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Tese de Doutorado

Avaliação do risco de extinção e priorização espacial para conservação de aves no Brasil

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Orientador: Prof. Dr. Rafael Dias Loyola

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Nathália Machado e Sousa

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"We cannot win this battle to save species and environments without forging an emotional bond between ourselves and nature as well... for we will not fight to save what we do not love." Stephen Jay Gould (1941-2002)

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Sumário

Introdução

Introdução

A preocupação em conservar a biodiversidade nunca foi tão intensa como no presente momento. Estima-se que a taxa atual de extinção é 100 a 1000 vezes mais alta que à do passado (Butchart et al., 2010). Porém, se por um lado vivenciamos a perda continua de biodiversidade, por outro, reunimos limitado conhecimento sobre a nossa diversidade biológica, sendo que ainda conhecemos apenas uma parcela das espécies existentes no planeta, déficit de conhecimento este denominado "lacuna Lineana" (Brown & Lomolino, 1998). Apesar dos valores variarem de acordo com o método empregado, estima-se que cerca de 80% das espécies no planeta permanecem ainda desconhecidas (Mora et al., 2011). No Brasil, um país megadiverso e pouco estudado, estima-se que existam, no mínimo, sete vezes mais espécies que o descrito atualmente (Lewinsohn & Prado, 2005). Mesmo para grupos relativamente bem conhecidos, como os vertebrados, ainda possuímos grande lacunas no conhecimento básico, como por exemplo em relaçao à distribuiçao geográfica em vários níveis: global, regional e local, déficit este este denominado "lacuna Wallaceana" (Lomolino, 2004). Tornando o cenário da conservação biológica ainda mais preocupante, inúmeras áreas do globo ainda permanecem pobremente estudadas, ou mesmo desconhecidas e grande parte dos dados de distribuição e das compilações referem-se a unidades geopolíticas, sem significado biológico, enviesados pelo contexto histórico de amostragens que variam enormemente no espaço (Whittaker et al., 2005).

Além da existência de lacunas referentes ao conhecimento básico da diversidade biológica acima citado (lacunas Lineana e Wallaceana), pode-se adicionar a carência de estudos relacionados à conservaçao da biodiversidade. A região Neotropical, por exemplo, na qual o Brasil está inserido, apesar de ser uma das regiões mais ricas e com maior número de espécies de aves endêmicas e ameaçadas (IUCN, 2013), é uma das regiões com biodiversidade menos conhecida, e possui poucos estudos relacionados à conservação das espécies quando comparado às outras regiões (Brito & Oprea, 2009), apesar do número de trabalhos com esse enfoque conservacionista vir crescendo atualmente (Pinto et al. 2007; Loyola et al. 2009; Loyola et al. 2008).

A principal causa de perda de espécies do período atual tem origem principalmente em atividades antrópicas, sendo as ameaças mais importantes: perda e fragmentação de hábitat, invasão de espécies exóticas, superexploração, e mais recentemente, a alteração climática global (Croxall et al., 2012; Diamond, 1984; Krauss et al., 2010; Loiselle et al., 2010; Thomas et al., 2004). Porém, as características intrínsecas das espécies fazem com que elas respondam diferentemente às ameaças (Isaac & Cowlishaw, 2004; Sodhi et al., 2004), e algumas dessas são consideradas chave na determinação do risco de extinção, como por exemplo, tamanho corporal, distribuição geográfica, tamanho de ninhada, fecundidade e dieta (Becker & Loyola, 2008a; Bennett & Owens, 1997a; Boyer, 2009; Cardillo et al., 2005a, 2008a; Cardillo et al., 2006a; Collen et al., 2006a; Cooper et al., 2008; Davidson et al., 2009a; Gaston & Blackburn, 1995a; Harris & Pimm, 2008; Purvis et al., 2000a). Assim, a vulnerabilidade das espécies à extinção é determinada não apenas pela ação sinérgica de múltiplas ameaças, ou fatores externos, mas também por fatores intrínsecos de cada espécie (Cardillo, 2003; Cardillo et al., 2005). Além disso, devido ao fato das ameaças mudarem ao longo do tempo, a vulnerabilidade à extinção é melhor compreendida se incluirmos não apenas fatores intrínsecos, mas também externos nas análises (Bromham, Lanfear, Cassey, Gibb, & Cardillo, 2012; Cardillo et al., 2008).

Compreender como os fatores agem e interagem determinando a vulnerabilidade das espécies, fazer predições quantitativas mais robustas e ainda, avaliar como o risco de extinção está espacialmente distribuído, são passos cruciais do ponto de vista da conservação da biodiversidade, pois direciona as ações conservacionistas (Becker & Loyola, 2008a; Bennett & Owens, 1997; Harris & Pimm, 2008; Loyola et al., 2008). Além disso, modelos que avaliam o risco de extinção podem ser úteis na avaliação rápida de espécies para as quais temos poucos dados populacionais, sendo que a avaliação quantitativa, mais que a categorização do grau de ameaça, imprime maior objetividade e um valor de grandeza quantificável à categoria de ameaça, direcionando prioridades para conservação das espécies. Adicionalmente, predições podem ainda auxiliar na identificação de espécies que não estão atualmente ameaçadas, mas que podem estar em um futuro próximo, por possuirem características que incrementam sua vulnerabilidade, ou seja, espécies com risco latente de extinção (Cardillo et al., 2008). Essas espécies, em geral recebem pouca atenção, porém as ações conservacionistas podem ser mais eficientes se também forem direcionadas a tais espécies, como uma medida pró-ativa (Becker & Loyola, 2008b; Cardillo et al., 2006).

No entanto, a compreensão sobre como os fatores externos e internos interagem determinando a vulnerabilidade à extinção ainda é escassa (Anderson, Farmer, Ferretti, Houde, & Hutchings, 2011; Davidson, Hamilton, Boyer, Brown, & Ceballos, 2009b), e mesmo para as aves, um grupo relativamente bem conhecido quando comparado a outros vertebrados, existem poucos modelos quantitativos predizendo o risco de extinção, que esbarram na escassez de informação sobre as espécies (Jones et al., 2006). Essa situação é ainda mais acentuada quando o foco são as aves marinhas (Dulvy et al., 2003), que apesar de apresentarem-se em grande declínio populacional ainda recebem pouca atenção do ponto de vista de estudos e ações de conservação (Butchart et al., 2004; Croxall et al., 2012).

Mas se por um lado estamos diante de uma crise de conservação da biodiversidade, por outro lado, as estratégias de conservação ainda têm sido inadequadas frente à crescente pressão antrópica (Brooks et al., 2004; Butchart et al., 2010). As atuais redes de reservas, por exemplo, uma das ferramentas de conservação mais importantes, tem-se mostrado ainda pouco eficientes para a conservação biológica, devido principalmente à maneira que estas vêm sendo implementadas, considerando principlamente disponibilidade de terras e beleza cênica, e considerando pouco sua relevância ecológica (Rodrigues et al., 2004).

Desse modo, indo ao encontro da necessidade de diminuir a subjetividade na seleção de áreas prioritárias para conservação, surge na década de 80 o planejamento sistemático para conservação, que se destaca, dentre outras técnicas de planejamento espacial, por ser uma abordagem eficiente proposta com o objetivo de maximizar a conservação dos alvos de conservação em uma rede de reservas (Smith et al., 2006). Suas etapas passam pela seleção do alvo de conservação, estabelecimentos de metas para a região de interesse, mapeamento das áreas com alto valor de conservação, identificação dessas áreas para que as metas sejam atingidas e delineamento da estratégia de implantação visando alcançar as metas (Moilanen et al., 2009).

Desde seu surgimento, o planejamento sistemático para conservação tem passado por vários avanços em suas idéias, técnicas e relevância (Margules & Sarkar, 2007; Moilanen et al., 2009). Porém, apesar dos avanços, ainda existem limitações. Certos aspectos como inserção de custos para a avaliação da eficiência da priorização, alteração da distribuição geográfica da biodiversidade e também como a seleção de áreas prioritárias varia de acordo com a escala em que é aplicada, sendo que apenas atualmente começaram a ser explorados nesse campo (Dobrovolski et al., 2011; Faleiro & Loyola, 2013; Strange et al., 2006).

Porém, existe a necessidade de agir de modo não só a minimizar perdas, mas também de lidar com a rápida expansão de populações humanas sobre áreas naturais e a escassez de recursos financeiros destinados à conservação biológica (Balmford et al., 2003; Wilson et al., 2007), maximizando o retorno dos recursos investidos. Por isso, a definição de áreas prioritárias deve ser baseada não apenas na distribuição da biodiversidade e ameaças, mas também deve passar pela avaliação de abordagens que minimizem os custos de implantação (Bode et al., 2008; Strange et al., 2006; Wilson et al., 2007).

É notável a existência de competição entre as destinações do uso do solo, e assim, o processo de priorização espacial para conservação, com o desenvolvimento de ferramentas analíticas que incluam custos de implantação de rede de reservas para aumentar a eficiência dos recursos aplicados, passa a constituir o eixo central do planejamento espacial para conservação (Sarkar et al., 2006). Portanto, o desafio atual é conciliar a necessidade de definir áreas de conservação e alocar recursos em um cenário de conflito de uso do solo em que poucos recursos são destinados à conservação da biodiversidade.

Desse modo, as recentes aplicações do planejamento sistemático para a conservação têm aumentado a eficiência, em termos de custo-benefício, através da inclusão, não apenas de informações sobre a distribuição da diversidade biológica, mas também de informações socioeconômicas tais como custo da implantação e ameaças (e.g., custo de oportunidade e densidade populacional) (Dobrovolski et al., 2013; Kark et al., 2009a) servindo como critério de restrição durante as análises de priorização. Os exercícios de priorização passam, portanto, de uma abordagem que considera apenas a representação das espécies, para uma abordagem progressivamente mais eficiente, que considera o contexto socioeconômico visando diminuir conflitos no uso do solo, aumentando a eficiência na aplicação dos recursos destinados à conservação.

Objetivo geral

Desse modo, a presente tese foi desenvolvida no contexto da crise da biodiversidade, visando gerar respostas que contribuam para o desenvolvimento de estratégias no campo da conservação da diversidade biológica. A tese é composta por três capítulos, além da introdução geral, em que avaliamos questões referentes aos fatores relacionados ao risco de extinção e avaliação da atual representatividade da biodiversidade de aves continentais (Primeiro capítulo) e marinhas (Segundo capítulo) nas Unidades de Conservação do Brasil. Avaliamos ainda, a eficiência da priorização para conservação em diferentes abordagens (escalas) de acordo com os princípios do planejamento sistemático para conservação (Terceiro capítulo).

Âmbito do estudo

A presente tese tem como foco as aves do Brasil, país com grande riqueza de espécies de aves (aproximadamente 1800 espécies, 20% das espécies de aves existentes), compondo mais de 50% das espécies da região Neotropical e que abriga grande quantidade de espécies endêmicas e ameaçadas (IUCN, 2013). No entanto, assim com toda a região Neotropical, continua sendo pobremente estudado, quando comparado a outro países do globo (Brito & Oprea, 2009). Além disso, existe grande heterogeneidade na distribuição das pesquisas entre as regiões e as espécies (Marini & Garcia, 2005).

Apesar dos esforços governamentais para definição de áreas prioritárias levando em consideração a importância biológica e critérios socioeconômicos, no momento da definição da localização real e limites das Áreas Protegidas brasileiras (Unidade de Conservação), ainda tem-se adotado principalmente o critério de disponibilidade do local, seguindo o padrão de outras regiões do globo (Rodrigues, 2006; Rodrigues et al., 2004), o que torna a seleção de reservas pouco eficientes em relação a aplicação dos recursos. Atualmente o Brasil possui aproximadamente 11% de seu território sob proteção de Unidades de Conservação de Proteção Integral. Além disso, existem 38 Unidades de Conservação Marinhas, correspondendo a 0,14% das áreas costeiras e marinhas (dados disponíveis em http://www.icmbio.gov.br/portal/servicos/geoprocessamento/51-menu-servicos/4004-downloads-mapa-tematico-e-dados-geoestatisticos-das-uc-s.html). Porém, levando em consideração as metas de Aichi estabelecidas pela Convenção de Diversidade Biológica, da qual o Brasil é signatário, o país ainda possui muito o que fazer no campo da conservação da biodiversidade. Dentre as metas de Aichi para conservação da biodiversidade, foi acordado que, até 2020, cada país signatário deveria ter 17% das áreas terrestres e águas continentais e 10% das áreas marinhas e costeiras, sob a proteção de Unidade de Conservação. Portanto, o Brasil, apesar de ter iniciado o processo de internalização e definição das metas nacionais através do Ministério do Meio Ambiente, atualmente está muito aquém das metas estabelecidas, sendo necessário ampliar sua rede de reservas em todo território nacional.

Resumo Geral dos capítulos

Mais especificamente, o primeiro capítulo tem como foco a avaliação do risco de extinção das espécies de aves brasileiras (exceto marinhas) e representatividade nas Unidades de Conservação. Assim, o objetivo foi de (1) avaliar como as variáveis atuam definindo o risco de extinção das espécies, (2) avaliar se e como o risco de extinção está geograficamente estruturado e (3) avaliar a representatividade das espécies nas Unidades de Conservação (em presença de espécies e proporção de sua distribuição geográfica). Para responder tais perguntas, nos modelamos o risco de extinção de 1557 espécies de aves usando Árvore de Classificação e avaliamos a contribuição de cada variável para a determinação do risco de extinção, avaliando também a representação e proporção da distribuição geográfica nas Unidades de Conservação brasileira. A conversão de habitat foi a variável mais importante, seguida pelo tamanho da distribuição geográfica. O Cerrado abriga alta proporção de espécies ameaçadas e, de modo geral, a representatividade das aves é baixa nas Unidades de Conservação.

No segundo capítulo também focamos na avaliação do risco de extinção e representatividade nas Unidades de Conservação, porém para espécies de aves marinhas. Nosssos objetivos foram de (1) avaliar como as variáveis atuam definindo o risco de extinção das aves marinhas, (2) definir quais variáveis são mais importantes na determinação do risco de extinção das espécies, (3) avaliar como o risco de extinção está geograficamente estruturado e (4) avaliar a efetividade das Unidades de Conservação Marinhas em representar espécies com alto e baixo risco de extinção. Para responder tais perguntas, nós modelamos o risco de extinção de 54 espécies de aves marinhas usando Árvore de Classificação e avaliamos a contribuição de cada variável para a determinação do risco de extinção. O tamanho da distribuição geográfica reprodutiva e a captura acidental por navios de pesca foram as variáveis mais importantes. Além disso, demonstramos que as Unidades de Conservação marinhas não são efetivas para proteger as aves marinhas, representando menos de 10% das distribuições no território brasileiro.

