells in the agrosolution was correlated neither with the distribution of minimum range size of species assemblage ($r = -0.059$; $P = 0.385$; Table 1), nor with the distribution of maximum extinction risk ($r = 0.093$; $P = 0.114$). The number of populations protected according to this solution was 9222 (19.7%). The average proportion of species' range protected was of 23.8% (±16.8), ranging from 100% for species with range size equal to 1 cell to 3% for Herpestes urva, the crab-eating mongoose (range = 138 cells, threat category = least concern), which had 4 populations under protection. 32 species were protected in less than 10% of their range; the minimum number of populations protected in this group is one for Genetta tigrina (threat category = least concern), the species with the smallest range size among them (16 grid cells).

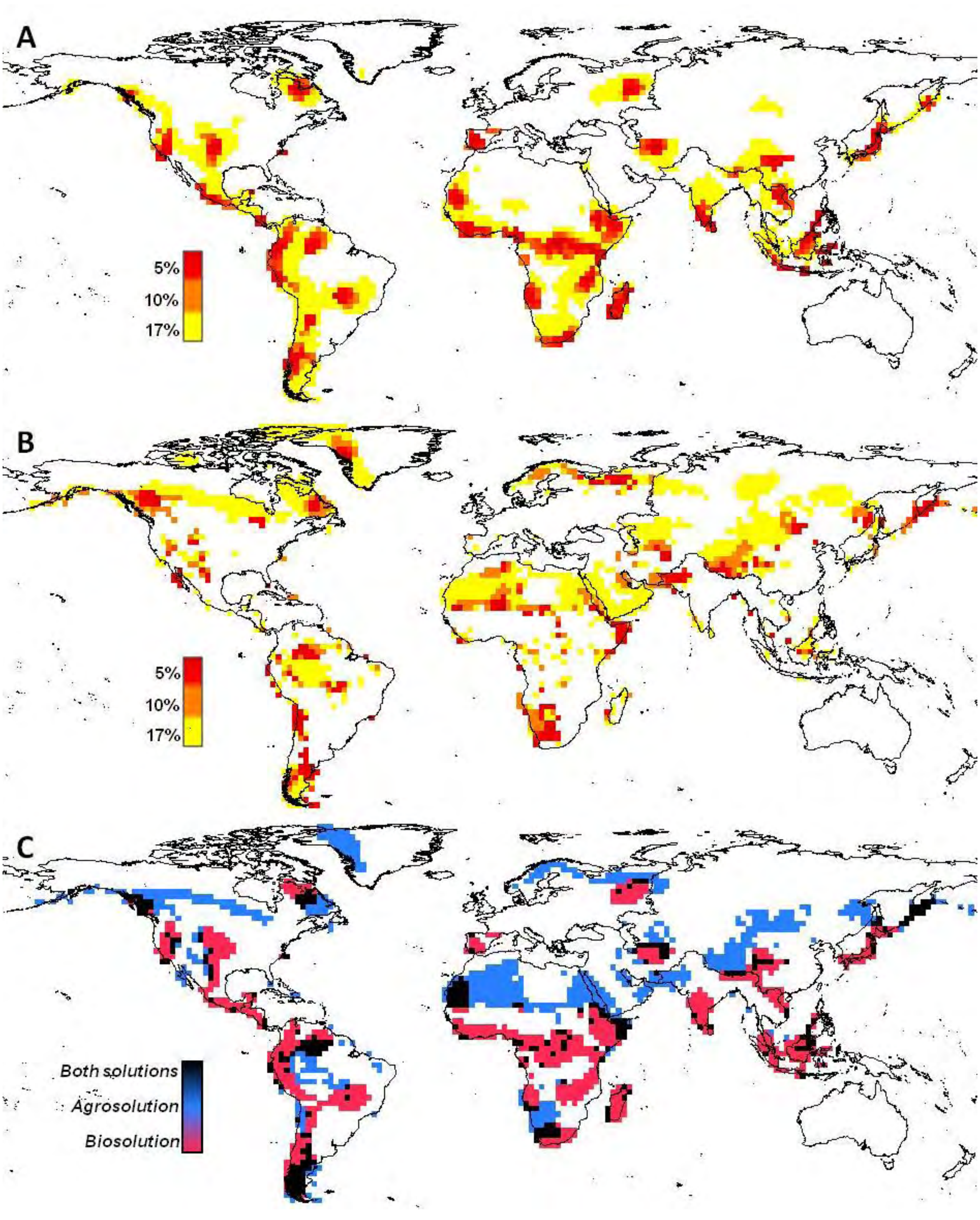

Figure 3. Priority map for conservation of world carnivores. Map A represents an ideal unconstrained solution based on biological value (distribution of species) by the original core-area Zonation. Map B is a solution constrained by the agriculture impact in the 21st century according to IMAGE 2.2 (Figure 1). The top 5% cells are represented in red, 10% in orange and 17% in yellow. C represents the combined solution where in red are the best cells selected according agrosolution, in blue the solution according to biosolution and in black, cells selected by both solutions.

We found a positive correlation between agriculture expansion and carnivores' species richness (r = 0.427; P < 0.001; Table 1). This positive correlation also holds for the ranking of grid cells according to the biosolution (r = 0.339; P < 0.001; Table 1). The best 17% of grid cells for conservation of carnivores according to biosolution totaling an agricultural cost of 35908.33 grid cells × year, representing 27.8% of the world area cultivated per year in the 21st century. The agrosolution was negatively correlated with agricultural expansion (r = -0.593; P < 0.001; Table 1) and the total agricultural value of the 17% network was very low compared to the biosolution (2696,7 grid cells x year; 2.1% of the total).

Table 1. Correlation between i) the richness of carnivore (Figure 2); ii) the rank of the cells according to Zonation 2.0 analysis that represents an ideal unconstrained choice (Solution 1; Figure 3A); iii) the rank of the cells obtained by a analysis constrained by the agriculture impact in the 21st century according to IMAGE 2.2 (Solution 2 –Figure 3B) and species richness, the size of minimum geographical range of the species and the maximum extinction risk value (threat), agriculture expansion and the proportion of cells that are under protection.

Ranking	Statistics	Richness	Range (min)	Threat (max)	Agriculture	Prot. Areas
Solution 1	*r*	**0.693**	**-0.545**	**0.474**	**0.333**	-0.101
	$F(df)_{Clifford}$	**53.13 (57.54)**	**24.21 (57.28)**	**29.91 (103.05)**	**13.24 (105.9)**	1.71(165.08)
	$P_{Clifford}$	**<.001**	**<.001**	**<0.001**	**<0.001**	0.192
Solution 2	*r*	0.137	0.062	0.093	**-0.561**	0.088
	$F(df)_{Clifford}$	2.45 (127.36)	0.41 (106.19)	2.51 (290.64)	**124.55 (271.74)**	2.14 (275.28)
	$P_{Clifford}$	0.120	0.525	0.114	**<0.001**	0.144
Richness	*r*	—	—	—	**0.427**	-0.056
	$F(df)_{Clifford}$	—	—	—	**18.5 (83.2)**	0.43 (135.92)
	$P_{Clifford}$	—	—	—	**<0.001**	0.513

The degrees of freedom (df), F value (F) and P value (P) were corrected using the method proposed by Clifford *et al.* (1989). The Pearson's correlation coefficient is represented as r.

The biosolution overlapped substantially with the Biodiversity Hotspots (54.4%, P < 0.001; Table 2) and the Crisis Ecoregions (48.7%, P < 0.001; Table 2), both reactive conservation schemes. The overlap with the high biodiversity wilderness areas (HBWA) was lower albeit significant (16%; P < 0.001; Table 2). In contrast, the agrosolution overlapped mostly with the proactive conservation priority schemes: Last of the Wild (56.4%; P < 0.001; Table 2); Frontier Forests (25.2%; P < 0.001; Table 2); and HBWA (10.3%; P < 0.001; Table 2).

