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

**José Hidasi Neto**

**CONSERVAÇÃO DE DIVERSIDADE FUNCIONAL E FILOGENÉTICA:  
IDENTIFICANDO PADRÕES E DEFININDO PRIORIDADES**

**Orientador: Dr. Marcus Vinicius Cianciaruso**

**Co-orientador: Dr. Rafael Dias Loyola**

**Goiânia-GO  
Março de 2014**

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País:	Brasil	UF: GO	CNPJ: 036.017.781-65
Título:	Conservação de diversidade funcional e filogenética: identificando padrões e definindo prioridades		
Palavras-chave:	Biodiversidade, Conservação, Diversidade Funcional, Diversidade Filogenética, Aves, Mamíferos.		
Título em outra língua:	Conservation of functional and phylogenetic diversity: identifying patterns and defining priorities		
Palavras-chave em outra língua:	Biodiversity, Conservation, Functional Diversity, Phylogenetic Diversity, Birds, Mammals.		
Área de concentração:	Biodiversidade		
Data defesa: (dd/mm/aaaa)	17/02/2014		
Programa de Pós-Graduação:	Ecologia e Evolução		
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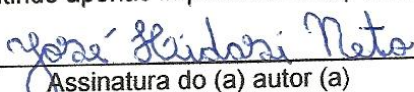
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Dissertação apresentada à Universidade Federal de Goiás, como parte das exigências do Programa de Pós-graduação em Ecologia e Evolução para obtenção do título de *Magister Scientiae*.

**Goiânia-GO  
Março de 2014**

**Dados Internacionais de Catalogação na Publicação na (CIP)  
GPT/BC/UFG**

Hidasi-Neto, José.  
H632c Conservação de diversidade funcional e filogenética:  
identificando padrões e definindo prioridades [manuscrito] /  
José Hidasi Neto. - 2014.  
vii, 65 f. : il., figs, tabs.

Orientador: Prof. Dr. Marcus Vinicius Cianciaruso; Co-  
orientador: Prof. Dr. Rafael Dias Loyola  
Dissertação (Mestrado) ó Universidade Federal de Goiás,  
Instituto de Ciências Biológicas, 2014.  
Bibliografia.

1. Biodiversidade ó Conservação 2. Diversidade  
Funcional 4. Diversidade Filogenética 5. Aves ó Brasil ó  
Extinção 6. Mamíferos ó Brasil ó Preservação I. Título.

CDU: 574.1



sé Hidasi Neto

## CONSERVAÇÃO DE DIVERSIDADE FUNCIONAL E FILOGENÉTICA: IDENTIFICANDO PADRÕES E DEFININDO PRIORIDADES

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

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*"Stop with all the lies', all the questions so confusing  
Answer the riddles they deny, losing hope, the child cries*

*Dream onõ*

*Do you believeõ all the things that you're seeing are true?*

*The start's where the end's leading you*

*Do you believeõ all's as twisted as one would perceive?*

*Seek the answersõ and soon you'll believe"*

Through The Looking Glass  
(Música do grupo Symphony X)





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Agradeço aos presentes e ausentes que me ajudaram a alcançar este novo degrau em minha vida acadêmica. Cada filósofo, cientista ou político teve seu papel para que eu pudesse beber da fonte do conhecimento humano. Cada um dos meus familiares contribuiu para o meu desenvolvimento sociocultural. Cada amigo me ajudou a manter minha estabilidade emocional. Claro, não me esquecendo de cada professor que transformou a minha realidade em relação ao mundo natural.

Os professores do departamento de Ecologia merecem um agradecimento especial no que se diz respeito ao meu aprendizado. Meu orientador, Marcus Cianciaruso, foi capaz de me tornar muito mais independente como cientista. Se hoje consigo pensar em hipóteses e discutir sobre elas, foi graças ao trabalho dele. Devo lembrar-me também do meu co-orientador, Rafael Loyola, que teve contribuições indispensáveis nos trabalhos em que participei. Agradeço ao Mário Almeida pelas minhas experiências como monitor durante a disciplina de Métodos em Ecologia (para o curso de Ecologia e Análise Ambiental). Ao Adriano Melo, por ter me incentivado a criar meu blog, [rfunctions.blogspot.com](http://rfunctions.blogspot.com), que me deu mais vontade de ler e escrever sobre assuntos relacionados à Estatística e Ecologia. Também aos professores que ministraram disciplinas em que participei: Bini, Daniel Brito, Guida, Joaquin Hortal, José Alexandre, Paulo De Marco e Thiago Rangel.