Para complementar a avaliação do risco de extinção das aves e sua representatividade nas Unidades de Conservação, no terceiro capítulo focamos na avaliação da eficiência, em termos de custo-benefício, de diferentes estratégias de seleção de áreas prioritárias no Brasil. Assim, nosso objetivo foi de avaliar se (1) a estratégia de definição de áreas prioritárias é mais eficiente se aplicada em escala nacional, de biomas ou Estadual, (2) existe um balanço entre eficiência e vantagens para a biodiversidade quando comparamos as diferentes escalas, e (3) qual a melhor estratégia de conservação quando o custo e benefícios são igualmente pesados. A estratégia aplicada em escala nacional foi aquela com maior eficiência e com mais vantagens, em termo de conservação da biodiversidade de aves no Brasil.

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Capítulo 1

A comprehensive quantitative assessment of bird extinction risk in Brazil

A comprehensive quantitative assessment of bird extinction risk in Brazil *

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Abstract

In an effort to avoid species loss, scientists have focused their efforts on the mechanisms making some species more prone to extinction than others. However, species show different responses to threats given their evolutionary history, behavior, and intrinsic biological features. We used bird biological features and external threats to (1) understand the multiple pathways driving Brazilian bird species to extinction, (2) to investigate if and how extinction risk is geographically structured, and (3) to quantify how much diversity is currently represented inside protected areas. We modeled the extinction risk of 1557 birds using classification trees and evaluated the relative contribution of each biological feature and external threat in predicting extinction risk. We also quantified the proportion of species and their geographic range currently protected by the network of Brazilian protected areas. The optimal classification tree showed different pathways to bird extinction. Habitat conversion was the most important predictor driving extinction risk though other variables, such as geographic range size, type of habitat, hunting or trapping and trophic guild, were also relevant in our models. Species under higher extinction risk were concentrated mainly in the Cerrado Biodiversity Hotspot and were not quite represented inside protected areas, neither in richness nor range. Predictive models could assist conservation actions, and this study could contribute by highlighting the importance of natural history and ecology in these actions.

Keywords

Brazil, classification tree, extinction risk, latent risk, species loss, threat status.

Introduction

The current biodiversity crisis has stimulated a rising tide of questions about species extinction, most of them focusing on the mechanisms making some species more prone to extinction than others [1–4]. Previous studies have reported several threats that are directly associated with species extinction, including habitat loss and fragmentation, hunting, climate change, and alien species invasion [5–8]. However, not all species respond equally to these threats as a result of evolutionary history, behavior, and intrinsic biological features [9,10]. This serves to explain why, apart from a plethora of external threats, the major components of extinction risk relate to intrinsic features of a particular species [2,11], some features being positively or negatively associated with extinction risk. This is the case with body mass [11–15], size of geographic range [2,11,16,17], clutch size [1], fecundity [13], and diet [3,14]. Therefore, extinction pathways are usually defined by inter independent combinations of these multiple features [2,3,15,16,18]. In this study, we modeled extinction risk based on several biological features and external threats, and showed to what extent these variables define multiple species-specific pathways to extinction, which are also known to be geographically structured.

Extinction risk models produce robust quantitative predictions and can help to evaluate how extinction risk is geographically structured, a crucial step in developing effective conservation actions aimed at reducing species loss [19–21] . Yet, our knowledge on how multiple factors interact to define extinction risk is still limited, even for well-known vertebrates such as birds [22]. In fact, several studies have established the significance of birds as mobile links in the dynamics of natural and human-dominated ecosystems [23,24]. They also serve as good indicator groups for establishing conservation actions [25], even when aiming at the surrogacy of functional and phylogenetic diversity [26].

Although Brazil harbors some of the richest avian fauna in the world, the country also contains the largest number of critically endangered bird species [27]. Our goal was to use the birds of Brazil as a case study to quantify and map extinction risk based on the biological features of species and external threats. We also evaluated how the current level of protected land areas in Brazil relates to such risk. In particular, we want to (a) understand how specific variables set pathways to bird extinction, (b) define which variables contribute most in defining extinction risk and the thresholds between threatened and non-threatened species, (c) evaluate the geographic structure of extinction risk in Brazil, and (d) quantify how much of the geographic range of species predicted to be under high and low extinction risk is actually contained by the current network of protected areas in Brazil.

Methods

Data **-** We compiled a database of bird species occurring in Brazil along with their respective biological features (n=1557 species, excluding marine birds) and identified external threats. We chose biological features and external threats based on their role in defining extinction risk in the literature as well as on the basis of data availability. We used the following features: (1) total geographic range size in km² (based on digital maps provided by the BirdLife International [28], available at http://www.birdlife.org/datazone/info/spcdownload), (2) mean body mass in grams (not considering intraspecific variation or sexual dimorphism), (3) trophic guild (nectarivore, frugivore, piscivore, herbivore, carnivore, detritivore, insectivore, granivore and omnivore), (4) diet breadth (the total number of items in their diet), (5) type of habitat (the preferred habitat that the particular species inhabits: freshwater, forest, shrub, and grassland), (6) habitat breadth (number of habitats which the species occupied), (7) clutch size, (8) elevational amplitude distribution (in meters), (9) activity period (diurnal, nocturnal or both), and (10) migratory behavior (non-migrants or migrants). We compiled these data from several different sources (see Appendix S1).

We also compiled external threats for each species from the Red List of Threatened Species published by the International Union for Conservation of Nature (IUCN) [29]. These threats were: (11) habitat conversion, (12) hunting or trapping, (13) diseases, (14) climate change and (15) invasive species. We associated external threats to each species according to the information available in the IUCN Red List. These threats were treated as a binary variable in our analysis. For instance, if a given species was threatened by climate change according to IUCN, it was assigned a "1" in the data matrix. Otherwise, if the species was not threatened by climate change, then it received a value of "0" (zero). We repeated the process for all external threats listed above. Therefore, more than a single factor could threaten a species, but each threat was treated independently. This methodology allowed us to include external threats in our analysis, while retaining all the statistical properties and power of using decision trees (see below).

We also used the threat status of all species according to the IUCN Red List [29], which assigns species to different threat categories according to distinct criteria: Criterion A – species threatened because of a recent decline in population, Criterion B – species threatened because of a limited geographic range, Criteria C and D – species threatened because of low abundance (<2500 individuals, and <250 individuals, respectively) and Criteria E – species threatened based on quantitative analysis. We did not include species listed solely under criterion B (n=17) to avoid potential circularity in extinction risk models given that we included range size as a predictor of extinction risk in our analyses. Also, there were no species listed under criterion E in Brazil. We considered any species classified as Least Concern (LC) and Near Threatened (NT) as 'non-threatened species', whereas those species classified as Vulnerable (VU), Endangered (EN), and Critically Endangered (CR) were classified 'threatened species' following the IUCN [28].

We downloaded data detailing the network of protected areas in Brazil (PAs) from the IUCN and UNEP-WCMC [30]. In our analyses, we considered those areas classified I-IV by the IUCN as 'strictly protected areas' and those areas classified VI as 'not-strictly protected areas' [31].

Analyses - We modeled extinction risk using decision tree, a logical model represented by a tree that shows how the response variable (in our case, threat status) could be predicted by explanatory variables (here, bird biological features and external threats) [32]. When the decision tree has a categorical response (such as our response: threatened or non-threatened) it is called a classification tree. This technique was designed to deal with complex interactions, such as those related to extinction risk, which can differ among taxa in non-linear ways, and should not be viewed as hypothesis-testing routines, instead as hypothesis-generating [32–34]. Because this method is capable of dealing with complex interactions among variables, it has been applied for a number of ecological data analyses. In our case, decision tree models are particularly useful as they do not assume/require any specific statistical distribution for the predictor variable or data independence, avoiding potential concerns about pseudo-replication [22,34]. The main issue, when not controlling for the phylogenetic structure of extinction risk, is that species cannot be considered statistically independent, owing to phylogenetic autocorrelation. This autocorrelation can generate spurious values for degrees of freedom and p-values, biasing the results. However, this is not an issue in decision tree models because they do not test for significance, therefore any level of inflation in degrees of freedom does not alter the structure of trees [33]. Furthermore, our models did not attempt to unravel the evolutionary basis of bird extinction risk. Given that we were not using a linear regression model, there was no need to consider the phylogenetic relationship between species and associated practical problems of generating independence (Please see Jones & Sullivan [22], for more details).

The model splits the initial dataset into homogeneous subsets in terms of the response variable, using a single predictor variable at each node. We measured homogeneity within subsets using the Gini Index [32]. The initial result of a classification tree is usually a large tree that could be over-fitted. Therefore, we pruned the tree to its optimal size using results from 10 cross-validations, establishing a trade-off between prediction accuracy and model complexity [32]. Then, to estimate a proportion of extinction risk we divided the number of threatened species (according to IUCN Red List) by the total species at each node.

To evaluate the contribution of each variable in predicting extinction risk, we built 499 random classification trees using random forest. Random forest is a method that builds several independent classification tree models (excluding each predictor variable from the model at each time) and combines the results of all trees [32]. By comparing the accuracy of the models built by random forest with those built by our original classification tree, we could assess the importance of each variable used to predict extinction risk.

To evaluate model accuracy we used the Cohen's Kappa statistics (package 'irr' in the R software [35]) to measure the concordance between the species categorization generated by the model and their current status based on the IUCN Red list (threatened or non-threatened). In addition, we calculated the percentage of species correctly classified (PCC), the percentage of non-threatened species correctly classified (specificity), and the percentage of threatened species correctly classified (sensitivity).

The proportion of non-threatened species in our data was high (i.e. most species were not currently threatened according to the IUCN). To assess whether a high proportion of species were classified correctly by our models (as a result of the small percent of at-risk species), we undertook a comprehensive sensitivity analysis. We systematically resampled our data to show how the accuracy measures for threat status predictions differed among samples having different proportions of threatened to non-threatened species (see Table S1). We did all analyses using the R software [36], used the 'rpart' package to build classification trees and package 'randomForest' to build random forests [37].

To correlate extinction risk with geographic area in Brazil, we overlaid digital maps illustrating the geographic distribution of all species predicted to be threatened (or not) by our model onto an equal-area grid of the entire Brazilian territory (with spatial resolution of 0.25°x 0.25° of latitude/longitude). We created maps of four species groups according to our model predictions: (A) species predicted to be threatened, (B) predicted to be non-threatened, (C) predicted to be threatened by our model but currently listed as non-threatened according to the IUCN (latent risk species), and (D) those predicted as non-threatened by our model, but currently threatened according to the IUCN (bad luck species). After this, we created distribution maps of proportional species richness (total number of species in each group described above divided by the total number of species occurring in each grid cell).

We then overlaid digital maps of species distribution onto the network of PAs in Brazil and quantified species richness and the proportion of species within a geographic range covered by PAs (i.e. the current level of protection of species). We also evaluated the representation of species in the PAs network, considering a species as 'represented' when at least one grid cell of their range overlapped with PAs. We analyzed species representation considering different PAs categories: (1) only strict PAs (IUCN I-IV categories), and (2), all PAs (IUCN I-IV and VI categories).

Results

Classification trees (expanded and optimal) and random forest models both accurately predicted bird extinction risk (see summary statistics in Table 1 and Table S1). The optimal tree (Fig. 1) had four splits (pruned based on the results of 10 cross-validations, Fig. S1). Despite high model accuracy in predicting extinction risk, the model sensitivity was low. This result indicated that a model stating there are no species at risk' would be correct almost 95% of the time - a very accurate model. However, the ability of our model to predict at risk species was also low. Such low sensitivity was clearly related to the unbalanced proportion between threatened (n=85) and non-threatened species (n=1472). Reducing this unbalanced proportion increased sensitivity values (see Table S1), which resulted in increased model accuracy when the number of threatened and non-threatened species were similar in the analyses.

The optimal classification tree showed different pathways to bird extinction in addition to threshold values for features contributing to extinction. In Brazil, *ca*. 5% of the birds included in our analyses were currently threatened with extinction (see Fig. 1, node A). Extinction risk increased or decreased depending on which features were considered and how these features interacted in the model. Species threatened by habitat conversion had a higher extinction risk (34%, node B) than those not threatened by this external threat (0.4%, node D). Furthermore, those species threatened by habitat conversion and occupying geographic range size smaller than 67,770km² had the highest extinction risk (92%, node C). Species with an intermediate-sized range occupying grasslands also had a high risk of extinction risk (69%, node E).

Table 1. Accuracy measures for predictions of threat status in birds species with current geographic range size and external threats (n=1557 species).

	Classification Model		
Accuracy Metric	Classification Tree: expanded (n=23)	Classification Tree: optimal (n=4)	Random Forest
PCC	97.88%	95.82%	95.3%
Specificity	99.25%	99.45%	99.45%
Sensitivity	74.11%	32.94%	23.5%
Error rate (null error=5.4%)	2.12%	4.18%	4.7%
Kappa (*p*-value)	0.781 (<0.0001)	0.445 (<0.0001)	0.421 (<0.0001)

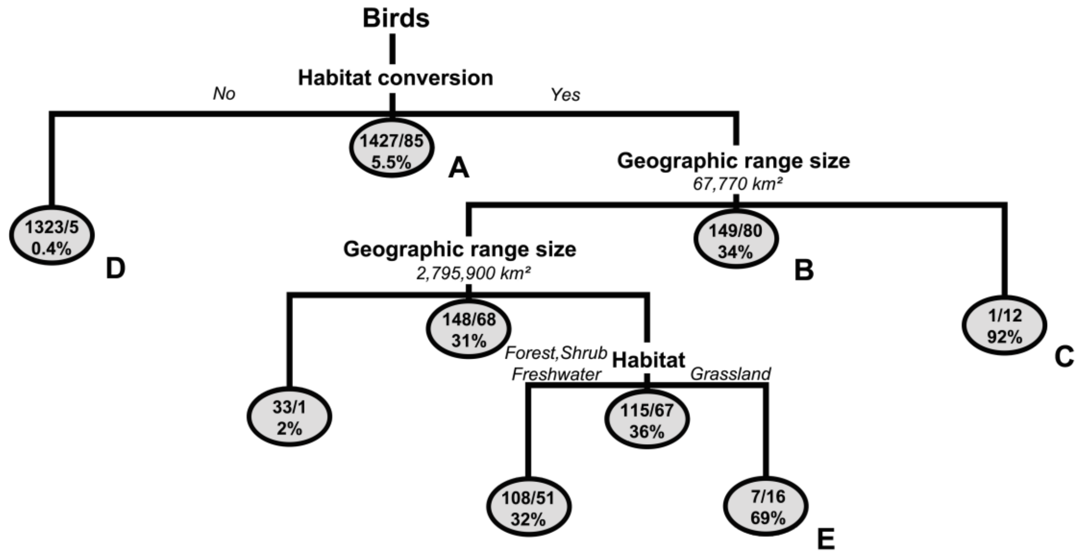

Figure 1. Classification tree showing bird extinction risk in Brazil (according to external threats and intrinsic biological features) and the relative risk of species. Labeled nodes are referenced in main text.