Finally, the proportion of cell area currently protected did not correlate with the ranking according to the two conservation solutions (Pearson's correlations; biosolution: r = -0.101; P = 0.192; agrosolution: r = 0.088; P = 0.144), nor with carnivores species richness (r = -0.056; P = 0.513).

Table 2. Overlap between the 17% of the best grid cells for global carnivore conservation according to species distribution (biosolution) and agriculture impact in the 21st century according to IMAGE 2.2 (agrosolution) and the global conservation priorities (* : P<0.05 – See Methods).

Scheme	Total		Biosolution			Agrosolution		
	n cell	%	n cells	(%)		n cells	%	
bh	1217	24.4	461	54.4	*	148	17.5	
ce	1748	35.1	413	48.7	*	164	19.3	
ff	1023	20.5	189	22.3		214	25.2	*
hbwa	393	7.9	136	16.0	*	87	10.3	*
lw	1972	39.6	265	31.3		478	56.4	*
world	4986	100	848	17.0		848	17.0	

*** P value < 0.05**

Discussion

Conservation Conflicts

According to our results, there is a clear conservation conflict between agricultural expansion in the 21st century and carnivore conservation. This was found for the two metrics of conservation value we used here, i.e., species richness and importance of grid cells as defined by the systematic conservation planning approach (which promotes, among other goals, complementarity in species representation). Our specific method, i.e. spatial conservation prioritization output based on core area Zonation (Moilanen, 2007), is rarely used for global prioritization (but see Eklund et al., 2011). This approach was very successful in retaining the biodiversity and a high number of populations, especially for the most rare and threatened species, as shown by the correlation between the rank of the grid cells according to the biosolution and rarity or extinction risk. The use of a Zonation output differentiates our study from previous conservation conflict ones, which represented biodiversity by species richness. The use of systematic conservation planning approach is grounded in complementarity, which is more successful in representing biodiversity (Williams et al., 1996; Araújo & Rahbek, 2007).

Our findings of conservation conflict expands, for carnivores and future agricultural expansion, at the global scale, the results of previous studies that investigated the ongoing spatial congruence between human enterprise (generally measured by human population density) and areas of high value for conservation identified using species richness (reviewed in Luck, 2007b and Araújo & Rahbek, 2007) (for other studies on future conflicts, see McKee et al., 2004; Scharlemann et al., 2004; Araújo et al., 2008; Dobrovolski et al., 2011a; b).

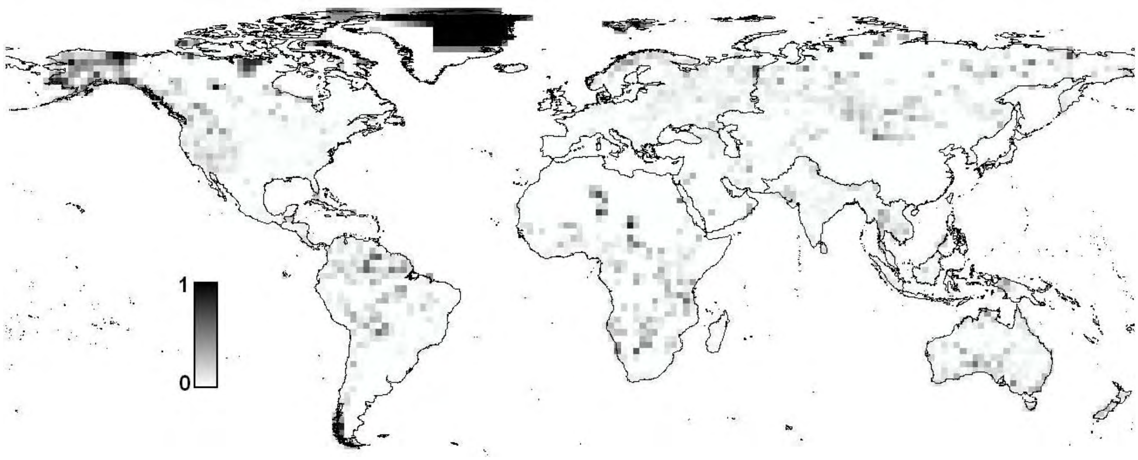

Figure 4: Map of the proportion of each cell protected by the current global network of protected areas (IUCN categories I-IV).

Alleviating Conflicts

The inclusion of agricultural expansion as a cost in the prioritization process, following the tendency of incorporating human-driven threats through socioeconomic data, allowed circumventing the conservation conflict with carnivore conservation, a particularly compelling group in ecosystemic and societal terms, as demonstrated by the negative correlation between agricultural impact in the 21st century the ranks of the grid cells according to the agrosolution. Such "conflict avoidance" (see also Luck et al. 2004; Carwardine et al. 2008) exemplifies the benefit of incorporating socioeconomic data in systematic conservation planning – including future scenarios for threats to biodiversity (e.g. Sala et al., 2001; Pereira et al., 2011). However, the reduced number of carnivore populations protected under the agrosolution suggests that the benefits of this conflict alleviation charge a biological price. Such solutions should therefore be evaluated critically.

After including costs in the prioritization process, it remains necessary to check back the biodiversity value of the conservation solution and not only to evaluate the solution on the basis of the socioeconomic benefits achieved – as was most often done (e.g. Carwardine et al., 2008).

Overlap with other Global Conservation Priorities Schemes

By testing for spatial overlap between our biosolution and agrosolution, and the global conservation priorities used by non-governmental organizations (Brooks et al., 2006), we highlighted the similarities between constrained and unconstrained carnivores conservation strategies and proactive and reactive global conservation priorities, respectively, the two major approaches for conservation strategies establishment. In agreement with our initial hypothesis, the biosolution resembled reactive schemes – prioritization of highly vulnerable areas – (Table 2) emphasizing that many highly irreplaceable areas are also among the most threatened ones (e.g. Myers et al., 2000). In contrast, the agrosolution reproduced the spatial pattern of global priorities focusing on low vulnerability, i.e. proactive schemes (Table 2). Indeed, both proactive schemes and systematic conservation planning approaches seek to avoid conservation conflicts by taking into account socioeconomic information. Conversely, unconstrained prioritization approaches that seek only to achieve biodiversity representation are likely to generate conservation conflicts, due to the congruence between biodiversity and human impact (see also Luck et al., 2007a).

Despite criticisms (e.g. Mace et al., 2000) these global prioritization schemes continue to be used as a solution to the problem of maximizing return on investment in real world conservation applications (Brooks et al., 2006; Halpern et al., 2006). Here we highlighted varying degrees of spatial overlap between the two conservation solutions we found and global conservation priority schemes. This suggests that newly developed conservation strategies can be partially benefited from current conservation initiatives promoted by non-governmental organizations. These results also illustrate that different conservation strategies or methods for prioritization can lead to similar spatial solutions (e.g. biosolution and biodiversity hotspots). Consequently, the use of the most recent automatic algorithms for the selection of priority areas should not prevent conservation planners and practitioners to engage in dynamic processes involving stakeholders to define biodiversity targets and costs. These process should seek for the best trade-offs between biodiversity conservation (e.g. taking into account common, rare or threatened species, populations or the functional and phylogenetic facets of diversity) and feasibility (e.g. conflicts avoidance by taking into account socio-economical information such as agricultural needs, cost of the land, human population density, etc.).

Overlap with the current global Protected Areas Network

It has been stated that protected areas, the cornerstone tool for biodiversity conservation, are generally placed opportunistically in remote, devalued areas (Ando et al., 1998; Margules & Pressey, 2000). This fits better with the description of a biodiversity conservation constrained by socio-economical costs. However, we found spatial congruence of the current global protected area network neither with the agrosolution nor with the biosolution. These results agree with previous studies regarding the inefficiency of current protected areas network in protecting biodiversity (e.g. Rodrigues et al., 2004; Carwardine et al., 2008; Visconti et al., 2011) and highlighted the general mismatch between conservation investment and biodiversity value (Halpern et al., 2006). These findings argue for the use of systematic prioritization in the expansion or the redesign (Fuller et al., 2010) of a "truly" planned global protected areas network.