Meu grande amigo Nelson Silva Pinto não só discutiu comigo sobre tudo o que aprendemos nesses últimos dois anos, mas também me mostrou o final do Resident Evil 2 e do Code Veronica. Nelson, valeu pelo %aAnd Justice For All! O pessoal do RPG também merece um lugar especial aqui. Esses são os nerds: Lucas Marques (O Mestre), Eu (Haast), Carlos Klein (Bran Maverick), Pedro Henrique (The Unnamed), Poliana Mendes (Lyra Seldon) e Zander Augusto (Kleber). Franciele

rubiatabense mais legal que existe! Davi Alves, Fernando Landa, Lucas Jardim (Douglas), Marcos Vieira, Marina Zanin e Nathália Machado, vocês foram ótimos colegas nesses dois anos. Pessoal do curso de Ecologia da Floresta Amazônica (EFA 2012), vocês possuem um local especial na minha memória (Ludmila e Vidal, sobrevivemos!). Relembro ainda dos meus amigos da época da graduação: Amanda Rafaela, Bárbara Regina, Fabyano Alvares, Leonardo Vergara e Vivian Ribeiro.

A minha família sempre me propiciou ótimas condições de estudo e, por isso, agradeço a ela por tudo o que um dia já alcancei. Em especial, minha mãe, Solanita Wanderley Hidasi, merece todos os agradecimentos possíveis por nunca ter deixado de me incentivar a buscar o meu sonho de ser cientista. Minhas irmãs, Ayra, Bárbara, Christine e Hilari são sempre a minha inspiração para alcançar aquilo que me parece impossível. Meu avô, José Hidasi, também sempre serviu de inspiração para a minha busca pelo conhecimento e foi o maior motivo por eu ter seguido o estudo da vida. Agradeço ainda à minha namorada, Patrícia de Souza Toledo, e sua família, por terem sido tão importantes na minha vida durante este período especial da minha vida.

Reconheço também o relevante auxílio financeiro da bolsa de pesquisa concedida pela Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) para a realização deste presente trabalho. Por fim, agradeço a todos aqueles que eu possa ter esquecido de mencionar aqui e encorajo todos os que leem este texto a terem essa experiência de estudo fascinante que é o Mestrado.



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Listas vermelhas de espécies ameaçadas categorizam os organismos vivos de acordo com a proximidade de serem extintos. Entretanto, essas listas ignoram diferenças ecológicas e evolutivas entre as espécies. Para determinar se ações conservacionistas baseadas em LV são efetivas para a proteção da diversidade funcional (FD, do inglês %functional diversity) e filogenética (PD, do inglês %phylogenetic diversity) de comunidades naturais precisamos saber se categorias de ameaça das LV possuem espécies com atributos ecológicos e histórias evolutivas distintas. Além disso, como espécies normalmente interagem em escala local, essa escala seria a mais indicada para quantificar perdas consideráveis de FD e PD. Sendo assim, no Capítulo 1, utilizamos 21 características ecológicas e as relações filogenéticas para todas as aves do Brasil a fim de determinar se espécies em categorias de ameaça das Listas Vermelhas global da IUCN, brasileira, e de seis estados brasileiros representam perdas maiores de FD e PD do que seria esperado pela extinção aleatória de aves. Analisamos a eficiência das listas vermelhas em escala nacional, regional e local, esperando que a FD e PD de aves fosse melhor representada na escala local, pois é nela onde ocorrem as interações bióticas. Encontramos que, independente da escala, as categorias de ameaça das Listas Vermelhas capturaram, de maneira geral, perdas de FD e PD iguais ou menores ao esperado ao acaso. Portanto, ações conservacionistas baseadas somente nas categorias das Listas Vermelhas não protegem mais FD e PD das aves brasileiras do que se o mesmo número de espécies (em cada categoria) fosse preservado ao acaso. No capítulo 2, sugerimos uma forma de integrar o grau de ameaça, atributos ecológicos e história evolutiva para medir o nível de prioridade de conservação de espécies. Utilizamos esse protocolo para medir a prioridade de conservação dos mamíferos do mundo. De modo geral, espécies mais prioritárias tenderam a ser mais ameaçadas, além de estarem concentradas nas regiões de alguns hotspots de biodiversidade, como o Cerrado, Indo-Burma, Mata Atlântica e Sundaland. Esses resultados possuem grandes consequências na conservação de espécies pois categorias de LV são normalmente utilizadas como ferramentas para a formulação de políticas relacionadas à conservação da biodiversidade.