Both biological features and external threats made distinct contributions in defining extinction risk. As expected, habitat conversion was the most important feature (Fig. 2) though geographic range, hunting or trapping, type of habitat and trophic guild were also important. Even though we excluded all species from our analysis that were classified as threatened by the IUCN due to their small geographic range, this feature was still critical to defining extinction risk. In fact, one of the first major splits in the classification tree was defined by range size (small vs. large range size) (Fig.1, node B).

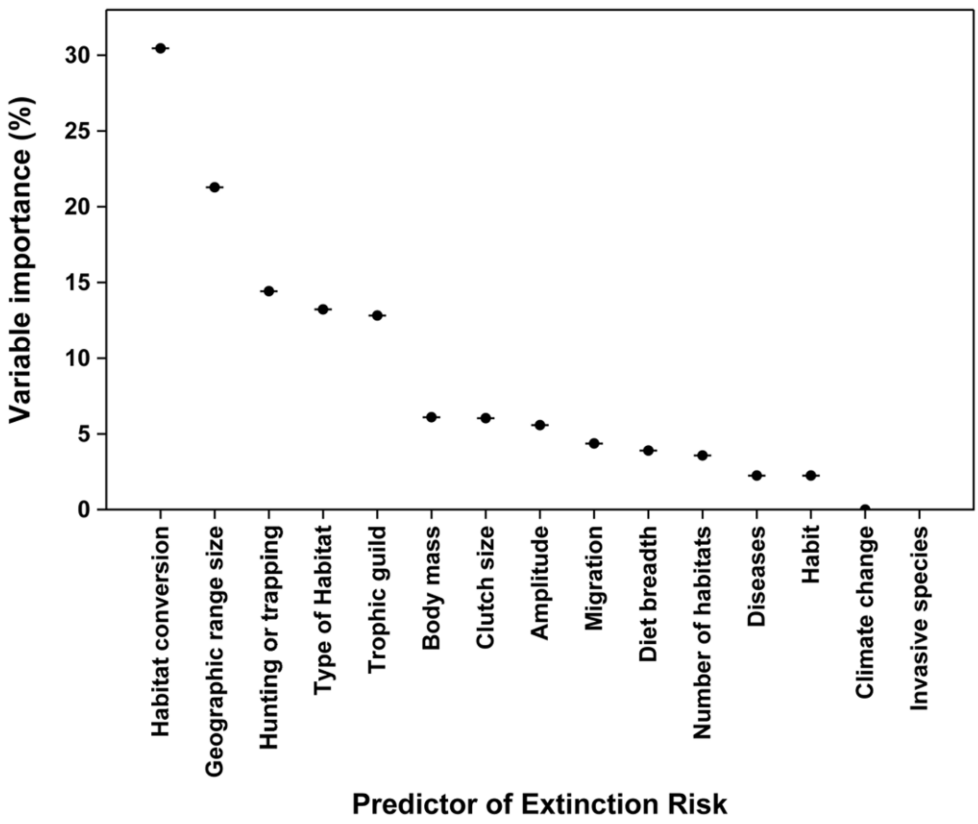

Figure 2. Relative importance of biological traits and external threats in predicting bird extinction risk in Brazil measured by the reduction in classification accuracy upon a stepwise removal of each trait in a set of 499 random forest trees. Error bars represent the standard deviation.

Our model suggest that eight species, currently classified as non-threatened by the IUCN Red List, could be threatened in the future as they share some features with threatened species, such as small range size and preferentially inhabiting grasslands: *Asthenes hudsoni*, *Alipiopsitta xanthops*, *Charitospiza eucosma*, *Cinclodes pabsti*, *Euscarthmus rufomarginatus*, *Picumnus limae*, *Porphyrospiza caerulescens* and *Sporophila hypochroma* (see Table S2 and S3).

The geographic pattern of species distribution predicted to be under high and low extinction risk were quite different. Species at high risk were concentrated mainly in the Cerrado Biodiversity Hotspot of Brazil, also an extinction risk hotspot (Fig. 3A).

Species under low extinction risk were located in the northwest (Amazon Forest) and southeast (Atlantic Forest Biodiversity Hotspot) of Brazil (Fig. 3B). Species currently classified as non-threatened by the IUCN Red List, but predicted as threatened by our model (latent risk species) were also primarily located in the Cerrado, a latent risk region (Fig. 3C). On the other hand, species currently threatened, but predicted to be safe (i.e. bad luck species), concentrated mainly along the coastal line of the Brazilian Atlantic Forest (Fig. 3D).

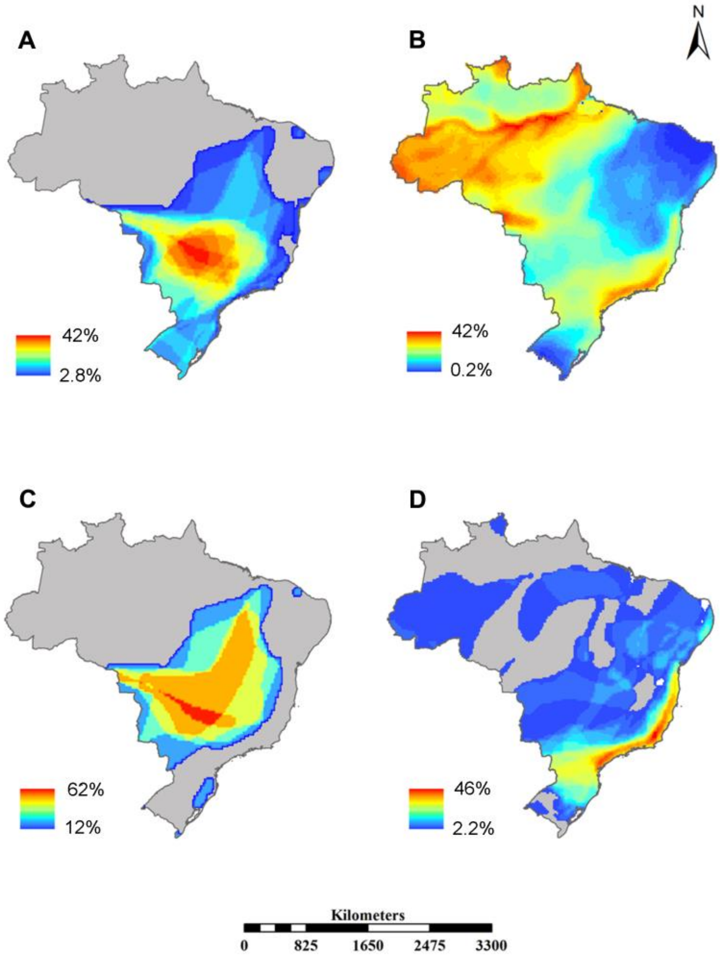

Figure 3. Spatial distribution of proportion of species for those predicted to be at high extinction risk (A), under low extinction risk (B), currently non-threatened but predicted by classification tree as threatened (C) and, currently threatened but predicted as non-threatened (D). The species richness is represented by graduated colors in the map.

Most PAs sheltered close to zero percent of species predicted to be under a high extinction risk (n=35 species protected in strict and all PAs). However, more than 30% of species under low extinction risk were represented in most PAs (Fig. 4A). Furthermore, the few species under high extinction risk whose distributions coincide with PAs have only *ca.* 5% of their range inside the strict PAs. This value increased to 10% when we also considered non-strict PAs together with strict ones. Species under low risk had *ca.* 11% of their ranges inside strict PAs and the inclusion of non-strict PAs increased their protected geographic range to almost 30% (Fig. 4B).

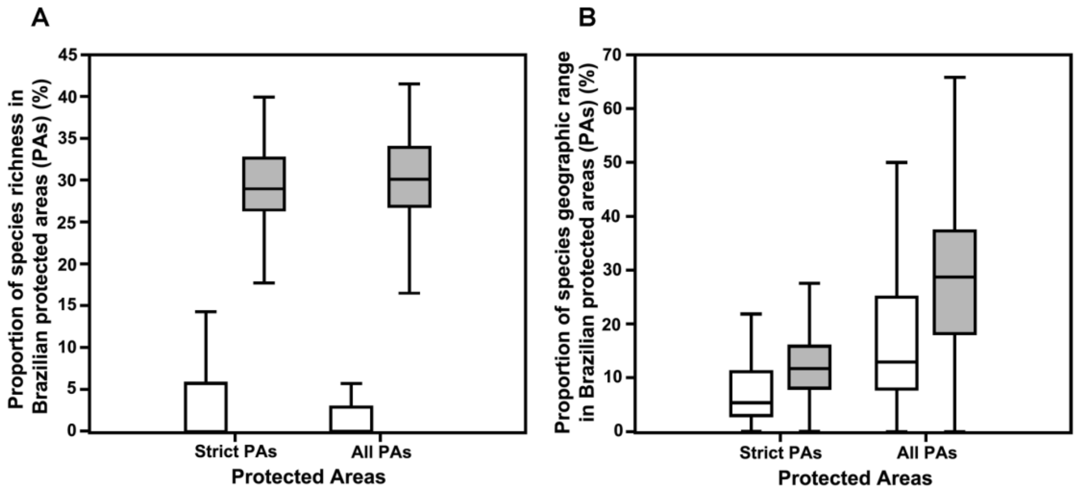

Figure 4. Proportion of species richness (A) and of species geographic range (B) predicted by classification tree model to be at high and low extinction risk considered protected by the current protected area network in Brazil: strict PAs (I-IV categories of IUCN) and All PAs (I-VI categories of IUCN). White bars represent species with high extinction risk, light gray represent species with low extinction risk. Species were considered as 'protected' when there was overlap between at least one cells grid of their range distribution and protected areas. Internal lines stand for the median. Line extensions form each box represent non-outlier range.

Discussion

This study shows a comprehensive quantitative assessment of bird extinction risk in Brazil. We also quantified and disentangled the effect of both intrinsic biological features and external threats in defining bird extinction risk in this megadiverse country, determining the most significant factors driving bird extinctions. It is known that the effects of external threats, as well as species features, are particularly important in defining vertebrate extinction risk [2,15,20,38]. The impacts of human activity, such as habitat conversion, have been largely documented as the main cause of species loss [5]. However, extinction risk predictors play a lesser or greater role defining extinction risk depending on synergic action and may only act in particular situations. For example, when species have a large range size, the effects of habitat conversion are minimized. In contrast, extinction risk changes according to the type of habitat in which a particular species lives being the highest in species occupying grasslands.

Although range size is a well-known predictor of extinction in vertebrates [15], the definition of what is considered a small or a large range-size value has previously been subjective. For birds species in Brazil, this threshold was found to be 67,000 km^2, although previous studies with forest birds found a lower threshold of 11,000 km^2 [20]. Therefore, thresholds may change if we only analyze particular species and its specific habitat. However, we must remember that these thresholds are still optimistic and may be overestimated. Even considering habitat conversion as an external factor, the range size we used was based on species extent of occurrences, which are often inaccurate, and by including all regions where species could occur, may overestimate the range size by dismissing unoccupied portions of remaining habitats [39]. Additionally, we should bear in mind that geographic range and bird taxonomy are still not completely understood (especially for tropical species) which could further bias our results. Amazonian birds, for example, inhabit regions with large, under-sampled areas, and their known ranges routinely expanding as new expeditions are conducted [39].

Larger body mass is also a well-known feature associated with high extinction risk in vertebrates [1,2,12,16]. Species sharing similar values for this trait may be more prone to extinction due to their low abundance, slower life history, lower reproductive rates, and larger home-ranges [15,16]. It is still important to note that some biological features are indirectly considered in each IUCN criterion used to classify species. Although not all features were necessarily considered when listing species, they could be confounded with criterions. For example, criterion A deals with population size, which is obviously related to body size, type of preferred habitat and clutch size (those three features are not formally considered in criterion A). Therefore, even after excluding species listed under criterion B, other criteria might have been confounded with the species biological features.

Grassland species had a higher extinction risk in our model. Grasslands are among the most endangered ecosystems in the world [40] and many species of grassland birds are area-sensitive [41]. This means that grassland birds with smaller range sizes would have more specific habitat requirements; consequently, they are more likely to be sensitive to habitat modifications. Surprisingly, clutch size and migration behavior did not figure significantly into our model. Long-distance migrants may be particularly vulnerable to alterations in habitat or climatic conditions in their breeding range [42]. Fecundity (measured by clutch size) is also associated with extinction risk [1,2] given that species with low fecundity take more time to recover their population after stochastic events [43]. The same happened with habitat breadth, although this feature is intuitively associated with extinction: the more habitats a species might occupy, the higher the chance of survival given their higher environmental plasticity. The low contribution of these variables to our model could be due to data refining. With respect to habitat type we used coarser habitat categories that may not have been as sensible as specific microhabitats.

Climate change is also recognized as a threat to biodiversity [7,44], but its impact on bird biodiversity is still poorly studied/understood in tropical regions (but see Anciães & Peterson [45] and Marini et al. [46]). However, negative effects are predicted in the future [7,47], which in turn could be reflected in its lower importance in defining extinction risk in our model [4].

Our model is an alternative tool to predict extinction risk, even for poorly known species for which we have little information about population dynamics [15]. Predictive models may help in prioritizing species for conservation action, rather than by using their current threat status [17]. Highlighting species predicted to have a high extinction risk, but currently listed as non-threatened, is of particular importance [19] given that these species usually attract minimal conservation attention [11].

This study indicated that some species currently classified as non-threatened by the IUCN are predicted as having a threatened status in our models. However, most of these species have already been recognized by the IUCN as having an elevated risk of extinction, and are currently classified as Near-Threatened species (Table S2). Nevertheless, we believe resources could be more efficiently allocated applied to the conservation of these species and avoiding forthcoming extinctions [11]. Moreover, extinction risk models are critical tools for evaluating species defined under IUCN criterion E, which accounts for quantitative analysis. Quantitative analysis which estimates the extinction probability of a taxon based on known life history, habitat requirements, threats and any specified management options. To our knowledge this study is the first to report a comprehensive quantitative analysis on the extinction risk of bird species in Brazil.

However, the accuracy of our models was clearly dependent on the ratio between threatened and non-threatened species. Our models had a high predictive accuracy for detecting species that were not at risk, but our ability to predict species at risk only increased when the number of threatened and non-threatened species were similar (see Table S1). Previous works also show a similarly low sensitivity in detecting threatened species [15,42]. This is an important consideration for conservation efforts, as the ability to predict for at-risk species is critical. Though our models could foster discussion or be used to evaluate the inclusion of species under criterion E, they should be applied with prudence given their inherent statistical limitations.

Extinction risk is influenced by external factors [2,17]. Even species that are relatively safe when only intrinsic features are considered may be severely affected by external threats (such as habitat conversion), increasing their probability of extinction. In addition, threats to biodiversity vary across species and sites. Our results corroborated previous studies assessing the pattern of geographic threat in South America that indicate the Cerrado region and Atlantic Forest as the main regions sheltering species at a higher risk[42,48–51]. Jenkins & Pimm [52] argued that sites of high conservation priority are also those which contain threatened habitats, indicating a link between habitat loss and threatened birds in the Atlantic forest region. The Cerrado region and Atlantic Forest are under higher anthropogenic pressure in Brazil [50,53–55], and in the case of Atlantic forest, harbor species with the smallest range size [49]. On the other hand, the Amazon forest is largely undisturbed and species at low extinction risk do not share geographic range with large human populations, unlike those of the Atlantic Forest ([17], but see Luck [56]).