Final considerations – an unified strategy for carnivore conservation?

Here, we typified two conservation options: to focus on the best biological solution, facing the forecasted agricultural expansion trend, which will be more difficult and more expensive. Another alternative would be, for a given budget, to rely on conservation solutions taking into account expanding threats, such as agriculture, de facto reducing costs, but at the price of lower performances. Particularly in the case highlighted here, accounting for agricultural cost in prioritization planning resulted in a conservation network 1.5 time less efficient in protecting carnivore populations when compared to the biosolution: such differences between contrasting approaches should not be ignored.

Hence, the best strategy could be the development of integrative approaches taking advantage of both solutions, in which different conservation actions could be used where they are likely to be the more successful. In doing so, one could, overcome fruitless dichotomies like the one of hotspots versus coldspots (Kareiva & Marvier, 2003) and contribute to a more comprehensive and effective conservation approach (Rondinini et al., 2011; Loyola et al., 2011). For example, in priority areas where no conflict with agriculture is predicted (agrosolution), there is room for megareserves (Peres, 2005). In the areas highlighted by the biosolution that will be under agriculture pressure in the future should be the focus of more refined actions, including detailed analysis of anthropic landscapes.

For example, the identification of patches of natural vegetation and their spatial configuration or the analysis of viability and genetic structure of remaining populations can help to devise conservation initiatives adequate to these circumstances, such as conservation agriculture practices (Baudron et al., 2009) and the use of private lands for conservation (Main et al., 1999). One could argue that these combined solutions would require more that 17% of the world to be effective. However, this target is related to protected areas coverage only (CBD, 2011). Nowadays, the conservationists do not manage only protected areas. Actions in private and indigenous people land and other areas under environmental law constraints proved to be extremely useful for biodiversity conservation (Joppa et al., 2008). Moreover, such combined solutions would embrace the full diversity of conservation practitioners (Langholz & Krug, 2004) and would help re-orienting them in terms of the location where and the way they are doing their job.

Some limitations may imprint this analysis, particularly the translation to effective action on the ground, which needs fine scale data and collaboration with local practitioners (Fonseca et al., 2000; Rondinini et al., 2011). Also the generality to other taxa of the parameters and prioritization patterns estimated here should be evaluated. However previous results on convergent patterns of diversity and endemism among vertebrates suggest that the areas highlighted here as important for carnivores can also be important for other taxonomic groups (Lamoreux et al., 2006; Rodrigues & Brooks, 2007; Loyola et al., 2007; Qian & Rickleffs, 2008; Trindade-Filho et al., 2011; but see Grenyer et al., 2006).

Finally, the use of information about future increasing threats to biodiversity such as agricultural expansion may help to overcome the inability of conservation efforts to look forward in time at the global scale (Visconti et al., 2011). Expansion of agriculture and other external threats can be harmful to biodiversity particularly when they interact synergistically with species' intrinsic extinction risk, driving them to extinction (Cardillo et al., 2004; 2006). In this case, even the best prioritization solutions may not allow an effective conservation for carnivores or other sensitive taxonomic groups. Consequently, conservation policies should focus also on the causes of the increase of threats to biodiversity (Visconti et al., 2011) and should aim to help preventing agricultural expansion (Foley et al., 2011) – the main environmental threat of our time.

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Capítulo 4: Globalization of conservation efforts helps saving species and feeding the world[3]

Food production must be increased if the needs of an enlarged human population are to be met[1]. However, increasing food production will likely challenge biodiversity conservation[2]. We explore solutions that integrate both conservation and agricultural targets, and compare them in three scenarios: globalization, regionalization and business as usual whereby conservation policies are determined nationally. Using mammals, we show that globalization of conservation policy would increase up to 19% the number of mammals protected with respect to national policies, without imposing losses in the world food production until 2100. Likewise, poorer or agricultural-dependent countries are not particularly affected in their food production by changes delivered by such conservation integration. These results support that a conservation plan which takes political boundaries into consideration harms both biodiversity and food production. Globalization of environmental policy would achieve greater conservation returns with no deleterious effects on human development.

Earth is home for more than seven billion people[3]. Humans capture 24% of Earth's primary net productivity and use 38% of its ice-free surface[4]. Yet, human population is expected to reach between 8.1 and 10.6 billion by 2050[1], and food provision for such a large population with increased *per capita* consumption is one of the greatest societal challenges by mid-century. Reducing food waste[5] and increasing agricultural yields[6] will certainly contribute to the solution, but the latter will have additional impacts on the world's biodiversity. Can biodiversity conservation and the human needs for increased food production be reconciled?

We propose that closer integration of conservation policies around the world can increase conservation returns, simultaneously allowing for a reduction of conservation

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[3] Esse capítulo é um manuscrito inédito de autoria de Dobrovolski, R., Loyola, R.D., Diniz-Filho, J.A.F. & Araújo, M.B.

conflicts with agricultural production. To test this proposition, we generated conservation scenarios for the world mammals and assessed their consequences for food production worldwide. Scenarios were built using optimization techniques that seek to maximize species conservation returns for a given cost. Two optimization problems were specified: (i) to identify a given set of areas that maximizes species occurrences; and (ii) to identify a given set of areas that achieves (i), while avoiding highly productive agricultural lands, whenever possible. Following the Convention on Biological Diversity[7], we developed scenarios that for setting aside 17% of the world's surface for conservation by 2020. Three political strategies were considered. The first is a "business as usual" scenario, whereby conservation priorities are defined at the scale of the individual countries. This strategy emulates the current approach for the establishment of national protected areas around the world. The second strategy involves setting conservation priorities at the scale of major economic blocks, assuming that current economic integration would gradually lead to some degree of political integration. An example is the Natura 2000 network implemented across the European Union[8], with priorities being defined at regional rather than at member-state level. Finally, a third strategy assumes that conservation priorities are defined globally. This strategy is analogous to global conservation schemes promoted by international non-governmental organizations[9], such as the World Wide Fund for Nature[10] and Conservation International[11]. We assessed the consequences of each one of the three conservation strategies by examining the foregone opportunities for food production associated with them using projections of agricultural yields by 2100.

To test if the participation in such a strategy will harm preferentially those countries which are poor and more dependent of agriculture, we correlated the difference in agricultural production per country based on the two strategies, with the following socioeconomics indicators: human development index (HDI), *per capita* Gross Domestic Product (GDP) and % of GDP added by agricultural production. The spatial distribution of priority areas for mammal conservation varies across strategies (Fig. 1), with protected-area coverage decreasing with latitude from global to local scenarios. Although all conservation scenarios conserve 17% of the earth surface, nationally-driven strategies conserve biodiversity less effectively than regional and global approaches: 36 out of 5206 mammal species are missing from national protected-area networks, while 100% of the species would be protected with regional or global approaches. The proportion of mammal distributions conserved with the different strategies also increases from local to regional and to global: 0.33%, 0.39%, and 0.43% (Tab. 1).