**Palavras-chave:** Biologia da conservação, Listas Vermelhas, Ecologia de comunidades, extinção, priorização de espécies, aves, mamíferos.

O presente trabalho está organizado em dois capítulos referentes à identificação de padrões e definição de prioridades relacionadas à conservação de componentes da biodiversidade que só recentemente começaram a ser considerados na Biologia da Conservação. Esses componentes representam as diferenças que as espécies possuem nas suas características ecológicas (referentes aos seus nichos ou papéis funcionais no ambiente) e na história evolutiva de grupos biológicos. Os parágrafos a seguir apresentam uma breve introdução sobre as ideias abordadas nos capítulos deste trabalho.

Ao longo da história da vida na Terra, a extinção se apresentou como um fenômeno muito comum. Sabemos que a grande maioria das espécies que habitaram o planeta (cerca de 99%) já desapareceu (Novacek, 2001). Em certos períodos do tempo geológico, ocorreram taxas expressivamente altas de extinção em comparação com outros períodos e que foram responsáveis pelo desaparecimento de mais de 75% das espécies da época (Jablonski, 1994; Barnosky et al., 2011). Atualmente, é muito provável que estejamos presenciando um novo grande evento de extinção em massa desde aproximadamente 540 milhões de anos atrás (Barnosky et al., 2011), provavelmente devido aos impactos causados por humanos.

Durante o desenvolvimento da Ecologia, foram criadas diversas medidas de diversidade (Cianciaruso et al., 2009). Entre elas, temos índices mais tradicionais que consideram a riqueza e a abundância relativa de espécies, como os índices de Simpson e Shannon. Entretanto, essas medidas não consideram as diferenças

espécies. Pensando nisso, foram criados índices de diversidade funcional(FD) e filogenética(PD) que medem, respectivamente, o quanto as espécies diferem entre si em relação às suas características ecológicas (Tilman et al., 1997; Mouchet et al., 2010) e história evolutiva (Faith, 1992; Cadotte et al., 2010). Essas medidas complementam o nosso conhecimento sobre a biodiversidade (Pavoine & Bonsall, 2011) e possibilitam novos testes acerca da distribuição e abundância das espécies (Diaz & Cabido, 2001; Faller et al., 2008). Além disso, elas permitem a identificação de vulnerabilidades que as espécies podem apresentar em relação às suas características ecológicas e evolutivas, o que pode ser considerado e implementado em ações conservacionistas.

Pesquisas recentes têm demonstrado o impacto da variação de características biológicas relacionadas a funções realizadas por organismos (FD) nos processos ecossistêmicos (Tilman et al., 1997; Díaz & Cabido, 2001; Cadotte et al., 2011). Por exemplo, Díaz & Cabido (2001) encontraram que alta diversidade funcional é uma boa preditora para a eficiência de captura de recursos em ambientes heterogêneos. À medida que a diversidade de características ecológicas aumenta em uma comunidade (espécies muito diferentes), maior seria a divisão dos recursos do ambiente onde ela está presente (McGill et al., 2006; Cadotte et al., 2011). Por sua vez, a diversidade de história evolutiva (PD) não só representa a diversidade de processos evolutivos que ocorreram durante a diferenciação da vida no planeta, mas também parece ter forte relação com a FD (Revell et al., 2008). Nessa perspectiva, espécies próximas seriam parecidas funcionalmente. Consequentemente, existem estudos que estimam a manutenção de processos ecológicos por meio da PD (e.g. Srivastava et al. 2012). Ainda, alta PD possibilita

de espécies se adaptarem em resposta a mudanças ambientais (i.e. potencial evolutivo; Rolland et al., 2012).