Nevertheless, given the fast growth rate of the human population, it would be better to identify the latent areas at risk and proactively set priorities for the conservation biodiversity [17,57,58]. We indicated that the Cerrado and Atlantic forest regions harbor species of concern. The Cerrado region is a highly heterogeneous domain, consisting primarily of seasonal tropical savanna that has been enormously and rapidly transformed by human activities with a concomitant los in species [51,55]. Furthermore, only 2.2% of this area is currently under legal protection [55,59]. Although grassland habitats have a high biodiversity value, they are under jeopardy, barely protected by currently PAs, have inadequate management [60,61], habitat conversion is occurring rapidly [55] and their bird populations are in decline [51].

The network of PAs in Brazil must be broadened to guarantee the inclusion of more species, given that many species are poorly represented in the majority of PAs. Clearly, current PAs are not adequate to protect species having high extinction risk. Similar to the global protected-area system [62], the Brazilian system is far from complete [63,64]. A recurrent and unresolved issue in conservation biology is about how much of a biological element's distribution actually needs to be represented in conservation areas [57], despite efforts to establish a blanket target [62]. Even without such a target, including intrinsic biological features in conservation planning analyses seems key to producing more effective and ecologically sound conservation plans [21,65,66]. Additionally, despite increased species representation with the inclusion of non-strict PAs, various types of economic activities happening within them could threat more sensitive species.

An increasing knowledge about species will probably serve to refine extinction risk models. Despite academic efforts to find better spatial solutions that account for biological features [21], the solution are poorly applied during the selection of proposed conservation areas. We hope the results of this study will help to highlight the importance of natural history and ecology in conservation biology and spatial conservation planning.

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Supporting information

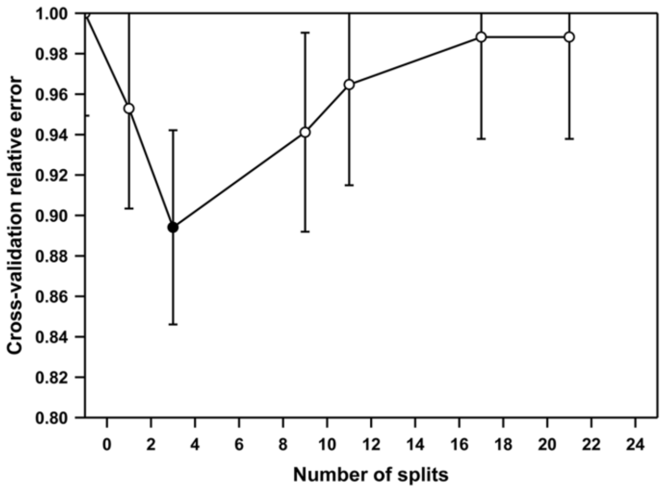

Figure S1. Relative error for the classification tree determined by 10 cross-validations. The optimal tree is indicated by a filled circle and has eight splits.

Table S1: Accuracy measures for predictions of threat status for different samples of species (The *n* values showed represent all species analyzed: 85 threatened species, plus random samples of non-threatened bird species).

n	Threat/No-threat Rate	Classification Tree expanded			Classification Tree prunned			Random Forest		
		PCC	Specificity	Sensitivity	PCC	Specificity	Sensitivity	PCC	Specificity	Sensitivity
n=170	1/1	92.0	89.7	94.3	89.0	82.8	95.3	86.1	85.1	87.2
n=255	1/2	93.8	95.4	90.7	81.5	76.4	91.9	76.5	84.5	60.5
n=340	1/3	95.4	98.8	84.9	95.4	98.8	84.9	81.7	93.8	49.0
n= 425	1/4	94.9	97.7	83.7	95.2	98.0	83.7	76.5	84.5	60.5
n=510	1/5	92.3	97.7	65.1	92.3	97.7	65.1	87.3	96.8	39.5
n= 595	1/6	95.5	98.5	78.2	91.6	98.3	52.8	88.1	96.9	34.9
n=680	1/7	95.4	98.7	68.6	92.7	99.7	36.0	92.1	99.1	34.9
n =765	1/8	96.1	99.6	64.0	93.2	99.6	34.9	91.5	98.7	25.6
n= 850	1/9	95.4	99.7	52.3	93.5	99.2	36.0	92.2	98.5	27.9
n =935	1/10	95.8	99.5	51.2	96.1	99.5	55.2	93.5	99.0	26.7
n=1360	1/15	96.6	99.8	53.5	94.9	99.5	34.9	93.8	99.2	23.3

Table S2: Species currently classified as non-threatened by IUCN [1] but predicted as threatened by our classification tree model (optimal tree). NT: Near threatened, LC: Least Concern. The column "Classification tree node" show the species position in the Classification tree optimal (see Fig. 1).

Species	**Common Name**	**IUCN Red List status**	**Population trend (IUCN)**	**Year assessed**	**Extintion Risk**	**Classification tree node**
Asthenes hudsoni (Sclater, 1874)	Hudson's Canastero	NT	decreasing	2009	69%	E
Alipiopsitta xanthops (Spix, 1824)	Yellow-faced Amazon	NT	decreasing	2008	69%	E
Charitospiza eucosma Oberholser, 1905	Coal-crested Finch	NT	decreasing	2008	69%	E
Cinclodes pabsti Sick, 1969	Long-tailed Cinclodes	NT	decreasing	2008	69%	E
Euscarthmus rufomarginatus (Pelzeln, 1868)	Rufous-sided Pygmy	NT	decreasing	2008	69%	E
Picumnus limae Snethlage, 1924	Ochraceous Piculet	LC	-	2010	92%	C
Porphyrospiza caerulescens (Wied, 1830)	Blue Finch	NT	decreasing	2008	69%	E
Sporophila hypochroma Todd, 1915	Rufous-rumped Seedeater	NT	decreasing	2008	69%	E

Appendix S1

1. Alves MA dos S, Cavalcanti RB (1990) Ninhos, ovos e crescimento de filhotes de Neothraupis fasciata: 91–94.

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Capítulo 2

Modeling extinction risk for seabirds in Brazil

Section: Research Letters

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Modeling extinction risk for seabirds in Brazil

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Abstract

Species extinction risk is associated with intrinsic features such as body mass, geographic range size and diet, and also, external threats, mainly anthropogenic pressure. Current biological knowledge on seascapes still falls behind knowledge from terrestrial ecosystems, and understanding the pathways to extinction for declining groups, such as seabirds, is of paramount importance. We provide the first estimates of seabird extinction risk derived from regressive models associating species intrinsic features and external threats, and evaluation of effectiveness of marine protected areas (MPA). We aimed to: (*i*) understand how intrinsic and external variables interact to set pathways to seabird extinction; (*ii*) define which variables are most important; (*iii*) evaluate the geographic structure of extinction risk; and (*iv*) evaluate the effectiveness of Brazilian MPAs in representing species at high and low risk. We used classification tree to model extinction risk and random forest to evaluate the importance of each variable. Our models were accurate to predict relative extinction risk of threatened species. Breeding range size and threat from fishing vessel were the most important drivers of extinction risk. Brazilian MPAs are not effective to protect seabirds and are short to cover a minimum of 10% of species ranges. We show that drivers of extinction risk act in a synergistic way and suggest that conservation of seabirds in Brazil should be considered high priority given their low current level of protection.

Keywords: classification tree, marine birds, protected areas, seascapes, species loss.

Introduction

Species extinction risk has been largely associated with biological traits such as body mass (Gaston & Blackburn 1995), geographic range size and diet (Purvis *et al.* 2000), clutch size and fecundity (Bennett & Owens 1997). External threats have also a crucial function to define extinction risk and several studies have reported threats that lead species to extinction such as habitat conversion, hunting, climate change, and alien species invasion (Sodhi & Ehrlich 2010). Species responses to external threats can vary given their evolutionary history, behavior, and intrinsic biological features. Thus, multiple intrinsic and extrinsic features define extinction risk (Davidson *et al.* 2009) and, because threats change over the time, species extinction is better understood if one analyzes both external threats and intrinsic features together (Cardillo *et al.* 2006).

Most studies on extinction risk have been conducted for terrestrial species. In marine environments, fishes are largely more studied than other groups of organisms, given the economic importance of fishery activities (Pinsky *et al.* 2011). However, seabirds also play a critical role in marine community structure and ecosystem functioning, acting as top predators (Sergio *et al.* 2008). Yet, concerns about the ecological integrity of seascapes are increasing fast due to ongoing habitat degradation caused by human activities (Halpern *et al.* 2008). Less than 1% of the world's seas are currently under protection, in contrast to the 11% of global land coverage provided by protected areas (Toropova *et al.* 2010). Thus, the target to protect at least 10% of coastal and marine areas until 2020 is still far from being achieved. Adding to this problem, only the presence of protected areas does not indicate that they are effective in achieving biodiversity conservation.

Over the last 20 years seabirds received smaller conservation attention and effort compared to non-seabirds, and thus seabird populations are declining fast (Croxall *et al.* 2012). It is generally assumed that the vulnerability is similar both to terrestrial and marine species, but unexpected patterns can emerge when analyses include only marine species (Pinsky *et al.* 2011). Hence, understanding how biological features and external threats interact to define seabird extinction risk allows for more robust quantitative predictions of extinctions and helps us to evaluate the geographic structure of extinction risk – both crucial steps to help us set more effective conservation actions.

Here we provide the first estimates of seabird extinction risk derived from models that associate intrinsic biological features and external threats, evaluating also if species under high risk are well represented in marine protected areas (MPAs). We aimed to: (*i*) understand how intrinsic biological features of seabirds and external threats interact to set different pathways to species extinction, (*ii*) define which features are key drivers of extinction risk, (*iii*) evaluate how extinction risk is spatially distributed, and (*iv*) evaluate the effectiveness of MPAs to protect seabird biodiversity, using the species of Brazil as our case study.

Material and Methods

Data

We built a database of seabird species occurring in marine habitats in Brazil (n=54 species, excluding vagrant species). We chose biological features according to their role in defining extinction risk as reported in the literature, as well as on the basis of data availability. We used the following intrinsic features: (1) total geographic range size (i.e. global distribution) and (2) total breeding range size [both in km_2 and based in extent of occurrence maps provided by BirdLife International and NatureServe (Ridgely *et al.* 2011)], (3) mean body mass of adults (in grams), (4) diet (piscivore, carnivore, insectivore and omnivore), (5) diet breadth (number of type of items in their diet), (6) mean clutch size, (7) habit (nocturnal, diurnal or both),(8) type of habitat (the habitat primarily used by species: sand beaches/ coastal water or pelagic water), (9) number of habitats the species occur [7-9 according to Stotz *et al.* (1996)], (10) migratory behavior (non-migrants or migrants), (11) foraging strata (terrestrial, water and aerial), (12) foraging site(water, ground, vegetation, air, mixed, (13) foraging site breadth. We compiled all these data from several sources (see Appendix S1 in Additional Supporting Information available at www.abeco.org.br).

We also used external threats for each species from the Red List of Threatened Species published by the International Union for Conservation of Nature (IUCN 2011). These threats were: (14) threat by fishing vessel, (15) habitat disturbance, (16) predation by introduced species, (17) hunting or harvesting, (18) diseases, (19) prey overexploitation, and (20) climate change. We associated external threats to each species according to the information available in the IUCN Red List (IUCN 2011). These threats were treated as a binary variable in our analysis. For example, if a given species is threatened by habitat disturbance according to IUCN (2011), it was assigned a “1” to this threat in our data matrix. Otherwise, if the species is not threatened by habitat disturbance, then it received a value of “0” (zero).

We also used species threat status according to IUCN (2011). The Red List assigns species into different threat categories using distinct criteria: (A) species threatened because of recent population declines;(B) species threatened because of small geographic distribution, and (C) and (D) species threatened because of small population sizes (<2 500 individuals, and <250 individuals, respectively) and Criteria E – species threatened based on quantitative analysis. We excluded all seabird species listed as threatened under criterion B by IUCN Red List (species threatened because of small geographic size) to avoid potential circularity in the extinction risk model, given that range size was set as a predictor in our analyses. Further, we did not include species listed under criterion E because there is no species listed under this criterion in Brazil. We considered species classified by IUCN criteria as ‘Least Concern’ (LC) and ‘Near Threatened’ (NT) as ‘non-threatened’, and species classified as ‘Vulnerable’ (VU), ‘Endangered’ (EN), and ‘Critically Endangered’ (CR) as ‘threatened’ species. We downloaded data on the network of integral marine protected areas in Brazil (henceforth MPAs) from *protectedplanet.net*.

Analyses

We modeled the relative extinction risk using decision tree, a logical model represented by a binary tree that shows how the response variable (in our case, threat status: threatened or non-threatened) can be predicted by the explanatory variables (here, intrinsic biological features and external threats) (Breiman *et al.* 1984). When decision tree has a categorical response (such as threatened or non-threatened) it is called classification tree. This technique was designed to deal with complex interactions such as those related with extinction risk, which can differ among taxa in a non-linear ways (De’ath & Fabricius 2000). Thus, two key principles could be incorporate to our model using the classification tree approach: more than one factor can threat species, and the factors can be important only in particular situations with synergic action to others variables (Davidson *et al.* 2009).

Decision tree models are particular useful in our case because, differently from linear regression models, they do not assume/ require (1) any specific statistical distribution of predictor variables, neither (2) data independence, avoiding potential concerns about pseudo-replication (De'ath & Fabricius 2000). During the analysis, the model splits the initial dataset into subsets as homogeneous as possible in terms of the response variable, using one predictor variable at each node. We measured homogeneity within response variable subsets with the Gini Index (Breiman *et al.* 1984). The initial result of the classification tree is a usually large tree that could be an over-fitted tree. Thus, we pruned the tree to its optimum size using the results of 10 cross-validations, making a trade-off between prediction accuracy and complexity of the model. To estimate the relative extinction risk of species we divided the number of species currently threatened in each node [according to IUCN Red List (IUCN 2011)] by the total of species, in each node.

To evaluate the contribution of each variable in predicting extinction risk we built 499 random classification trees, using random forest. Random forest is a method that builds many independent classification tree models excluding a subgroup of predictor variable at each time from the model and combining the results of all trees (Liaw & Wiener 2002). Therefore, comparing the accuracy of the models built by random forest, we could access the importance of each biological feature used to predict the extinction risk.

To evaluate the accuracy of the overall models we used Cohen's Kappa statistics (*irr* package in the R software; Gamer *et al.* 2010) that measures the concordance between the species categorization (threatened or non-threatened) generated by the model and the current status based on the IUCN Red list (IUCN 2011). In addition, we calculated percentage of species correctly classified (PCC), non-threatened species correctly classified (specificity) and the percentage of threatened species correctly classified (sensitivity). We ran all analyses in R software using *rpart* package to build classification trees and the *randomForest* package to run the random forests (Liaw & Wiener 2002).