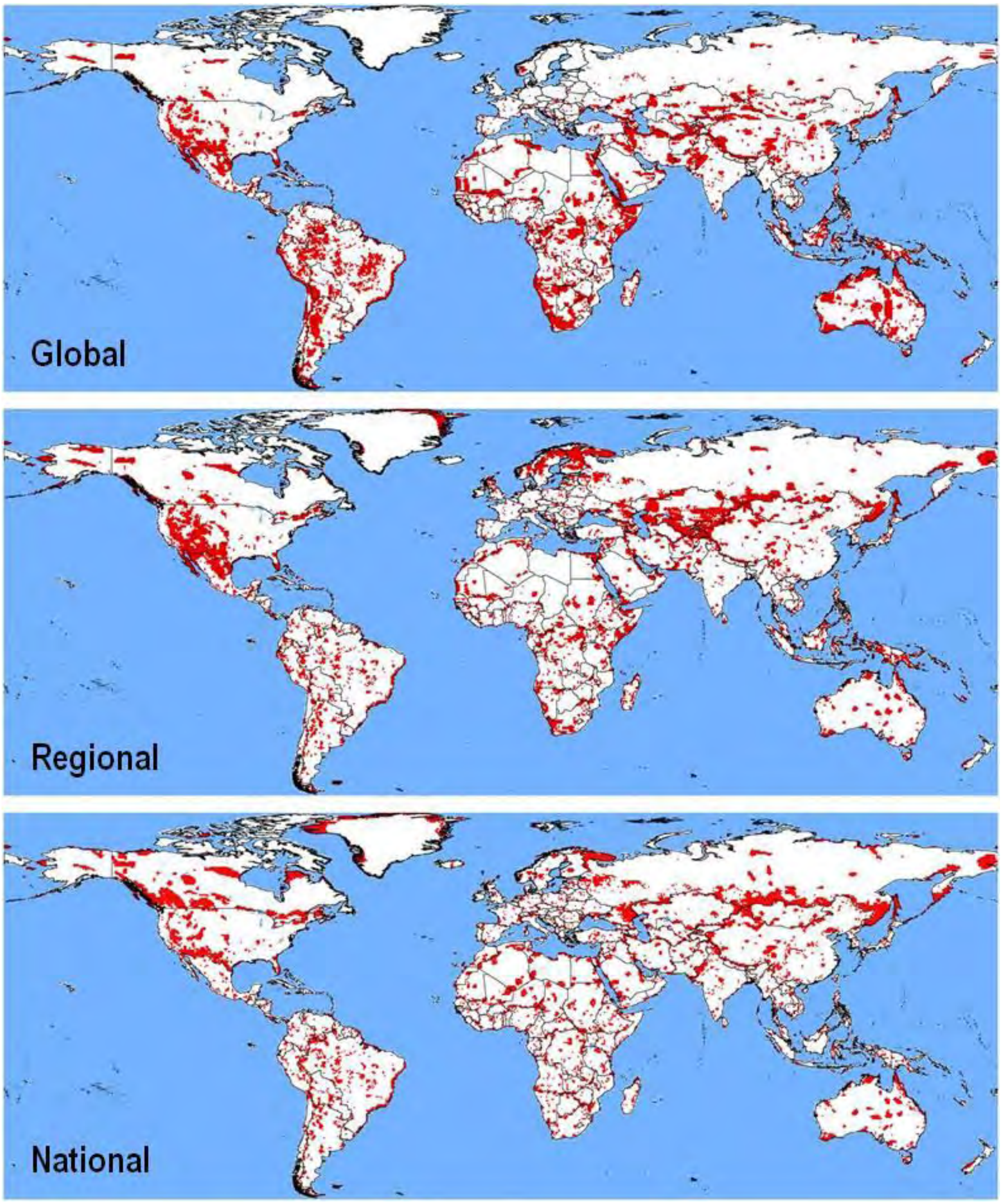

Figure 1: Best scenarios for mammal conservation with the 17% global protected area coverage, taking in account the need to minimize conflicts with agricultural production by the end of the 21st century. The upper map represents the globally integrated strategy, and the middle and bottom map represent conservation strategies that designed to maximize biodiversity at regional national levels, respectively.

Agricultural production would slightly decrease if global solutions for biodiversity were sought as opposed to national solutions (-0.26%). This is because several of the best areas for biodiversity are also located in highly productive lands for agriculture (Tab. 1).

Regional solutions would offer a middle-ground agricultural loss and also middle-ground biodiversity benefits (Tab. 1).

We found no relationship between agricultural production loss owing to the agreement in the global conservation strategy and HDI (R^2 = 0.02; P = 0.06), and *per capita* GDP (R^2 = 0.02; P = 0.06). For percentage of GDP added by agriculture, there is a very weak relation (R^2 = 0.03; P=0.03). Countries with more than 5% of agriculture loss due to the agreement in the global conservation strategy are Comoros Islands, Solomon Islands, Samoa, Armenia, São Tomé and Príncipe, Costa Rica, Papua New Guinea, Ecuador, Panama, Madagascar, Taiwan, Rwanda, Sri Lanka, Comoros, which include countries with low HDI and *per capita* GDP, as well as high dependence of agriculture. Among them Comoros Islands, Papua New Guinea and Rwanda, are countries of special concern because they had more than 30% of GDP arising from agriculture, and are considered low-developed countries given their HDI.

Table 1: Comparison between the three global mammal conservation strategies evaluated: global, constrained by economic blocks (regional) and national political boundaries limits; in terms of global agricultural loss, number of gap species, species presences and average of the proportion of range under protection.

Level	Agricultural Loss	Agricultural Loss (%)	Gap Species	Presences	Range Protected (%)
National	1662.43	3.983	36	655152	0.3323773
Regional	1769.22	4.239	0	690281	0.3903127
Global	1772.09	4.246	0	780732	0.4312256
World Total	41733.32		5206	3532089	

We show that more biodiversity benefits can be achieved if, in addition to thinking globally, society acts globally. The results presented here suggest that biodiversity and agricultural production can benefit by a paradigm shift in the way conservation planning have been done, in terms of international integration. We extend to the global scale the benefits of political integration found in previous studies done in an intra-national level[12,13] and in North America[14], Southern Africa[15] and the Mediterranean basin[16]. The global integration showed the highest benefits whereas the regional integration represents an improvement of conservation benefits in relation to the usual country-level conservation policy. This regional approach represents an integration of biodiversity conservation plans among countries that already participate in economic blocks, such as the European Union and North American Free Trade Agreement. Consequently, if these economic initiatives are directed to the protection of biodiversity, it can represent a first step towards a global integration that guarantees the maximum benefits.

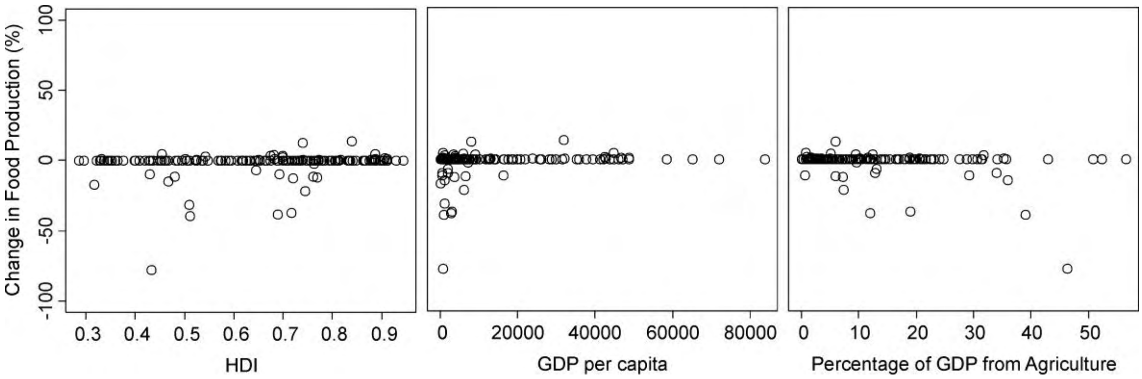

Figure 2: Change in national agricultural production when a global conservation strategy versus a national strategy is taken against socioeconomic indicators: Human Development Index (HDI), Gross Domestic Product (GDP) *per capita*, percentage of the GDP accrued by agricultural activities.

The fact that we found no correlation between change in agricultural production and the development level of countries, shown by HDI and GDP *per capita* (Fig. 2), suggests that the option to cooperate in a globally integrated conservation strategy will not harm the most poor and undeveloped countries in general. However, the particular cases in which poor countries will be affected should be considered by this international agreement. Consequently, resource transference and compensatory measures should be taken into account[17]. To correct current international investments that are done disregarding the needs of countries or the proportional value of biodiversity[18] can also help in this global task.