Vários são os estudos em que a biodiversidade é discutida em diferentes escalas, como a local, regional ou global (e.g. Brooker et al., 2009). Sabemos que diferentes escalas podem gerar diversos resultados acerca da distribuição e abundância de organismos (Brooker et al., 2009). As interações bióticas (e.g. competição interespecífica) normalmente ocorrem em escala local (Lortie et al., 2004; Brooker et al., 2009). Sendo assim, esperaríamos encontrar mais facilmente nesse nível de organização biológica maior FD entre espécies, pois elas seriam muito diferentes em relação às suas características biológicas. Como espécies muito distintas filogeneticamente são normalmente muito diferentes funcionalmente, esse padrão se repetiria para a PD. Essas questões relacionadas à escala podem e devem ser consideradas quando são feitos planejamentos de ações conservacionistas (Boyd et al., 2008).

Nesse contexto, no primeiro capítulo do trabalho, *Conservation Actions Based On Red Lists Do Not Capture the Functional and Phylogenetic Diversity of Birds in Brazil*, exploramos se Listas Vermelhas de espécies ameaçadas conseguem ajudar a conservar alta FD e PD de aves brasileiras. Fizemos isso calculando se a FD e PD de aves nas categorias de ameaça de listas vermelhas (uma global, uma nacional e seis regionais) são maiores do que a FD e PD de aves escolhidas ao acaso. Além disso, fizemos esse teste nas escalas local, regional e nacional para saber se a escala local é melhor do que escalas mais amplas para

D. Esse capítulo foi publicado em setembro de 2015 na revista PLOS ONE (Hidasi-Neto et al., 2013).

Em 2007, foi criado um programa de conservação pela Zoological Society of London chamado EDGE . Evolutionarily Distinct & Globally Endangered (Isaac et al., 2007). O programa utiliza o estado de ameaça das espécies na lista vermelha da IUCN - International Union for Conservation of Nature e o combina com uma medida do quanto elas são distintas filogeneticamente. As espécies mais ameaçadas que também são mais originais filogeneticamente são consideradas como as de maior importância para a conservação (Isaac et al., 2007). Apesar de adicionar a diversidade filogenética das espécies na conservação, o programa não leva em conta a diversidade funcional. Dessa forma, o funcionamento dos ecossistemas não é considerado, o que pode ser preocupante para o futuro das comunidades (Petchey & Gaston, 2002). Portanto, necessitamos de medidas que possam integrar tanto a diversidade filogenética (Cadotte et al., 2010) quanto a funcional (Pavoine et al., 2009) na conservação de espécies ameaçadas.

O segundo capítulo, EcoEDGE: Identifying Ecologically and Evolutionarily Distinct and Globally Endangered Species, inspira-se na demanda por medidas de priorização que não indiquem somente quais espécies são originais filogeneticamente, mas também funcionalmente. Sendo assim, apresentamos o índice EcoEDGE, que identifica espécies ecologicamente e evolutivamente distintas e globalmente ameaçadas. Nós ainda apresentamos mapas com as regiões onde se concentram as espécies de mamíferos ameaçadas que são distintas ecologicamente, evolutivamente, e tanto ecológica quanto evolutivamente. Esse



mbro de 2013 para a revista *Diversity and Distributions* e esta atualmente em revisão.

Esperamos que as considerações feitas aqui não fiquem somente na literatura científica. As contribuições funcional e filogenética que cada organismo possui nos ecossistemas e a importância da priorização de organismos ameaçados de extinção representam ideias que precisam ser encaminhadas para o público em geral. Além disso, uma simplificação do que está apresentado nesta dissertação pode ajudar a encaminhar nossas ideias para institutos que formulam leis e ações relacionadas ao meio ambiente (e.g. ICMBio). Somente dessa forma podemos atingir diretamente o meio político. Pensando nisso, nossa **Conclusão Geral** é composta por um texto escrito em linguagem simplificada voltada para alunos e professores do ensino médio. Nele, abordamos, de modo geral, o que é discutido na presente dissertação e indicamos uma direção futura para pesquisas relacionadas ao assunto. Esse texto foi submetido para concorrer ao  $\pm$  Prêmio SBPC/GO de Popularização da Ciência promovido pela Secretaria Regional de Goiás da Sociedade Brasileira para o Progresso da Ciência.