We also mapped species predicted as threatened and non-threatened by our model to show how extinction risk is geographically structured in Brazil. The geographic extent of our analyses was the Brazilian Exclusive Economic Zone (EEZ) and Continental Shelf, which was divided into 0.25° × 0.25° of latitude/longitude grid cells. To evaluate the effectiveness of MPAs, we quantified how much of the geographic range of seabirds in Brazilian EEZ and Continental Shelf is covered by MPAs, and how many species are included in MPAs. Here, instead of total geographic range previously used to model extinction risk, we used only range placed in Brazilian jurisdiction (in Brazilian EEZ and Continental Shelf). We overlaid species' distribution to the network of MPAs currently established in Brazil (no-take zones or IUCN strict protected areas categories I-IV). Then, we calculated the proportion of their geographic range located inside protected areas (i.e. their current level of protection). All species with at least one grid cell of their range overlapped by MPAs were considered as represented in MPAs.

Results

We found different pathways to seabird extinction, as well as threshold values for features contributing more or less to extinction risk (Figure 1). In Brazil, seabirds had *ca*. 16% of extinction risk (Figure 1, node A). Extinction risk can be modulated to higher or lower values depending on which variables are included in the model. Species threatened from fishing vessels had very high extinction risk (61%, Figure 1, node B). Species with larger total breeding range size (higher than 505,000 km_2) had lower extinction risk (0%, Figure 1, node D). However, species with smaller breeding range size had higher extinction risk values (72%, Figure 1, node E) and when they had smaller clutch size their extinction risk increase (87%, Figure 1, node F). Additionally, the most important variables driving extinction risk in seabirds were breeding range size and fishing vessel, respectively (Figure 2).

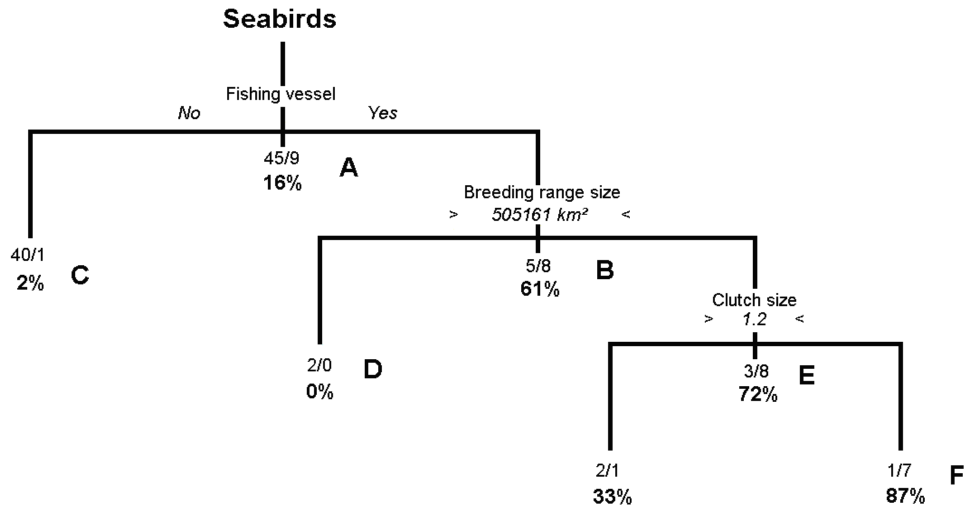

Figure 1. Classification tree showing seabird extinction risk in Brazil according to their intrinsic biological features and external threats, and the number of species currently non-threatened and threatened at each node (non-threatened/threatened). Labeled nodes are referenced in main text.

Optimal classification tree, pruned based on the results of 10 cross validations (Figure S1 in Additional Supporting Information), had three splits and had the same size of the expanded tree (Figure 1). Both tree classification models, as well as the random forest model, were accurate to predict relative extinction risk and threatened species (Table 1). Additionally, only two species currently listed as threatened by the IUCN Red List were predicted to be non-threatened by our model (the Trindade Pretel, *Pterodroma arminjoniana* and Olrog's Gull, *Larus atlanticus*).

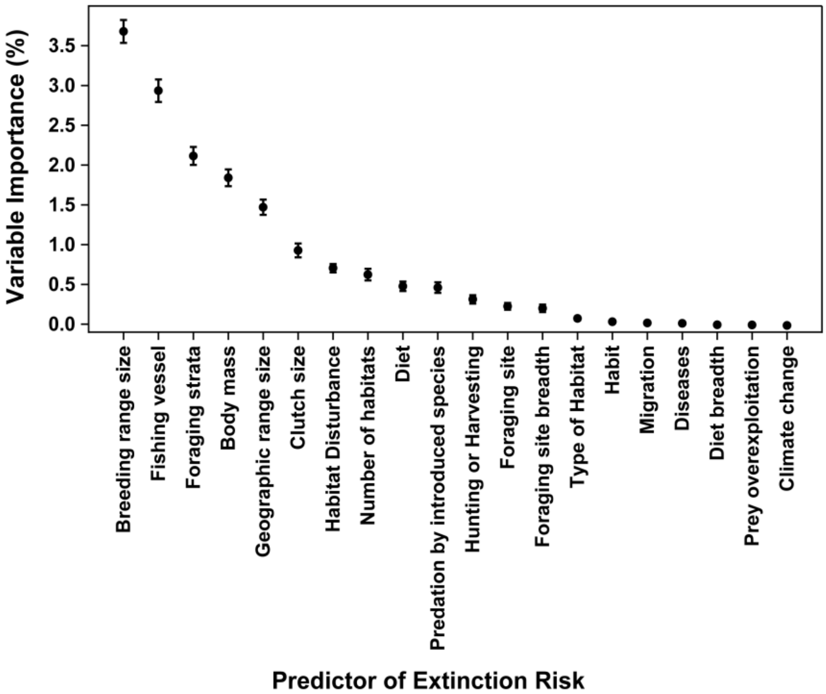

Figure 2. Relative importance of intrinsic biological features and external threats in predicting seabird extinction risk in Brazil measured by reduction in classification accuracy upon a stepwise removal of each variable in a set of 499 random forest trees. Error bars represent standard deviation.

Species richness varies along the Brazilian coast (Figure 3A). Species under low extinction risk are located mainly in the coastal region (Figure 3B), where as those with high extinction risk are concentrated in southern Brazil (Figure 3C). Also, the proportion of species' range inside MPAs was lower for species under high extinction risk (1% ± 0.5 of their range size) compared to those under low extinction risk (28% ± 23 of their range size).

Table 1. Accuracy measures for predictions of seabirds' extinction risk in Brazil (n=54).

	Classification Model		
Accuracy Metric	Classification Tree: expanded (n=3)	Classification Tree: optimal (n=3)	Random Forest
PCC	94.4%	94.4%	90.7%
Specificity	97.8%	97.8%	97.8%
Sensitivity	77.8%	77.8%	55.6%
Error rate (null error=1.7%)	5.6%	5.6%	9.3%
Kappa (*p*-value)	0.79 (<0.0001)	0.79 (<0.0001)	0.62(<0.0001)

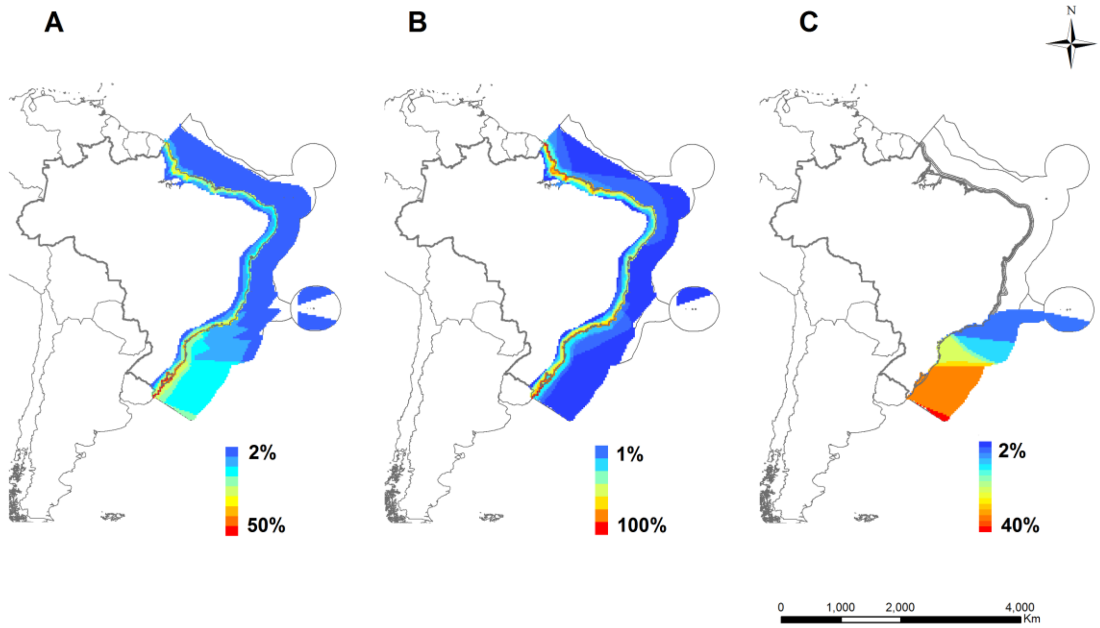

Figure 3. Species richness patterns of seabirds in Economic Exclusive Zone in Brazil (A), of species predicted under low extinction risk (B), and species predicted under high extinction risk (C).

Discussion

Seabird conservation undergoes a fragile moment: we must identify or better understand how different predictors interact to guiding them to extinction and also, how extinction risk is spatially structured (Croxall *et al.* 2012). We showed that Brazilian MPAs are highly deficient to protect seabirds [as other biodiversity features, see Magris *et al.* (2013)], either those species with high extinction risk, and those with low extinction risk, even under a broad criteria used by us to define species as represented (at least, one cell grid of overlapping). This is no surprise as Brazilian MPAs overlap with only very few Important Bird Areas (IBAs) (Croxall *et al.* 2012). To make matters even worse, the few areas covered by MPAs in Brazil have small size.

We found that total breeding range size was a pivotal biological feature driving seabird extinction risk even after removing species classified by IUCN (2011) as threatened under criterion B. Seabirds generally have distinct size of breeding range and winter range and most part of Brazilian seabirds does not breed within Brazilian limits (Sick 2001). Despite wintering range is important mainly during resting period, breeding site should be more sensible to impacts, and when smaller, more chance of offspring be negatively impacted by anthropic actions (Neves *et al.* 2006).

Clutch size is also figured as an important variable driving extinction risk in our model in accordance with results reported in previous studies (Krüger & Radford 2008). Species with small clutch sizes and small breeding populationsare more vulnerable and have limited capacity to recover after impacts (Croxall *et al.* 2012). In fact, pelagic seabirds, which have the smaller clutch sizes, are the most threatened group and have faced faster population declines than coastal species (see Croxall *et al.* 2012).

Only two species currently classified as threatened by the IUCN Red list (IUCN 2011), were predicted as non-threatened by our model (the Trindade Pretel *Pterodroma arminjoniana* and Olrog's Gull *Larus atlanticus*). These species are listed as Vulnerable by the IUCN mainly because of their very small breeding range and small populations (IUCN 2011). However, the status of *Pterodroma arminjoniana* would need a re-evaluation if the breeding population of Round Island (in the Indian Ocean) was confirmed to be part of this species (Birdlife International 2013).

In 2006, the International Commission for the Conservation Atlantic Tunas (ICCAT) request an assessment of threat from their fisheries to seabirds that occur in their jurisdiction (Tuck *et al.* 2011), and Brazilian government created a national conservation plane for seabirds inhabiting their territory (Neves *et al.* 2006). We showed that for seabirds, main causes of decline are threat from fishing vessel and habitat disturbance. Longline vessels are reported catching a large and unsustainable number of seabirds (Tuck *et al.* 2011). However, these threats are also geographically structured and species with high and low relative extinction risk occur in very different sites. Even though species richness is higher in the coast; species with higher extinction risk are located in the south, far from the coast. Thus, sites with high richness are not necessarily those more important to seabird conservation.

The Brazilian network of MPAs was designed mainly to cover coastal environments, largely neglecting the open sea biota (Game *et al.,* 2009). Although the establishment of MPAs is of paramount importance, evaluation of their effectiveness must be included within conservation schemes (Magris *et al.*2013) as well as mapping the geography of extinction risk. Currently, site-selection of MPAs for safeguarding seabirds has been proposed using different approaches (e.g. protection of areas associated with breeding colonies and aggregations of non-breeding birds, and protection of migratory bottlenecks) (Grecian *et al.* 2012; Thaxter *et al.* 2012). We believe that including sites that comprise geographic range of species with high extinction risk, as those showed here, could increase spatial prioritization effectiveness avoiding species losses.

Here we show that drivers of extinction risk act in a synergistic way. Further, Brazilian MPAs are not effective to protect seabirds being unable to cover a minimum of 10% of species' ranges for those species under high extinction risk. Therefore, we suggest that conservation of seabirds in Brazil should be considered high priority given their low current level of protection and that our work help in the discussion on how and when to implement conservation actions in Brazil.

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Supporting Information

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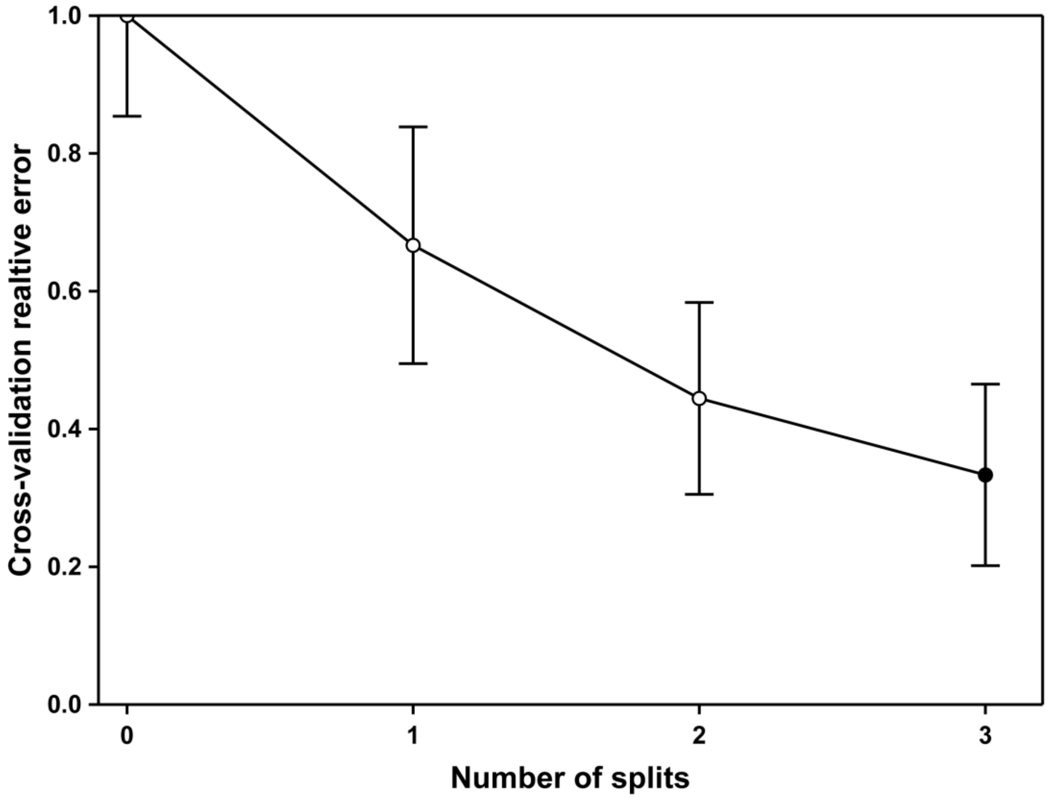

Figure S1. Relative error for the classification tree determined by 10 cross-validations. The optimal tree (indicated by a filled circle) has three splits.