The global integration of humans from different countries, which can be roughly defined as globalization, started in 16th Century. However it was mainly driven by economic reasoning, being considered both as a possibility to overcome the restrictions of geographic distance and political boundaries on one hand[19]; but, on the other hand, being indicted of affect badly specially the developing countries if free market is adopted carelessly[20]. Our work demonstrates that globalization can be beneficial to biodiversity if applied to conservation strategies, helping to avoid conflict with food production, which should be very useful in the crowded and hungry world of the future. In this process some poor countries can be especially affected, indeed. Consequently the adoption of a globalized conservation strategy can be tightly linked to compensatory payments to the poorer countries. This monetary help can contribute both to the agreement of this countries in this global task and also to the overcome of social problems that affect them and impair conservation, such as inequality[21] and lack of governance[22].

In conclusion, conservation can be improved if food production is taken into account and political integration is adopted. A more crowed planet can still coexist with biodiversity, but a paradigm shift regarding how biodiversity businesses are undertaken is required.

Methods summary

We created maps of potential agricultural production in the 21st century by synthesizing land cover maps from IMAGE[23], a global model that predicts agricultural expansion in the 21st century and GAEZ[24], and the Global Agro-Ecological Zonation, which mapped constraints for agricultural production. We defined the best set of areas for conservation of 5216 mammal species using the Zonation[25] software in two steps: firstly, we defined the minimum set of areas necessary to protect at least one population of each mammal species. Secondly, using agricultural potential production as a cost layer and the basic core-area Zonation rule, which gives higher importance to rarer species, we increased this network to 17% of grid cells according to three approaches: the country level (i.e. choosing the best set of grid cells within each country); the regional level and the global level. We compared the three approaches by contrasting the following statistics obtained by the final global network of priority: number of species, number of presences (i.e. species populations), average proportion of species' range protected, amount of food production lost. We correlated the amount of food production lost for each country with the respective Human Development index, Gross Domestic Product (GDP) *per capita* and percentage of GDP added by agriculture[26].

Acknowledgements

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Capítulo 5: Agricultural Expansion Can Menace Brazilian Protected Areas During the 21st Century[4]

Abstract

The main current threat to biodiversity is habitat destruction, which is motivated mostly by agricultural expansion. This threat is especially important in Brazil, a megadiverse country devoted to agribusiness. Here, we addressed the following hypotheses: i) protected areas are less covered by agriculture than areas not protected to date; ii) this pattern will hold throughout this century; iii) these effects differ between categories of protected areas. We overlaid an agricultural expansion model for the 21st century (IMAGE) and the Brazilian protected areas to calculate the conflict between these two land uses. Agricultural extent represents 22% of Brazilian area in current time but should increase up to 40% by 2100. Although the absolute values are relatively smaller, the increase of agricultural extent will be much higher in protected areas (12 to 30%). Consequently, strategic actions are needed to reduce the damages of this agricultural expansion to biodiversity.

Keywords

Biodiversity Conservation, Brazilian Amazon, Conservation Conflict, Global Change, Land Use and Land Cover Change, Megadiverse Countries.

Introduction

Currently and in the foreseeable future, the main threat to biodiversity is the loss and degradation of natural habitats (Sala *et al.* 2000; Green *et al.* 2005). Such loss has been motivated by different human land uses, especially by agriculture (Foley *et al.* 2011). Studying the impacts of agricultural expansion is particularly relevant in the face of the global increase in human population and the consequent projected agricultural expansion,

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aimed at increasing food production (Green *et al.* 2005). Brazil is a megadiverse country and a key agricultural producer which indeed have promoted agricultural expansion as mean for development (Rodrigues *et al.* 2009); hence agricultural expansion must be considered a key component of strategic plans for both food production and for biodiversity conservation.

In a changing world it is important to make use of models that forecast the consequences of future possible scenarios, including those for land-use/land-cover change (see Sala *et al.* 2000). Such models may predict the extension of agricultural areas and other land uses in the future and help to envisage future conservation-development conflicts when these activities reach areas of high conservation value (Scharlemann *et al.* 2004; Dobrovolski *et al.* 2011). In Brazil this is likely to be the case, for example, in the Atlantic Forest and the Cerrado (Myers *et al.* 2000), along with some Amazon regions with high levels of endemism that were already impacted by agriculture (Da Silva *et al.* 2005).

The establishment of protected areas remains as the cornerstone of conservation actions (Bruner *et al.* 2001; Joppa *et al.* 2008, but see Curran *et al.* 2004). They may be designed to fulfill different conservation objectives of either strict conservation or sustainable use (Dudley 2008). The strict conservation or integral protection protected areas (IPPAs) is exclusively devoted to biodiversity protection, research and regulated visitation related to tourism or environmental education. Geographically, protected areas have been located on areas too remote or unproductive to be economically valuable (Margules & Pressey 2000) and this should be particularly true for IPPAs. The sustainable use protected areas (SUPAs) allow the use of natural resources, and their effectiveness against threats to biodiversity is a permanent source of debate (*e.g.*, Redford & Sanderson 2000; Schwartzman *et al.* 2000). The SUPAs are more permissive to human activities inside them, including subsistence farming. As these areas are related to some economic activities, SUPAs are supposed to be close to populated areas and roads or waterways that are routes of access to consumer markets. Consequently, SUPAs are supposed to be more susceptible to threats to biodiversity. However, a previous analysis has found that both kinds of protected areas are effective in terms of protecting biodiversity (evaluated by land cover change; Joppa *et al.* 2008).

As the two different types of protected areas are supposed to be located in areas with different susceptibilities to agricultural use, we tested four hypotheses related to the spatial congruence between protected areas and agricultural expansion: i) Brazilian protected areas are less covered by current agriculture presence than areas not protected; ii) this difference will hold in the future; iii) the increase in the proportion of Brazilian protected areas covered by agriculture will be lower than in the areas not protected; iv) the impact of agriculture is higher in protected areas of sustainable-use relative to areas of integral protection.

Methods

Data

We defined agricultural land according to the map generated by the Integrated Model to Access the Global Environment (IMAGE, version 2.2) (Image Team 2001). This is a geographically explicit model that considers cropping and livestock systems, based on demand for food and energy crops. It accounts for factors such as productivity, distance from agricultural land and water bodies to infer the presence of agriculture in each 0.5° x 0.5° latitude-longitude grid cell (Image Team 2001). Current and future agricultural extents were taken from the A1B scenario, which seems the scenario that better reflects current trends of the world society (*i.e.*, socially oriented to market and globally integrated). Also, the area affected by agriculture in the future according to the A1B scenario has an intermediate value amongst other scenarios, which made our analysis a conservative one (Figure 1).

We used these land cover maps to evaluate the present state and future trends of agricultural cover in Brazil. We represented the present state by the map for the year 2000. For the future, we combined the maps from 2010 to 2100. The grid cells covered by agriculture anytime during this period were considered as covered by agriculture. We did this combination for future because there will be a spatial variation in the agriculture cover during the time and some areas may be abandoned and used for restoration, however these areas do not have the same value for conservation than original ones (Barlow *et al.* 2007). For more details about the IMAGE model and our approach, see Dobrovolski *et al.* (2011).

We obtained the polygons of protected areas from the World Database of Protected Area (WDPA 2009). We selected the protected areas based in Brazil and that are classified as the IUCN categories I-IV (integral protection, IPPA) and V-VI (sustainable use, SUPA). We excluded protected areas not included in any of these categories like "Indigenous Areas". The final set of protected areas was composed of 448 IPPAs and 396 SUPAs, with the total amount of 488,320 and 2,835,078 km2 protected, respectively (Figure 2). We created 10 km buffers around each protected area polygon to represent the legal buffer zone usually used in Brazil, which is an area where human activity is restricted (Alexandre *et* *al.* 2010). We transformed the vector polygons of the protected areas and their buffer zones into a raster image with 0.5° × 0.5° degree resolution, the same resolution as the IMAGE map. To be classified as a protected area, any given cell must have more the 50% of its area covered by the protected area polygon. If an area was covered by an integral protection and a sustainable use protected area simultaneously, we defined this area as an integral protection one.