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## CAPÍTULO 1

### CONSERVATION ACTIONS BASED ON RED LISTS DO NOT CAPTURE THE FUNCTIONAL AND PHYLOGENETIC DIVERSITY OF BIRDS IN BRAZIL

#### **Modificação do Trabalho publicado na revista PLoS ONE**

Hidasi-Neto, J., Loyola, R.D. & Cianciaruso, M.V. (2013). Conservation Actions Based on Red Lists Do Not Capture the Functional and Phylogenetic Diversity of Birds in Brazil. *PLoS ONE*, 8:e73431.

## Red Lists Do Not Capture the Functional and Phylogenetic Diversity of Birds in Brazil

José Hidasi-Neto, Rafael Dias Loyola, Marcus Vinicius Cianciaruso

### Abstract

Red Lists of threatened species play a critical role in conservation science and practice. However, policy-making based on Red Lists ignores ecological and evolutionary consequences of losing biodiversity because these lists focus on species alone. To decide if relying on Red Lists alone can help to conserve communities' functional (FD) and phylogenetic (PD) diversity, it is useful to evaluate whether Red List categories represent species with diverse ecological traits and evolutionary histories. Additionally, local scale analyses using regional Red Lists should represent more realistic pools of co-occurring species and thereby better capture eventual losses of FD and PD. Here, we used 21 life-history traits and a phylogeny for all Brazilian birds to determine whether species assigned under the IUCN global Red List, the Brazilian national, and regional Red Lists capture more FD and PD than expected by chance. We also built local Red Lists and analysed if they capture more FD and PD at the local scale. Further, we investigated whether individual threat categories have species with greater FD and PD than expected by chance. At any given scale, threat categories did not capture greater FD or PD than expected by chance. Indeed, mostly categories captured equal or less FD or PD than expected by chance. These findings would not have great consequences if Red Lists were not often considered as a major decision support tool for policy-making. Our results challenge the practice of investing conservation resources based only on species Red Lists because, from an ecological and evolutionary point of view, this would be the same as protecting similar or random sets of species. Thus, new prioritization methods, such as the EDGE of Existence initiative, should be developed and applied to conserve species' ecological traits and evolutionary histories at different spatial scales.

**Keywords:** Avifauna; biodiversity; conservation; IUCN; species prioritization; threatened species

Earth could experience an extreme loss of diversity within a few centuries if current threats to species are not reduced [1]. To overcome this issue, several conservation approaches based on species prioritization are being applied worldwide. The Red List of Threatened Species published by the International Union for the Conservation of Nature (IUCN) is recognized as the most comprehensive, objective global approach for evaluating the conservation status of plant and animal species+[2]. Red Lists became popular after 1994, when the IUCN defined several scientific criteria to evaluate the number and how much species are endangered worldwide, publishing results periodically. These criteria are based on demographic variables such as rarity, population fluctuations, a species' extent of occurrence, and a species' area of occupancy [3]. Following these criteria, when a species is evaluated it can be placed into eight different categories: Data Deficient (DD), Least Concern (LC), Near Threatened (NT), Vulnerable (VU), Endangered (EN), Critically Endangered (CR), Extinct in the Wild (EW), and Extinct (EX) [3].

Red Lists drive national and regional conservation actions and policy in many nations across the globe [4-6]. Yet, their validity as conservation and policy instruments has also been a matter of dispute [7-10]. One must notice, for example, that Red Lists were designed to indicate the overall risk of species extinction based on demographic variables alone [6], that is, on a species' extinction probability, not on the consequences of losing a given group of species. Therefore, they do not explicitly incorporate other aspects of biodiversity, such as a species' genetics, evolutionary history and ecological traits, which is now a clear tendency in conservation literature [11-16]. These aspects are important for the maintenance of





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relevant from a conservation point of view [17,

10].

Traditional measures of biodiversity (e.g., species richness and diversity indices that include evenness) are commonly used together with Red Lists to understand how species and assemblages are being threatened by human activities [19, 20]. However, so far we have no evidence on whether Red Lists are able to protect species' ecological traits and evolutionary history, and how this inability affects conservation planning [11, 16, 17, 21-25]. Moreover, identifying the consequences of species extinction to species' trait diversity and evolutionary history can help us understand if and how conservation actions can protect multiple components of biodiversity, considering finite resources directed to conservation [26, 27].