Appendix S1

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Capítulo 3

Nationally-coordinated strategies are more cost-effective than regional or local ones for protecting birds in Brazil

Nationally-coordinated strategies are more cost-effective than regional or local ones for protecting birds in Brazil

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Abstract

Conservation actions are usually implemented at the local scale; although conservation decision is usually made at higher levels. Further, costs and priorities vary significantly among geopolitical units, and because of this, it is crucial to quantify the cost-effectiveness of a portfolio of conservation strategies. Here we show that nationally coordinated strategies are more cost-effective than regional or local ones, resulting in higher benefits for biodiversity. Here, we used Brazil and bird diversity as a case study to analyze the cost-effectiveness of spatial conservation plans developed at different geopolitical units and scales of action by building a plan for the whole country, for each biome, and for each state administrative unit. We used the opportunity costs and population densities to evaluate the cost-effectiveness at different scales of spatial prioritization. Under a nationally-coordinated strategy, priority sites tend to be more clustered. Also, this strategy held the lowest cost and also reduced to the lowest level average extinction risk of species. Our analyses showed that coordinated actions could deliver more cost-effective strategies. Also, under this strategy, trade-offs between costs and biological value are easier to solve.

Key-words: biodiversity benefits, conservation opportunity, conservation costs, scale effect, spatial prioritization, systematic conservation planning.

Introduction

Coordinated strategies for biodiversity conservation are imperative when resources available for implementing actions are scarce, and costs are distributed among multiple stakeholders. Conservation actions are usually implemented at the local scale, being circumscribed by geopolitical units at the intra-national level. However, conservation decision is usually made at higher levels, integrating national strategic plans that match the commitments established by countries in international agreements (e.g. the Aichi biodiversity targets for 2020, CDB 2010). Here we show that nationally-coordinated strategies are more cost-effective than regional or local ones, resulting in higher benefits for biodiversity.

Costs and priorities vary significantly among geopolitical units, and decision makers at different levels typically have different values and priorities for the conservation of biodiversity and its components (Arponen *et al.* 2014). Therefore, it is crucial to quantify the cost-effectiveness of a portfolio of conservation strategies (to be implemented at different levels), especially for those that include geopolitical units sharing biota (Bladt *et al.* 2009; Rodrigues & Gaston 2002). In fact, the incorporation of financial constraints and opportunities into conservation planning have expanded considerably in the last decade (Cabeza & Moilanen 2006), aiming for the biggest bang for each conservation buck (Ando *et al.* 1998; Carwardine *et al.* 2008). However, many studies still rely on simple costs (i.e. the amount of area required for protection or, in better cases, land-acquisition costs), without considering socio-economic drivers of implementation (Faleiro & Loyola 2013).

Because of this, cost information has been increasingly applied as a metric, which combines both economic (e.g. land-acquisition cost, opportunity costs) and social costs (e.g. human population density, willingness to act) increasing the efficiency of propose network of priority sites for action (Diniz-filho *et al.* 2008; Dobrovolski *et al.* 2013; Faleiro & Loyola 2013; Kark *et al.* 2009). Further, several studies have shown that the spatial extent can influence the output of conservation plans (Erasmus *et al.* 1999; Strange *et al.* 2006; Wiersma 2007). While some authors suggested there is need to consider broader spatial extents when planning for biodiversity conservation (under a coordinated spatial planning) (Dobrovolski *et al. 2014* ; Kark *et al.* 2009; Moilanen *et al.* 2013), other authors have argued that a coordinated planning is likely to guide resource allocation to regions with highest diversity or endemism, while other regions may be left entirely without resources, which may not be politically acceptable (Moilanen & Arponen 2011).

Here we use Brazil and bird diversity as our case study. Brazil is a megadiverse country and harbors the second richest avian fauna in the world (the first being Colombia, Lewinsohn & Prado 2005). The country also holds the largest number of IUCN's Critically Endangered bird species (Birdlife International 2011).The first proposition of priority sites for the conservation of Brazil's biodiversity was published in the 1970s, with a focus on the Amazon, and based on the representation of phytogeographic regions (Wetterberg *et al.* 1976). Around of 20 years later, the government also considered species richness, biodiversity importance to traditional populations and indigenous people, and site vulnerability, expanding this proposal to all country. It also established particular conservation targets to each of these features of interest and considered the total area needed for protection as a (poor) proxy to cost (MMA 2007).

Brazil makes an interesting case study because although priority sites for biodiversity protection are defined at the national level (by the Brazilian Environmental Ministry), implementation is done considering the idiosyncrasies of each Brazilian biome (as indicated by the Chico Mendes Institute for Biodiversity Conservation-ICMBio) and, usually, actions are taken at the state level (being a responsibility of State's Environmental Secretariat). Therefore, our aim in this paper was to analyze the cost-effectiveness of spatial conservation plans developed at different geopolitical units and scales of action by building a plan for the whole country, individual plans for each biome, and plans for each state administrative unit. Three main questions motived us: (1) would a fully-coordinated national strategy be more cost-effective than those built at the biome or state level?; (2) is there a trade-off between cost-effectiveness and biodiversity benefits when comparing scales?; and (3) what is the best scale for planning when costs and benefits are equally weighted?

Methods

Species distribution modeling – Because species distribution maps have, in general, coarse resolution tending to overestimate species occurrence and detailed data of distribution of species are not available (Rodrigues 2011; Rondinini *et al.* 2011), we decided to model species' distribution, instead of using extent of occurrence maps. This procedure has been adopted previously to provide finer resolution estimates of species occurrences to use in spatial planning analyses (Elith *et al.* 2006; Guisan & Thuiller 2005; Rondinini *et al.* 2006).

We modeled the distribution of birds occurring in Brazil (1304 species) as a function of abiotic variables using extension occurrence information provided by BirdLife International (Ridgely *et al.* 2007), available at http://www.birdlife.org/datazone/info/spcdownload). We excluded marine biomes from our analysis. We mapped each species in a grid of 3057 cells with a spatial resolution of 0.5°x 0.5° of latitude/longitude (about of 55 kilometers at the equator) covering all the

Brazilian territory. We built a presence-absence matrix from overlapping species' range maps and our grid. Species were considered as present in a grid cell when their range covered more or at least 50% of the cell. We also built a matrix of abiotic variables: altitude and climatic variables (mean temperature of warmest quarter, mean temperature of coldest quarter, annual precipitation and precipitation seasonality). We obtained these variables from of the WorldClim database and they were generated by an interpolated climate data from 1950 to 2000 periods (Hijmans *et al.* 2005).

Many studies have shown that projections coming from alternative species' distribution models can be variable and, in addition, the sensitivity of each species to the models is unknown (Diniz-Filho *et al.* 2009). Therefore, as we were interested in a large number of species, with a range of biological traits and sensibilities unknown, we modeled species' distribution applying an ensemble forecasting approach in which different methods for ecological niche modeling were combined (Araújo & New 2007). This procedure provides more robust consensus forecasts and is especially important for conservation purposes while reducing uncertainties (Araújo & New 2007; Meller *et al.* 2013) that may mislead conservation actions making them less cost-effective (Rangel & Loyola 2012).

We modeled the ecological niche of species using the following methods: Maximum Entropy (MaxEnt; Phillips & Dudik 2008; Phillips *et al.* 2006), Random Forest (Breiman *et al.* 2011), and Genetic Algorithm for Rule Set Production (GARP, Stockwell & Noble 1992). For details about each one of these methods, see Franklin (2009). We chose these machine-learning methods because their predictions are more conservative, i.e. they tend to commit less commission error than distance and statistical methods (Franklin 2009). In practice, it means that the chance of resource misallocation in spatial planning is reduced (on this issue, see Rangel & Loyola 2012).

To build each ecological niche model we partitioned randomly the species data into calibration data (75%) and validation data (25%) replicating this process for 50 times (to run a cross-validation test). We used true skill statistics (TSS) (Allouche *et al.* 2006) as our measure of model performance, given by:

TSS = sensitivity + specificity – 1

where, sensitivity is the proportion correctly identified species presences and specificity is the proportion of correctly identified species absences (both calculated from validation subset). Models with TSS lower than 0.45 were excluded from analyses. Species' occurrence resulting from our ecological niche models was expressed as frequencies of occurrence at which they appear in each cell. Models were calibrated at a resolution of 0.5 x 0.5 of latitude/longitude and then resampled at 0.1° x 0.1° of latitude/longitude, because this resolution allowed us to evaluate how many species occur inside protected areas in Brazil).

Scales of spatial prioritization – To evaluate the cost-effectiveness at different scales of spatial prioritization we applied it at three scales, which reflect the reality of Brazilian conservation actions: national scale (hereafter, coordinated strategy), biome scale (henceforth, partly coordinated strategy), and state scale (hereafter, uncoordinated strategy). Brazil has six terrestrial continental biomes: Amazon, Cerrado, Caatinga, Atlantic Forest, Pampa and Pantanal, classified mainly according to geo-climatic zones and vegetation cover, and their physiognomy varying among forest to savanna and grassland fields (IBGE 2004). Furthermore, Brazil is divided administratively in 27 federal units (26 States and one Federal District). Currently, conservation actions and prioritization are done using these biomes as a base to evaluate and implement conservation actions by the Brazilian government in each state.

Spatial conservation planning - We produced conservation priority rankings creating three scenarios at different scales (country, biome and state) using the Zonation framework and software (freely available at www.helsinki.fi/bioscience/consplan) (Moilanen *et al.* 2004, 2009). The Zonation algorithm generates a nested hierarchical ranking series of units (here, grid cells) maximizing the highest occurrence level (here, the frequency of occurrence of each species) divided by the cost of the cell (here, gross value added to each municipality from agriculture and livestock Industry, see below) accounting for species' range complementarity (Moilanen *et al.* 2009).

The Zonation framework can be divided into two parts: the Zonation meta-algorithm and the cell removal rule. Cell removal rule has several alternatives and determines which cell leads to smallest marginal loss of biodiversity value (i.e. the relative contribution of the cell to achieve the conservation goal) (to details, please, see (Moilanen *et al.* 2004). We used Core Area Zonation as our cell removal rule, which first remove a cell with smallest conservation value (minimum marginal loss of biological value), through calculation of removal index of each cell (Moilanen *et al.* 2009).

We used federal Brazilian protected areas currently established (only strictly protected, i.e. protected areas assigned to IUCN categories I to IV) as a mask layer forcing the inclusion of them in the analyses, indicating areas that complement them and, at same time, forcing exclusion of sites with high population densities (as a proxy to threat, once population density has been associated with species extinction. See Cardillo *et al.* 2004; Eglington & Pearce-Higgins 2012). The spatial data of Brazilian protected areas was taken of Chico Mendes Institute for Biodiversity Conservation (available at http://www.icmbio.gov.br/portal/servicos/geoprocessamento/51-menu-servicos/4004-downloads-mapa-tematico-e-dados-geoestatisticos-das-uc-s.html) and information on population densities was based on the Gridded Population of the World database (available at http://sedac.ciesin.org/gpw).

We also used the gross value added by agriculture and livestock industry in each Brazilian municipality and considered it as a cost layer. Gross value added by agriculture and livestock industry is a measure of production in an economic area subtracted by intermediate consumption and so, we used it as a proxy to opportunity costs of conservation (i.e. the potential economic gains of an area, according to a landowner perspective). We obtained these data from the Brazilian Institute of Geography and Statistics - IBGE (available at http://www.ibge.gov.br/home/estatistica/economia/pibmunicipios/2010).

Thus, we analyzed the cost-effectiveness of each spatial level of prioritization. Also, we assessed average species' extinction risk (as a function of a species-area relationship using a power-law model) and the percentage of species' distribution protected at each level as our measure of conservation benefit (both are Zonation outputs). Finally, as Brazil is a signatory to the Convention of Biological Diversity (CBD), for practical purposes, we show here only the top 17% sites of landscape to be protected at each scenario following the target proposed by the Aichi Biodiversity Targets for terrestrial environment to 2020 (CDB 2010).

Results

As expected, the spatial location of priority sites changed according to prioritization strategies (Fig. 1). Under the coordinated strategy (country scale) priority sites tend to be more clustered than under the partially coordinated (biome scale) and the uncoordinated strategy (states scale) (Fig. 1A). Further, in this coordinated strategy most priority sites are located in the northeast-southeast axis and northern part of the country. On the other hand, both the partially and uncoordinated strategies had priority sites scattered throughout the country (Fig. 1B and C).