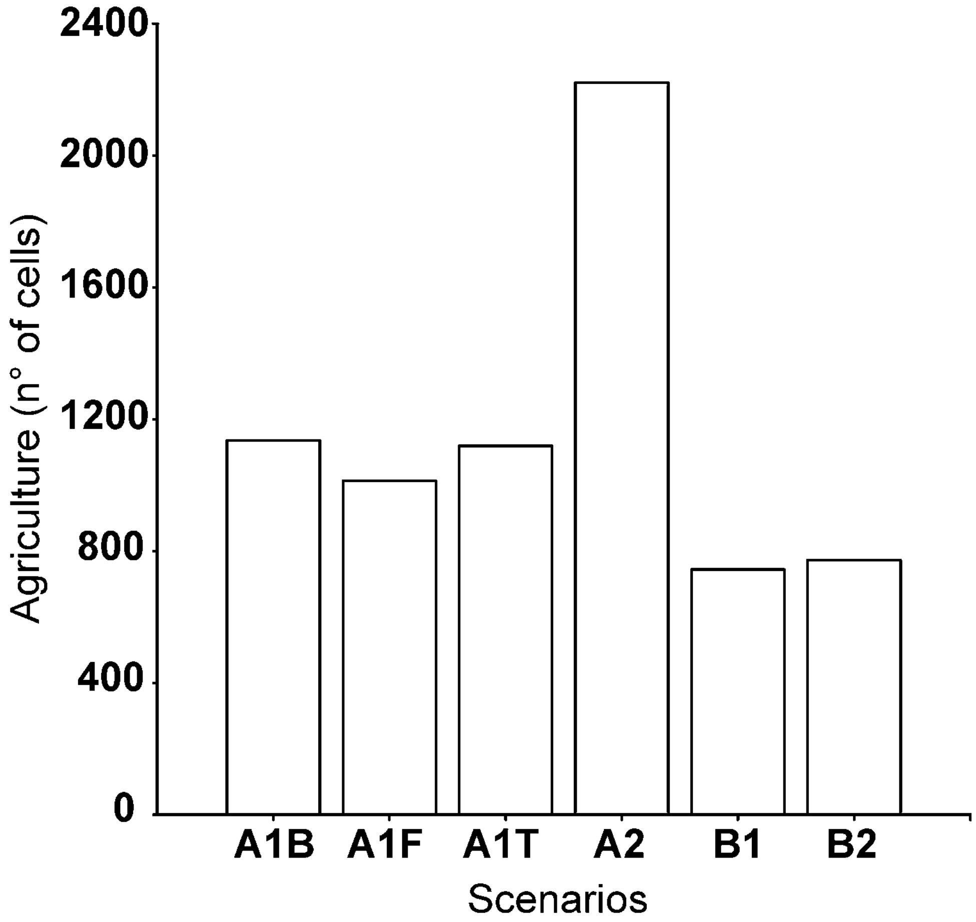

Figure 1. Area covered by agriculture in Brazil during the 21st century, represented by the number of cells, according to the six different scenarios of IMAGE (version 2.2).

Analysis

We overlaid the maps of agricultural extent in the present (2000) and future (2100) on the map of the protected areas. We calculated: i) the number of grid cells protected by IPPAs or SUPAs covered by agriculture in the present and in the future; ii) the increase of the impact of agriculture in both sets of protected areas as the ratio between the number of protected grid cells covered by agriculture in the future and in the present.

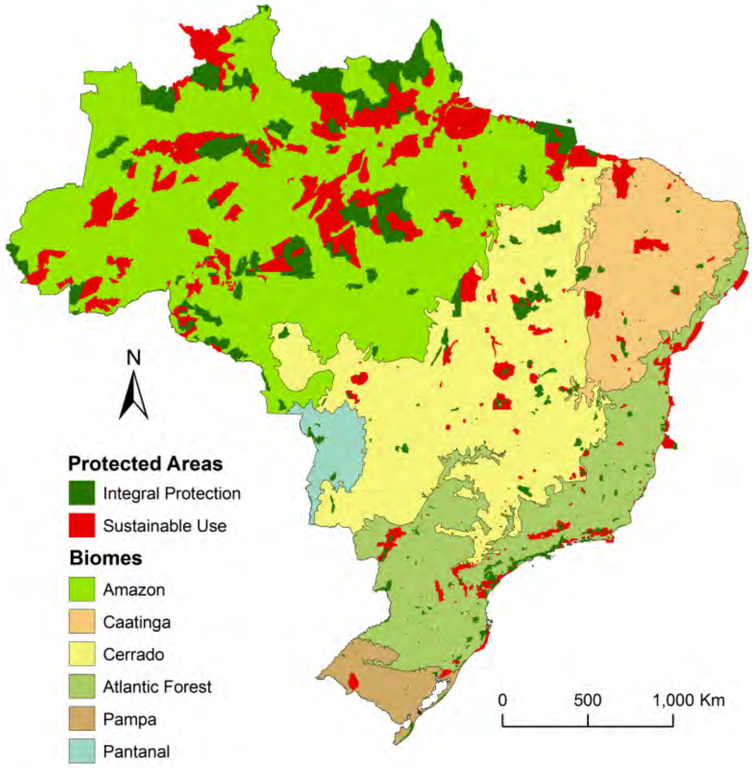

Figure 2. Map of the Brazilian protected areas, including the integral protection (IUCN I-IV) and sustainable use (IUCN V-VI) categories. The Brazilian biomes are also represented.

To test if these values were significantly greater than those that might be obtained by chance, we performed a Monte Carlo analysis. We shuffled the positions of the protected area cells (both kinds together) 1000 times and calculated the metrics explained in the paragraph above for each. Then, we evaluated the number of times that we obtained impact metrics higher than the observed ones (*i.e.*, this gives the P-value). The analyses were done in R (R Development Core Team 2009).

Results

According to the A1B scenario of the IMAGE model, in the present period (the year 2000), 21.9% of Brazil is covered by agriculture. This effect differs among regions and varies from 2.5% in the Amazon to 46% in the Pampa biome (Table 1). In respect to protected areas, 11.9% of the IPPAs are covered by agriculture. For SUPAs this percentage is 9.7%. The Brazilian protected areas are less covered by agriculture than would be expected by chance ($P < 0.001$ for both IP and SU). Also, the two kinds of protected areas do not differ in relation to agriculture impact ($P = 0.13$) (Figure 3a).