Ignoring that species may differ both ecologically and evolutionarily can hide negative human effects on biodiversity. For example, Ernst et al. [28] found that the diversity of ecological traits in anuran assemblages (i.e., functional diversity) was greater in primary than in exploited forests despite the lack of differences in species richness between these forests. Therefore, it is possible to use indices of functional and phylogenetic diversity, which quantify, respectively, the ecological and phylogenetic dissimilarity among species [29-31], in conservation assessments. Functional and phylogenetic diversity could be used to evaluate how natural and anthropogenic disturbances alter assemblages in relation to ecological and evolutionary dissimilarities in their species [32-35]. Further, one way to understand the effect of extinctions on biodiversity and assemblage functioning is through simulated extinction scenarios in which assemblages are disassembled using some

to use extinction scenarios to simulate the loss of functional and phylogenetic diversity caused by the extinction of threatened species assigned to Red Lists categories. However, the consequence of losing threatened species in terms of their contribution to functional and phylogenetic diversity is still an unanswered question.

Knowing if sets of species assigned to categories of greater concern (e.g., Critically Endangered) on national to regional Red Lists aggregate more functional and phylogenetic diversity than expected from any other set of species can help us understand how and whether Red List categories are able to optimize conservation of the functional and phylogenetic diversity of assemblages [37, 38]. Moreover, regional Red Lists have slightly different criteria for evaluating how close species are to extinction [4-6]. Because species are more likely to interact at local scales [39, 40], broad scale analysis can produce null models that include species that do not necessarily co-occur. This model creates a scenario of ~~false~~ complementarity in which species artificially compensate for the loss of functional or phylogenetic diversity generated by the loss of species that do not co-occur with them at the regional or local scales. Therefore, the likelihood of Red List categories capturing true losses in functional and phylogenetic diversity would be higher at narrower scales. Hence, we could expect that Red Lists can do better at representing functional and phylogenetic diversity when considering assemblages at regional or local scales.

Brazil holds about 18% of all birds in the world [41]. From these species, about 160 are threatened according to the Brazilian Red List of Threatened Species [42]. The

50 Brazilian bird species are globally threatened [2]. There are also Red Lists for particular individual states in Brazil, which indicate several species that are also threatened regionally [43-48]. Here, we used global, national, and regional Red Lists to test if species assigned under different categories concentrate greater bird functional and phylogenetic diversity than expected by chance. We then tested if more threatened categories (e.g., Critically Endangered) capture essential aspects of diversity better than non-threatened categories (e.g., Least Concern). If not, several resources directed to the conservation of species might be being spent on organisms with little contribution to ecological and evolutionary aspects of biodiversity. We tested this for the whole country, states, and local sampling sites to evaluate if Red Lists are more likely to capture functional and phylogenetic diversity at narrower scales.

## **Materials and Methods**

We assessed IUCN categories for Brazilian bird assemblages from national, regional and local scales and considered four categories in this study: Near Threatened (NT), Vulnerable (VU), Endangered (EN) and Critically Endangered (CR). We did not include Data Deficient (DD) because there are no DD bird species in Brazil. Least Concern (LC) species were not considered because they represent the largest number of birds in all lists of species, which would bias our null model results. Extinct species (EW and EX) were also excluded from our analysis, because they do not prompt conservation actions.

For national scale analysis, we built a matrix with all non-vagrant birds of Brazil [49] and distributed these species into categories according to the IUCN Red List [50]

ened Fauna [42]. For regional scale analysis, we overlaid extent of occurrence maps (available at <http://www.iucnredlist.org/technical-documents/spatial-data>) onto a grid covering a map of Brazil and clipped them together to generate lists of species for six Brazilian states (hereafter ~~regions~~) that have their own Red Lists: Espírito Santo [47], Minas Gerais [46], Paraná [45], Rio de Janeiro [43], Rio Grande do Sul [44], and São Paulo [48]. Finally, for local scale analysis, we used local lists of bird species for each of the selected regions. We initially compiled 73 lists, but then only selected lists that had at least two species in at least one IUCN category, the Brazilian Red List or in the respective State Red List. These lists comprise bird assemblages of the Atlantic Forest and Cerrado regions (see Table S2 and Table S3 for more information). We ended up with 48 local lists: four from Espírito Santo, 12 from Minas Gerais, seven from Paraná, five from Rio de Janeiro, six from Rio Grande do Sul, and 14 from São Paulo.