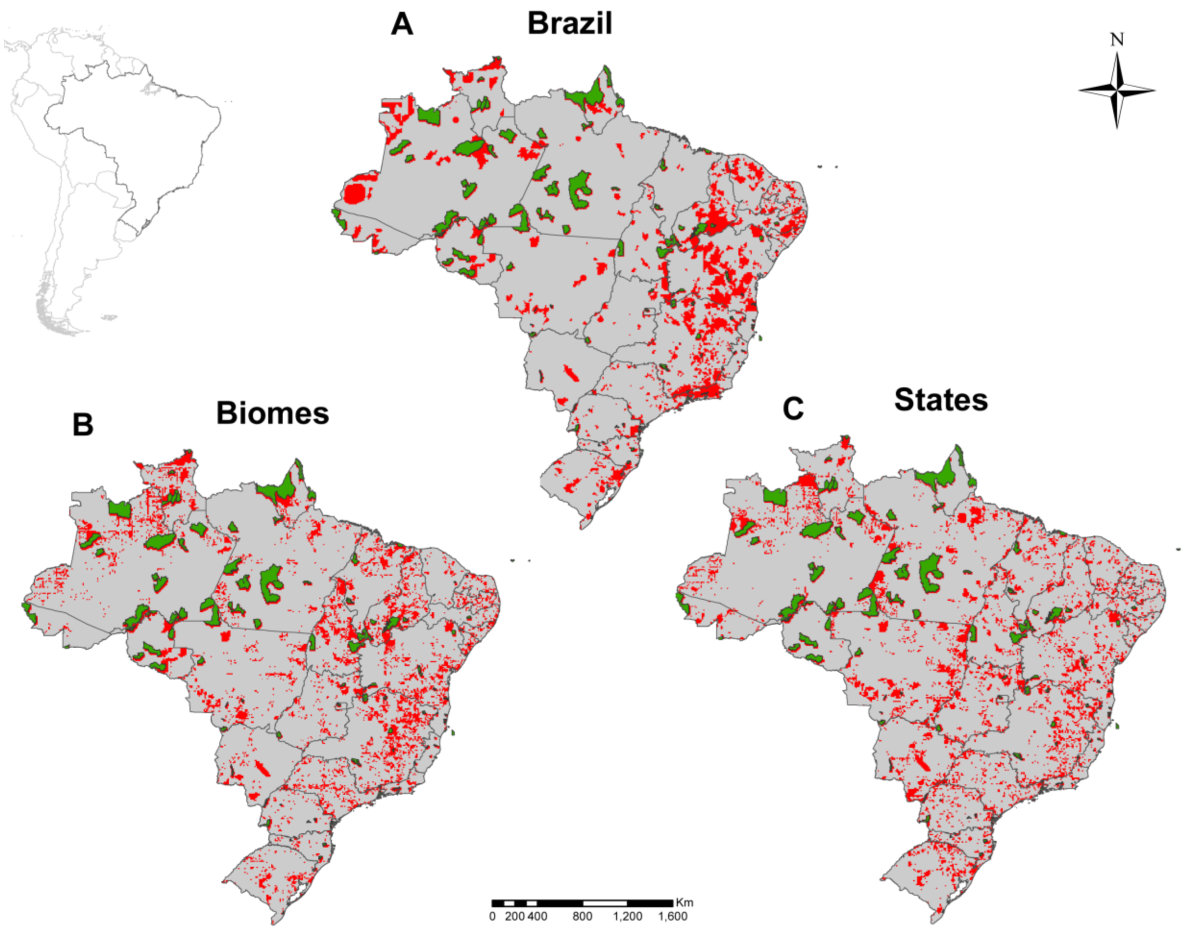

Figure 1. Priorities sites for the conservation of birds in Brazil developed at different scales of spatial prioritization: (A) national level – coordinated strategy, (B) biome level - partly coordinated strategy, and (C) state level, uncoordinated strategy. All analyses considered the gross value added by agriculture and livestock as a proxy to opportunity costs of conservation, and population densities as a proxy to threat. The target considered was of 17% of total area

surface. Red polygons represent priorities sites. Green polygons represent Brazilian strict Protected Areas (IUCN I-IV categories).

The cost-effectiveness of spatial plans also varied according to our strategies. The coordinated strategy held the lowest cost (Table 1). For comparison purposes we considered this coordinated strategy as our baseline (i.e. cost defined as 100%). In this comparison, the average cost of the uncoordinated strategy was around six times more expensive than that of a coordinated one, whereas the average cost of the partly coordinated strategy was much higher (ten times that for the coordinated strategy). In others words, average cost to protect 17% of area in each state or biome is much higher when the spatial planning is done individually by each of these units than when done at the national level.

Table 1: Total cost of conservation strategies that selected top 17% of area surface relative to different scales of spatial prioritization: national level – coordinated strategy, biome level - partly coordinated strategy, and state level, uncoordinated strategy.

	Coordinated	Partly coordinated	Uncoordinated
Total Area (17%)	15.1 ($x10^6$ km^2)	2.5 ($x10^6$ km^2)	0.6 ($x10^6$ km^2)
Total Cost	100%	1123%	626%
Average % of species' range protection	18.2%	20.0%	18.4%
Average species' extinction Risk	36.2%	38.0%	44.7%

In addition to higher costs of conservation action, when prioritization is not planned under a coordinated strategy, average species' extinction risk is also higher (Table 1). The percentage of species' distribution protected in each approach is similar between the coordinated and uncoordinated strategy, and a little higher in the partly coordinated strategy (Table 1). Further, the relative contribution (in number of grid cells) destined to conservation at each unit (into biomes or states) also varies according to prioritization approaches. Hence, some units have more or less sites selected in the prioritization according to each spatial planning strategy (Table S1 and S2). For example, the Atlantic Forest, Caatinga and Pampa had more sites selected in the coordinated than in the uncoordinated strategy (Table S1). Also, the state of Rio de Janeiro contributed more, whereas the state of São Paulo contributed less, in the coordinated strategy (Table S2).

Discussion

We showed that a coordinated strategy for prioritizing sites undertaken at the national level is more cost-effective and carry higher (or similar) biodiversity benefits than those planned at smaller scales, such as biomes or federal states in Brazil. Under a coordinated strategy, trade-offs between costs and biological value are easier to understand and to solve, then priorities sites can be selected for minimizing opportunity costs across the space (Larsen *et al.* 2009).

Strategies and actions that do not consider the human dimensions of the conservation problem do not offer good solutions that avoid likely land use conflicts, being of little help for on-the-ground implementation of actions (Knight *et al.* 2008). Thus, here we corroborate previous analyses, which showed that coordinated strategies are indeed more cost-effective (Bladt *et al.* 2009; Kark *et al.* 2009; Strange *et al.* 2006). In the Mediterranean Basin, for example, coordinated strategy for biodiversity protection implemented at the European Union level is significantly more efficient than separate plans developed by each country (Kark *et al.* 2009). The same pattern was found to Western Hemisphere prioritization exercises, where continental and at each country scale was compared (Moilanen *et al.* 2013). Furthermore, Dobrovolski *et al.*

(2014) found that higher-level coordinated strategies could result in almost 80% of opportunity cost reduction while implement protected areas, increasing also biodiversity protection.

Although our analyses carry scientific methods and information to spatial planning, they do not intent to represent a final decision of where to place new protected areas, rather they show that coordinated actions can deliver more cost-effective strategies, but they do not substitute on-the-ground conservation actions (Knight *et al.* 2009). The maintenance of natural habitats generates benefits for all society, but from the perspective of the landowner, it means giving up high economic return on investment. Therefore, it is clearly necessary to consider other socioeconomic and cultural information in the process of area selection and negotiation with all stakeholders (Margules & Pressey 2000; Sarkar & Illoldi-Rangel 2010). Note that although we suggest a coordinated strategy for planning for the conservation of biodiversity, the database-building phase (i.e. biological and socioeconomic data capturing, cleaning and processing) should be conducted at the regional scale to improve data quality that will feed spatial plans at the national level.

It has been argued that costs of protection are higher in uncoordinated planning mainly because it demands multiple representation of species (or other biological features) when their ranges extends beyond more than one operational unit, and also, because of the occurrence of many widespread species (across the entire region) becoming rare in some of the units when part of their range are cut-off, therefore requiring additional areas (Moilanen *et al.* 2013; Rodrigues & Gaston 2002). In addition to higher cost-effectiveness of the coordinated strategy, priority areas tend to be more clustered than in other approaches, explaining also the lower extinction risk we found in the coordinated strategy.

Our coordinated strategy had major relative contribution to priorities areas in Amazon and Caatinga, contrasting with previously prioritization done by Brazilian governments which showed Amazon and Atlantic Forest as the sites with major relative contribution (MMA 2007). However, we should bear in mind that this previous prioritization did not take into account opportunity cost either population densities. The opportunity cost of some regions, such as those found in Cerrado biome is higher than Caatinga region, influencing the area selection as a result of a trade-off between biological and socioeconomics values. Our approach has the advantage of incorporating opportunity cost at different scales of spatial planning showing that when this layer is taken into account, priorities areas maps change to region with less opportunity cost. Specially in Brazil, this is a concern issue to deal with biological conservation due to strong power of ruralist politicians to take decisions about conservation laws which could decrease economic gains to landowner, translated as opportunity cost (see recent debate about changes in Forest Act in Brazil (Lewinsohn 2010; Metzger 2014). Thus, in addition to less money needed to implement reserves, it is also important to decrease social conflicts making conservation planning more real to be applied on-the-ground (Knight *et al.* 2008). Finally, in our analyses we did not limit the budget that could be applied for implementing the plans, while our goal was not to provide a detailed conservation work plan, but rather to compare different coordination scenarios. In practival terms, what determines better conservation strategies and actions is the relative, not the absolute, economic costs.

Due to current resource paucity allocated to conservation, it is critical to develop more cost-effective plans if we are seeking for successful spatial planning and biological conservation. Though conservation actions in Brazil has evolved to consider the core principles of systematic conservation planning (Wilson *et al.* 2009), priority-site selection still requiring more socioeconomics information reducing conflicts and increase efficiency. Thus, our work showed that we could be successful to deal with gains both for biological conservation and for agriculture and livestock industry if we consider socio-economic cost and also keep comprehensive view through an implementation of coordinated strategy conservation plan.

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Supporting information

Table S1. Relative contribution (in % of grid cells) indicated as priority at each Brazilian biome following an uncoordinated and a coordinated approach, and difference between them.

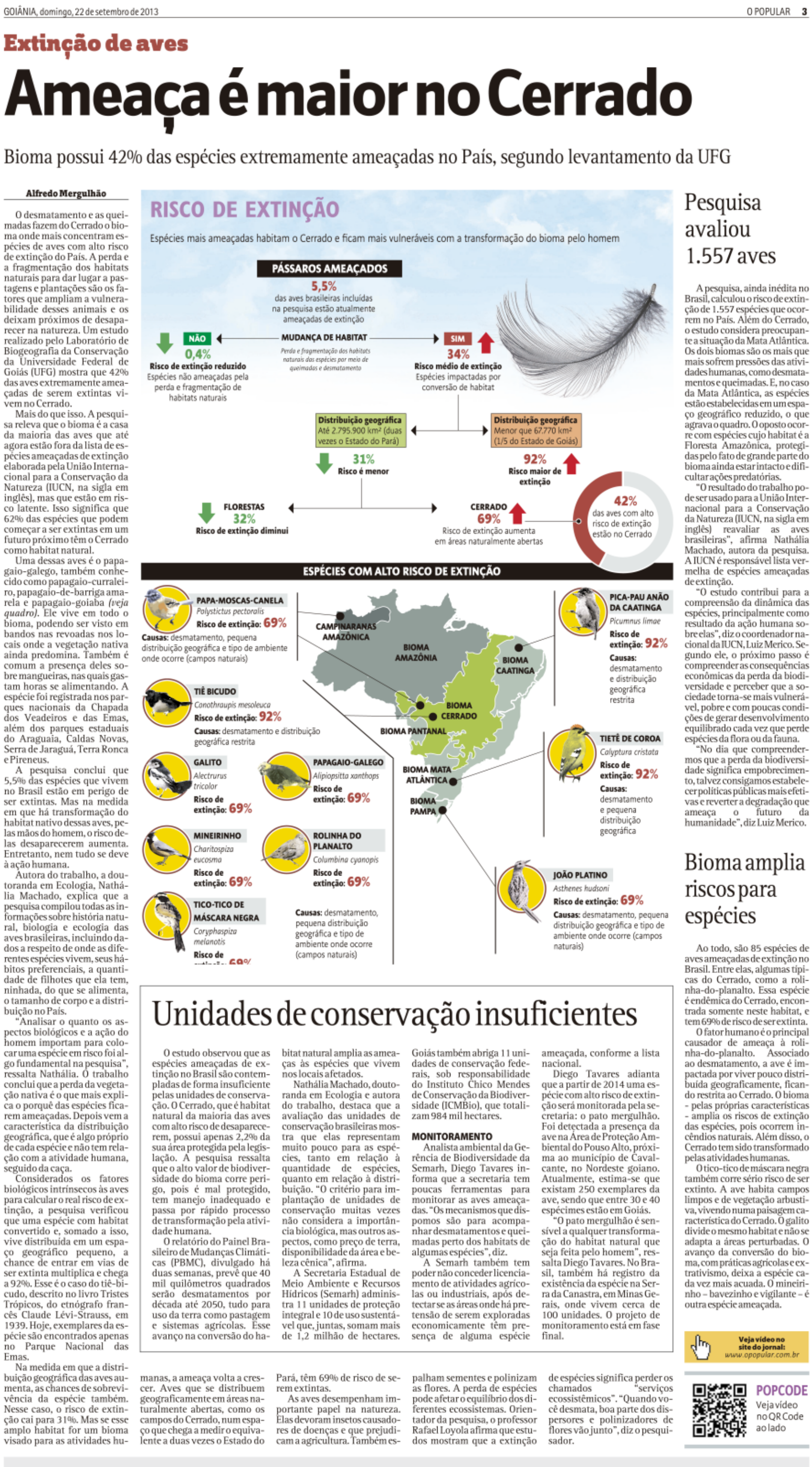
Biomes	Uncoordinated (%)	Coordinated (%)	Difference (%)
Amazon	48.8	44.2	-4.6
Atlantic Forest	13.1	16.1	3.0
Caatinga	10.0	18.9	8.9
Cerrado	23.8	16.8	-7.0
Pampa	2.5	3.7	1.1
Pantanal	1.7	0.3	-1.4

Table S2. Relative contribution (in % of grid cells) indicated as priority at each Brazilian State, following an uncoordinated and a coordinated approach, and difference between them.

Brazilian States	Uncoordinated (%)	Coordinated (%)	Difference
Acre	1.9	2.5	0.6
Alagoas	0.4	0.8	0.4
Amazonas	18.2	19.7	1.5
Amapá	1.8	5.0	3.2
Bahia	6.9	11.7	4.8
Ceará	1.8	2.3	0.5
Distrito Federal	0.1	0.1	0.0
Espírito Santo	0.6	0.4	-0.2
Goiás	4.2	2.0	-2.2
Maranhão	4.0	1.5	-2.5
Minas Gerais	6.9	10.0	3.1
Mato Grosso do Sul	4.3	1.3	-3.1
Mato Grosso	10.6	4.7	-5.9
Pará	14.0	7.8	-6.2
Paraíba	0.8	1.1	0.4
Pernambuco	1.0	1.7	0.7
Piauí	2.6	6.4	3.8
Paraná	2.6	1.8	-0.8
Rio de Janeiro	0.6	2.0	1.4
Rio Grande do Norte	0.5	0.7	0.1
Rondônia	2.7	3.9	1.2
Roraima	2.6	3.9	1.3
Rio Grande do Sul	3.8	3.4	-0.4
Santa Catarina	1.1	0.9	-0.2
Sergipe	0.2	0.1	-0.1
São Paulo	2.9	1.9	-1.0
Tocantins	2.9	2.4	-0.5

ANEXOS

Matéria publicada em 22 de setembro de 2013, no jornal *O Popular* sobre manuscrito "*A comprehensive quantitative assessment of bird extinction risk in Brazil*" apresentado no capítulo 1 da presente tese.