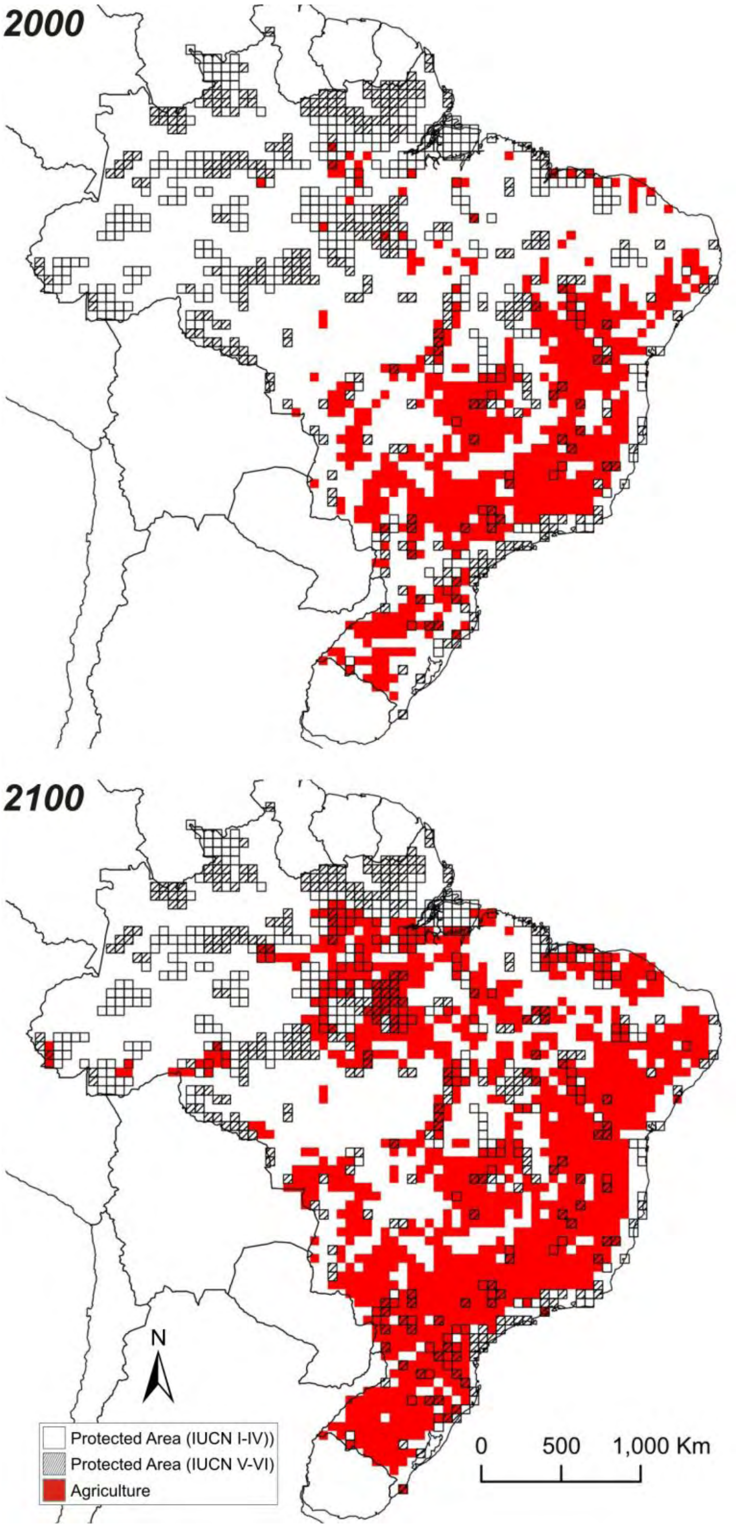

Figure 3. Map of the area covered by agriculture in Brazil, in 2000 and in 2100, according to IMAGE scenario A1B. The protected areas are shown in squares.

In the future, the area covered by agriculture in Brazil will increase up to 40% of the country's area, an expansion of 82% over present-day agriculture. In the Amazon and in the Pampa, the proportion of area covered by agriculture will reach 18.7% and 80.4%, respectively (Table 1). Protected areas will continue to be less covered than other areas ($P < 0.001$ for IPPAs and $P = 0.003$ for SUPAs), and the impact of agriculture in IPPAs (27.1%) and SUPAs (33.4%) will be similar ($P = 0.072$) (Figure 3b). However, the increase in agricultural impact in protected areas is substantial relative to non-protected areas, the IPPAs will be 4.3 times ($P = 0.004$) and SUPAs will be 3.8 times ($P < 0.001$) more impacted by agriculture in the future than in the present. Again, the two kinds of protected areas do not differ in terms of encroachment from agriculture expansion ($P \approx 1.000$).

Table 1. Protected and agricultural area information for each Brazilian biome as we considered in this study (See Figure 3 and methods section): i) total area; ii) percentage or Brazilian territory; iii) protected areas and buffer zones (PA); iv) and its proportion represented by sustainable use (SUPA); v) and integral protection (IPPA) categories; vi) proportion of each biome covered by agriculture according to IMAGE in 2000; vii) and during the 21st century.

Biome	Area	(%)	Protected (%)	SUPA (%)	IPPA (%)	Agric. 2000 (%)	Agric. 2100 (%)
Amazon	4229823.4	49.5	33.8	57.2	42.8	2.5	18.7
Caatinga	835844.1	9.8	12.4	67.8	32.2	38.5	68.1
Cerrado	2025023.0	23.7	15.4	44.3	55.7	38.2	50.4
Pampa	162907.7	1.9	8.1	40.3	59.7	46.0	80.4
Pantanal	149805.6	1.8	5.9	0.0	100.0	29.4	47.2
Atlantic For.	1133358.5	13.3	22.1	38.8	61.2	44.5	68.7
Total (Brazil)	8536762.3	100.0	24.8	53.3	46.7	21.4	40.0

Discussion

Habitat destruction motivated by agriculture is globally the most important threat to biodiversity (Sala *et al.* 2000; Foley *et al.* 2011; Green *et al.* 2005). Here, we showed that this threat is supposed to increase drastically in Brazil during the 21st century, according to IMAGE forecasts of agricultural expansion. Agricultural expansion could even reach protected areas and their buffer zones. Indeed, and contrary to our expectations, the results suggest that the current threat imposed by land use changes generated by agriculture is not higher in sustainable use protected areas compared to integral protection ones. Moreover, as the forecast of agricultural cover suggests, the pressure on protected areas should increase in the next century equally for both types of protected areas. Consequently, it will be necessary for sustainable use protected areas to continue to play an important role in the conservation of biodiversity, especially in terms of maintenance of land cover (Joppa *et al.* 2008).

Further, our results reflect a division we have in the Brazilian territory. The Amazon biome represents about half the country's area and it is a focus of an international conservation attention. In the same way, it is found in an undeveloped socioeconomic condition, relative to other Brazilian regions. These characteristics have contributed to the Amazon contained about two thirds of the Brazilian protected areas (Table 1), following the well-known pattern of a preferential creation of protected areas in remote regions (Margules & Pressey 2000). Finally, the Amazon is currently virtually unaffected by agriculture. On the contrary, the rest of Brazil (mainly Atlantic Forest and Cerrado) are poorly protected and intensively impacted by agriculture. Consequently, most of the area available for agricultural expansion is located in the Amazon and our forecast indicates that this region will have the higher amount of land use change. Also, protected areas will become disproportionately impacted by agriculture because most of them fall in the Amazon. In short, agricultural expansion is homogenizing Brazil's territory, making the entire country more vulnerable to biodiversity loss.

Furthermore, some caveats about our study should be discussed. First, the reliability of the model of agricultural extent predicted by IMAGE should be compared to other estimates. For instance, in 2000 the area covered by agriculture in Brazil according to IMAGE model is 1.83 million km2, while the Brazilian official agricultural census estimated 2.19 million km2 for both 1995/6 and 2006 periods (IBGE 2009). Consequently, the extension of agriculture presented here is a conservative one. For the future, the projections are dependent on the assumptions used by the model and the future scenarios of human development. Our option by the scenario A1B, which presents intermediate values of agricultural expansion (Figure 1), was also an attempt to be cautious, avoiding extreme forecasts (see methods). Moreover, the trend of agriculture expansion is suggested not only from land cover models such as IMAGE and others (*e.g.* Soares-Filho *et al.* 2006), but also from the deforestation rates. In the Brazilian Amazon these rates have been equal to 18141 (±5075 S.D.) km2/year between 1977 and 2010 (INPE 2011) and, in the Cerrado, equal to 14273 (±2366 S.D.) km2/year between 1988 and 2010 (MMA 2010) – although it has been observed a significant reduction in the deforestation rates in the last few years.

Another critical point is that IMAGE is supposed to integrate the protected area data for the year 1998 (Image Team 2001). However, we found agriculture land cover in protected areas and their buffer zones in the present and in the future, both for protected areas created before or after 1998, the year of the database used by IMAGE. Further, we used the present network of protected areas in Brazil, and hopefully this network will change until the end of the century. The addition of new protected areas can change some results of our analysis, but it is conservative in respect to biodiversity conservation and, more important, it is unlikely to change our general conclusions. In fact, we understand that the coincidence between agricultural and protected areas that we found in our analysis does not mean that agricultural activity occurs precisely in the predicted proportions inside protected areas – actually, this is not permitted in for IPPAs. IMAGE is a global model that evaluates general trends. Consequently the aim of our analysis is not to say exactly where there is or will be agriculture inside protected areas, but instead measures the trends of influence of this activity and potential conservation conflicts. The areas evaluated as being covered by agriculture are likely to be under pressure of this activity and may be converted if there is not sufficient surveillance. Also, it has been shown that although the protected areas are able to protect the natural features inside it, human activities may increase in their neighborhood (Ewers & Rodrigues 2008, but see Andam *et al.* 2008). Consequently, even if the agricultural expansion shown here will not affect protected areas, it can threaten their buffer zones putting at risk species' populations in these areas by habitat destruction and other threats such as fire and hunting that can act synergistically (Brook *et al.*2008). Despite the fact that agriculture can maintain part of biodiversity, particularly when agroecological practices are incorporated (Perfecto & Vandermeer 2010), many species are sensible to even supposedly biodiversity friendly agricultural practices (Phalan *et al.* 2011).

The habitat conversion to agriculture that is predicted to increase by 82% in this century will increase the pressure on protected areas. The risk of such an extent of the territory being converted into agriculture should raise concerns regarding how to make agricultural areas more wildlifefriendly, where to place different land uses (agricultural and protected areas) and which regulation tools might make this succeed. Currently, there is a wide discussion about changes to the Brazilian Forest Code (*e.g.*, Da Silva *et al.* 2011; Metzger 2010) in order to remove constraints on agricultural production. The expansion of agriculture has been suggested as a pathway for development despite the fact that such a process may not be sustainable (Rodrigues *et al.* 2009), while biodiversity protection can indeed contribute to alleviate poverty (Andam *et al.* 2010). We suggest that in face of the great expansion of agriculture threatening Brazilian protected areas and their buffer zones, the role of Brazilian Government should be to enforce the current legislation and supervise its observance. It is time to embrace portfolios of biodiversity protection (Ehrlich & Pringle 2008) and not to be compliant with environmental destruction.

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Considerações Finais

A Biogeografia da Conservação busca entender os padrões de distribuição e diversidade da vida, bem como utilizar o conhecimento desses padrões para orientar as ações de conservação em resposta às ameaças decorrentes das atividades humanas. A expansão agrícola deve continuar sendo uma importante fonte de impactos para a biodiversidade até 2100, segundo as projeções do IMAGE, podendo aumentar sua extensão dos 26.5% atuais para 44% da superfície terrestre em 2100.

As áreas consideradas como prioridades globais de conservação serão impactadas por essa expansão. Todavia, esse impacto pode ocorrer de maneira diferente conforme a abordagem adotada na definição dessas prioridades (Capítulo 2). As áreas consideradas reativas, que tiveram como critério de demarcação sua alta vulnerabilidade, estão submetidas no presente a um maior impacto agrícola, pois 50% de suas áreas está sob efeito de agricultura. No futuro essa proporção pode chegar a 75%. Já as áreas com baixa vulnerabilida (proativas) são impactadas pela agricultura em 10% de sua área no presente e em 25% até 2100. No entanto, as High Biodiversity Wilderness Areas são uma exceção, pois apesar de representarem um esquema de priorização proativo, atingem proporções semelhantes aos esquemas reativos, nos cenários em que há mais expansão agrícola.

Nosso estudo sobre o impacto da expansão agrícola para a conservação de carnívoros mostrou um conflito entre áreas prioritárias para esse grupo e a distribuição das áreas agrícolas no século XXI (Capítulo 3). Esse conflito pode ser amenizado se os dados de expansão agrícola são incorporados como um custo ao processo de priorização para a conservação, de maneira a penalizar aquelas área com alto custo agrícola. No entanto, essa incorporação altera profundamente a distribuição espacial das áreas prioritárias para a conservação e reduz a quantidade de presenças de carnívoros na solução final. As áreas prioritárias definidas a partir dos dados de distribuição dos carnívoros possuem alta congruência espacial com as prioridades globais de conservação reativas. Por outro lado, as áreas escolhidas quando as informações sobre a expansão agrícola são incorporadas, são congruentes com as áreas proativas.

Outro aspecto que pode afetar as características das redes de áreas prioritárias para a conservação é a integração entre os países. Nos capítulos 2 e 3, as prioridades são estabelecidas sem levar em consideração as divisões políticas do mundo. No capítulo 4 nós mostramos que a integração internacional pode beneficiar a proteção da biodiversidade. O número de presenças de mamíferos em uma rede de áreas prioritárias que corresponda a 17% da área terrestre global é 19% maior quando todos os países são integrados num esforço de conservação comum, comparado a uma estratégia em que cada país independentemente busque atingir, dentro de seus limites, essa mesma proporção de área protegida.

Dessas análises acima, conclui-se que as a informações sobre os cenários de expansão agrícola devem ser consideradas no conjunto do planejamento da conservação. Seja na definição de novas prioridades que utilize os métodos mais sofisticados recentemente desenvolvidos, seja na orientação das ações a serem desenvolvidas nessas áreas. Mesmo as ações a serem realizadas nas áreas definidas há mais tempo como prioridades, usando ainda critérios mais simples de escolha, como os *Biodiversity Hotspots* e que continuam atraindo recursos para a conservação, podem ser beneficiadas pelas informações sobre expansão agrícola. Estratégias que priorizem áreas altamente vulneráveis devem ser integradas com áreas menos vulneráveis em um esforço conjunto conservação da biodiversidade.

No Brasil, a extensão das áreas agrícolas deve aumentar de 20% para 40% segundo o cenário A1B – definido por uma sociedade humana direcionada pela economia e geograficamente integrada. Essa expansão deve ocorrer, potencialmente, inclusive sobre áreas protegidas (Capítulo 5). As áreas protegidas de proteção integral não foram diferentes em termos de impacto agrícola e, apesar de sua maior restrição de uso, não estarão necessariamente mais protegidas em termos de exposição à agricultura que as áreas de uso sustentável.

Desta maneira, a expansão agrícola pode ter um efeito negativo drástico sobre as unidades de conservação. Ainda que legalmente a agricultura agrícola seja proibida dentro dos limites das áreas protegidas, a expansão agrícola pode ameaçar o entorno dessa áreas, fundamentais para a conservação da sua biodiversidade e dos processos ecológicos locais.

Nesse contexto, a regulamentação da atividade agrícola e investimentos em desenvolvimento e difusão de tecnologias que reduzam o impacto da agricultura sobre a biodiversidade devem ser reforçados. Assim, as propostas de flexibilização do Código Florestal em discussão no Governo Federal brasileiro vão de encontro à urgência de proteger a biodiversidade brasileira dos impactos da expansão agrícola iminente.

Por fim, análises sugerem que a demanda agrícola deve aumentar no século XXI pelo aumento da população humana, do consumo per capita e do uso de alimentos para a produção de biocombustíveis (Foley et al., 2011). No entanto, essa demanda pode ser suprimida com ações incluem o fim da expansão agrícola e a redução do impacto global dessa atividade, com o uso eficiente dos meios necessários à produção, aumento de produtividade nas áreas agrícolas subaproveitadas e redução da perda de alimentos. Assim, os indivíduos e organizações envolvidos coma conservação da biodiversidade devem estar atentos aos rumos da agricultura e aos fatores que os determinam a fim de evitar que os piores cenários futuros de impacto dessa atividade se tornem realidade.

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