GOIÂNIA, domingo, 22 de setembro de 2013 — O POPULAR 3

Extinção de aves

Ameaça é maior no Cerrado

Bioma possui 42% das espécies extremamente ameaçadas no País, segundo levantamento da UFG

Alfredo Mergulhão

O desmatamento e as queimadas fazem do Cerrado o bioma onde mais concentram espécies de aves com alto risco de extinção do País. A perda e a fragmentação dos habitats naturais para dar lugar a pastagens e plantações são os fatores que ampliam a vulnerabilidade desses animais e os deixam próximos de desaparecer na natureza. Um estudo realizado pelo Laboratório de Biogeografia da Conservação da Universidade Federal de Goiás (UFG) mostra que 42% das aves extremamente ameaçadas de serem extintas vivem no Cerrado.

Mais do que isso. A pesquisa releva que o bioma é a casa da maioria das aves que até agora estão fora da lista de espécies ameaçadas de extinção elaborada pela União Internacional para a Conservação da Natureza (IUCN, na sigla em inglês), mas que estão em risco latente. Isso significa que 62% das espécies que podem começar a ser extintas em um futuro próximo têm o Cerrado como habitat natural.

Uma dessas aves é o papagaio-galego, também conhecido como papagaio-curraleiro, papagaio-de-barriga amarela e papagaio-goiaba *(veja quadro)*. Ele vive em todo o bioma, podendo ser visto em bandos nas revoadas nos locais onde a vegetação nativa ainda predomina. Também é comum a presença deles sobre mangueiras, nas quais gastam horas se alimentando. A espécie foi registrada nos parques nacionais da Chapada dos Veadeiros e das Emas, além dos parques estaduais do Araguaia, Caldas Novas, Serra de Jaraguá, Terra Ronca e Pireneus.

A pesquisa conclui que 5,5% das espécies que vivem no Brasil estão em perigo de ser extintas. Mas na medida em que há transformação do habitat nativo dessas aves, pelas mãos do homem, o risco delas desaparecerem aumenta. Entretanto, nem tudo se deve à ação humana.

Autora do trabalho, a doutoranda em Ecologia, Nathália Machado, explica que a pesquisa compilou todas as informações sobre história natural, biologia e ecologia das aves brasileiras, incluindo dados a respeito de onde as diferentes espécies vivem, seus hábitos preferenciais, a quantidade de filhotes que ela tem, ninhada, do que se alimenta, o tamanho de corpo e a distribuição no País.

"Analisar o quanto os aspectos biológicos e a ação do homem importam para colocar uma espécie em risco foi algo fundamental na pesquisa", ressalta Nathália. O trabalho conclui que a perda da vegetação nativa é o que mais explica o porquê das espécies ficarem ameaçadas. Depois vem a característica da distribuição geográfica, que é algo próprio de cada espécie e não tem relação com a atividade humana, seguido da caça.

Considerados os fatores biológicos intrínsecos às aves para calcular o real risco de extinção, a pesquisa verificou que uma espécie com habitat convertido e, somado a isso, vive distribuída em um espaço geográfico pequeno, a chance de entrar em vias de ser extinta multiplica e chega a 92%. Esse é o caso do tiê-bicudo, descrito no livro Tristes Trópicos, do etnógrafo francês Claude Lévi-Strauss, em 1939. Hoje, exemplares da espécie são encontrados apenas no Parque Nacional das Emas.

Na medida em que a distribuição geográfica das aves aumenta, as chances de sobrevivência da espécie também. Nesse caso, o risco de extinção cai para 31%. Mas se esse amplo habitat for um bioma visado para as atividades humanas, a ameaça volta a crescer. Aves que se distribuem geograficamente em áreas naturalmente abertas, como os campos do Cerrado, num espaço que chega a medir o equivalente a duas vezes o Estado do Pará, têm 69% de risco de serem extintas.

As aves desempenham importante papel na natureza. Elas devoram insetos causadores de doenças e que prejudicam a agricultura. Também espalham sementes e polinizam as flores. A perda de espécies pode afetar o equilíbrio dos diferentes ecossistemas. Orientador da pesquisa, o professor Rafael Loyola afirma que estudos mostram que a extinção de espécies significa perder os chamados "serviços ecossistêmicos". "Quando você desmata, boa parte dos dispersores e polinizadores de flores vão junto", diz o pesquisador.

Unidades de conservação insuficientes

O estudo observou que as espécies ameaçadas de extinção no Brasil são contempladas de forma insuficiente pelas unidades de conservação. O Cerrado, que é habitat natural da maioria das aves com alto risco de desaparecerem, possui apenas 2,2% da sua área protegida pela legislação. A pesquisa ressalta que o alto valor de biodiversidade do bioma corre perigo, pois é mal protegido, tem manejo inadequado e passa por rápido processo de transformação pela atividade humana.

O relatório do Painel Brasileiro de Mudanças Climáticas (PBMC), divulgado há duas semanas, prevê que 40 mil quilômetros quadrados serão desmatamentos por década até 2050, tudo para uso da terra como pastagem e sistemas agrícolas. Esse avanço na conversão do habitat natural amplia as ameaças às espécies que vivem nos locais afetados.

Nathália Machado, doutoranda em Ecologia e autora do trabalho, destaca que a avaliação das unidades de conservação brasileiras mostra que elas representam muito pouco para espécies, tanto em relação à quantidade de espécies, quanto em relação à distribuição. "O critério para implantação de unidades de conservação muitas vezes não considera a importância biológica, mas outros aspectos, como preço de terra, disponibilidade da área e beleza cênica", afirma.

A Secretaria Estadual de Meio Ambiente e Recursos Hídricos (Semarh) administra 11 unidades de proteção integral e 10 de uso sustentável que, juntas, somam mais de 1,2 milhão de hectares. Goiás também abriga 11 unidades de conservação federais, sob responsabilidade do Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio), que totalizam 984 mil hectares.

MONITORAMENTO

Analista ambiental da Gerência de Biodiversidade da Semarh, Diego Tavares informa que a secretaria tem poucas ferramentas para monitorar as aves ameaçadas. "Os mecanismos que dispomos são para acompanhar desmatamentos e queimadas perto dos habitats de algumas espécies", diz.

A Semarh também tem poder não conceder licenciamento de atividades agrícolas ou industriais, após detectar se as áreas onde há pretensão de serem exploradas economicamente têm presença de alguma espécie ameaçada, conforme a lista nacional.

Diego Tavares adianta que a partir de 2014 uma espécie com alto risco de extinção será monitorada pela secretaria: o pato mergulhão. Foi detectada a presença da ave na Área de Proteção Ambiental do Pouso Alto, próxima ao município de Cavalcante, no Nordeste goiano. Atualmente, estima-se que existam 250 exemplares da ave, sendo que entre 30 e 40 espécimes estão em Goiás.

"O pato mergulhão é sensível a qualquer transformação do habitat natural que seja feita pelo homem", ressalta Diego Tavares. No Brasil, também tem registro da existência da espécie na Serra da Canastra, em Minas Gerais, onde vivem cerca de 100 unidades. O projeto de monitoramento está em fase final.

Pesquisa avaliou 1.557 aves

A pesquisa, ainda inédita no Brasil, calculou o risco de extinção de 1.557 espécies que ocorrem no País. Além do Cerrado, o estudo considera preocupante a situação da Mata Atlântica. Os dois biomas são os mais que mais sofrem pressões das atividades humanas, como desmatamentos e queimadas. E, no caso da Mata Atlântica, as espécies estão estabelecidas em um espaço geográfico reduzido, o que agrava o quadro. O oposto ocorre com espécies cujo habitat é a Floresta Amazônica, protegidas pelo fato de grande parte do bioma ainda estar intacto e dificultar ações predatórias.

"O resultado do trabalho pode ser usado para a União Internacional para a Conservação da Natureza (IUCN, na sigla em inglês) reavaliar as aves brasileiras", afirma Nathália Machado, autora da pesquisa. A IUCN é responsável lista vermelha de espécies ameaçadas de extinção.

"O estudo contribui para a compreensão da dinâmica das espécies, principalmente como resultado da ação humana sobre elas", diz o coordenador nacional da IUCN, Luiz Merico. Segundo ele, o próximo passo é compreender as consequências econômicas da perda da biodiversidade e perceber que a sociedade torna-se mais vulnerável, pobre e com poucas condições de gerar desenvolvimento equilibrado cada vez que perde espécies da flora ou da fauna.

"No dia que compreendermos que a perda da biodiversidade significa empobrecimento, talvez consigamos estabelecer políticas públicas mais efetivas e reverter a degradação que ameaça o futuro da humanidade", diz Luiz Merico.

Bioma amplia riscos para espécies

Ao todo, são 85 espécies de aves ameaçadas de extinção no Brasil. Entre elas, algumas típicas do Cerrado, como a rolinha-do-planalto. Essa espécie é endêmica do Cerrado, encontrada somente neste habitat, e tem 69% de risco de ser extinta.

O fator humano é o principal causador de ameaça à rolinha-do-planalto. Associado ao desmatamento, a ave é impactada por viver pouco distribuída geograficamente, ficando restrita ao Cerrado. O bioma - pelas próprias características - amplia os riscos de extinção das espécies, pois ocorrem incêndios naturais. Além disso, o Cerrado tem sido transformado pelas atividades humanas.

O tico-tico de máscara negra também corre sério risco de ser extinto. A ave habita campos limpos e de vegetação arbustiva, vivendo numa paisagem característica do Cerrado. O galito divide o mesmo habitat e não se adapta a áreas perturbadas. O avanço da conversão do bioma, com práticas agrícolas e extrativismo, deixa a espécie cada vez mais acuada. O mineirinho – bavezinho e vigilante – é outra espécie ameaçada.

Veja vídeo no site do jornal: www.opopular.com.br

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Matéria publicada na Revista Pesquisa Fapesp, em dezembro de 2013

Critérios ignorados

revistapesquisa.fapesp.br/2013/12/20/criterios-ignorados/


O fim-fim (*Euphonia chlorotica*) é uma pequena ave brasileira que habita ambiente de floresta

Mudanças ambientais, provocadas ou não pela ação do homem, têm impacto na vida selvagem e estão refletidas na extensão da Lista Vermelha de Espécies Ameaçadas publicada pela União Internacional para a Conservação da Natureza (IUCN, na sigla em inglês). A listagem com 71.576 nomes de animais, plantas, fungos e microrganismos é a base para a elaboração de políticas de conservação mundo afora. No entanto, pesquisadores da Universidade Federal de Goiás (UFG) sustentam que a lista não deve ser o parâmetro único para planejar ações de conservação, pois aspectos ignorados pela IUCN podem colocar em xeque o êxito das medidas. Os pesquisadores brasileiros sustentam que é necessário avaliar a saúde dos ecossistemas em sua totalidade e não tomar isoladamente o risco de extinção de cada espécie.

Para fornecer dados mais fidedignos, os pesquisadores da UFG criaram um modelo para quantificar o risco de desaparecimento das espécies. Quase todas as aves do Brasil constam da tabulação feita para o trabalho científico, somando 1.557 espécies. Os brasileiros foram abrangentes, levaram em conta dados como a influência humana (caça, comércio ilegal, desmatamento), dieta dos animais (se se alimentam de frutas, folhas, insetos), além do ambiente em que vivem (floresta, ambiente aberto, savana), os hábitos (noturno ou diurno), a quantidade de ovos por ninhada e o tamanho dos bichos, além de 15 outras variáveis.

"Aplicando nosso modelo, somos capazes de prever se o animal ou planta têm, por exemplo, 30%, 40% ou 80% de chance de se extinguir em determinado momento. Descobrimos que a maioria dos exemplares de aves mais ameaçados de nosso país não estão sequer em áreas protegidas", explica o professor Rafael Loyola, co-autor, com a doutoranda Nathália Machado, do artigo *A Comprehensive Quantitative Assessment of Bird Extinction Risk in Brazil* , publicado na edição de agosto da revista *PLoS ONE*.

A IUCN, por outro lado, aplica somente 12 critérios para definir se uma espécies está em perigo ou não. Tamanho da população, número de indivíduos maduros, taxa de declínio, fragmentação das populações e área de ocorrência são alguns das variáveis usadas. Dessa forma, cada espécie recebe da IUCN uma etiqueta específica – dados insuficientes (DD), pouco preocupante (LC), quase ameaçada (NT), vulnerável (VU), em perigo (EN), criticamente em perigo (CR), extinta na natureza (EW) e extinta (EX).

Os pesquisadores esperam que o modelo auxilie em mais um parâmetro, a probabilidade de extinção, capaz de melhorar o planejamento das políticas ambientais. "O estudo amplia o conhecimento sobre o grau de ameaça das espécies e isso tem um peso político enorme, porque o governo só tem condições de tomar decisões mais eficientes quando conhece o nível de ameaça a uma espécie. Por exemplo, pode-se intensificar a fiscalização a uma região específica ou criar áreas de preservaçã para impedir a degradação daquele ecossistema", afirma Loyola.

Características ecológicas e histórias evolutivas

O outro artigo produzido pelo Departamento de Ecologia da UFG, intitulado *Conservation Actions Based on Red Lists Do Not Capture the Functional and Phylogenetic Diversity of Birds in Brazil* e também publicado na edição de setembro da revista *PLo ONE*, aprofunda o entendimento sobre as características ecológicas e histórias evolutivas de cada ave brasileira no ecossistema em que vive. São aspectos pouco avaliados pelas políticas de conservação, e isso inclui a Lista Vermelha da IUCN.

O objetivo dos cientistas foi avaliar o nível de diversidade funcional e de diversidade filogenética de ambientes para saber se o mesmos são saudáveis. Com essa informação em mãos, contam os autores do estudo, a aplicação de políticas de conservação teria maior impacto. A classificação poderia, por exemplo, ajudar a determinar quais regiões terão melhor resultado dentre aquelas que já estão muito degradadas, e que precisam de outras intervenções.

(cont. da matéria publicada na Revista Pesquisa Fapesp, em dezembro de 2013.)

O nível de diversidade funcional diz respeito à diferença ecológica entre as espécies presentes nos ecossistemas. Quanto mais alto é o índice, mais "saudável" é o local, porque ali existem espécies com múltiplas funções e isso garante o equilíbrio natural. "Quando há espécies ecologicamente muito diferentes habitando o mesmo ambiente, espera-se achar ali aves que desempenhem papéis diversos, tais como dispersão de sementes, polinização e predação, diz o professor Loyola, que também participou do estudo, e que tem co-autoria do mestrando José Hidasi Neto e de Marcus Cianciaruso, também professor da UFG.

Já o nível de diversidade filogenética indica o quão diferente são as espécies daquele ambiente do ponto de vista evolutivo. "Usamos como exemplo a ema, que é uma grande ave que não voa e ocorre em áreas abertas, ao contrário do fim-fim (*Euphonia chlorotica*), que é pequeno e habita ambiente de floresta. Essas várias linhagens (ou grupos evolutivos) convivendo na mesma área atestam a saúde de todo do ecossistema", explica Loyola.

Tweet

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