We collated information on 21 ecological traits [16, 32, 51, 52] for 1763 birds of Brazil [49]. We chose ecological traits that distinguish how much species use and compete for resources [38]. In particular, we selected dietary traits (vertebrates, invertebrates, leaves, fruits, grains and nectar; presence/absence), behavioural traits based on foraging methods (pursuit, gleaning, pouncing, grazing, pecking, scavenging and probing; presence/absence) and foraging substrate (water, mud, ground, vegetation and air; presence/absence), period of activity (diurnal and nocturnal; presence/absence), and body mass (in grams; continuous). These ecological traits were also used in previous studies about bird functional diversity [16, 34].

grams, which indicate how similar species are in relation to their ecological traits, for the birds of Brazil (national scale), for each of the six regions for which Red Lists were available (regional scale), and for each of the 48 local lists (local scale). To build the dendrograms, we used a modification of Gower's distance [53] to create a distance matrix from qualitative and quantitative traits, and the unweighted pair-group method using the arithmetic averages (UPGMA) clustering method.

We also made a consensus tree for the birds of Brazil based on 100 phylogenies from birdtree.org [54]. These phylogenetic trees were generated by combining a backbone phylogeny [55] with trees made for species with and without genetic data with the help of taxonomic information and a pure-birth model of diversification, and then assembled based on dated backbone trees and topologies from the literature [54]. We transformed the consensus tree into a cladogram, considering the length of the shorter branches of the cladogram as 1, while other branches were scaled proportionally according to the branching pattern among species. We built the consensus tree using the R software [56] (`consensusq` function from the `ape` package; [57]).

For each species pool (Brazilian avifauna, each region's avifauna and birds from local lists) we measured the amount of functional diversity (FD) [31] and phylogenetic diversity (PD) [29] captured by species within each category (NT, VU, EN, and CR). FD and PD are calculated by summing, respectively, the branch lengths of a functional dendrogram or phylogenetic tree that connect all the species in a given assemblage [29, 31]. For all birds, we calculated FD and PD using the

ilian Red List, whereas for the regional and local lists we used the IUCN, Brazilian and respective State Red Lists. By doing this, we observed if categories established at different scales (national, regional and local) were able to capture bird FD and PD to a greater extent than expected by chance (see below).

To test whether categories captured more FD and PD than expected by chance, we used null models to compare observed FD and PD values with randomly generated values. At the national scale, we calculated FD and PD values for each category of the IUCN [50] and the Brazilian Red List of Threatened Fauna [42]. At the regional and local scales, we calculated FD and PD based on the IUCN, the Brazilian Red List and the Red List of the respective region. Then, for each category in all analysed scales, we calculated 999 FD and PD values from randomly generated assemblages by shuffling the taxon labels across the tips of the functional dendrogram or cladogram of all species from Brazil or the regional or local lists, holding species richness of each analysed category. Next, we calculated  $p$  values as the rank of the observed FD or PD value divided by the number of randomized values + 1. In that way, for each Red List category, observed FD or PD could be less than ( $p$  equal to or less than 0.025), equal to ( $p$  between 0.025 and 0.975) or greater than ( $p$  equal to or greater than 0.975) than expected by chance.

To test if IUCN, the Brazilian Red List and regional Red List categories from regional and local lists protected, in general, birds that were more functionally and phylogenetically different than expected by chance, we ran Mann-Whitney tests [58] to compare observed FD and PD against the respective mean of randomized FD and



Whitney test because the observed and mean values of FD and PD were not normally distributed. If the observed values were less than the mean of randomized values, it indicated that less FD or PD is being captured by species assigned into that category. However, if the observed values were higher than the mean of randomized values, the category captured more FD or PD than expected by chance. Both the null models and the Mann-Whitney tests were done in R software [56] (`ses.pdf` function from the Picante package; [59]).

## Results

We observed that IUCN, Brazilian and regional Red List categories assembled different pools of species (see Table S1 for details). Indeed, only the VU and EN categories on the IUCN and Brazilian Red Lists shared more than half of their species. Therefore, categories in the regional lists shared only small numbers of species with both the IUCN and Brazilian Red List categories. At all scales, species assigned to any of these categories did not capture more functional or phylogenetic diversity than expected by chance (see Table 1 and Table 2).

States and sites with threatened birds in categories of the Red Lists which had values of observed functional diversity lower, equal or higher than expected by chance (see Supplementary Material for more information). %N+ represents the number of States or sites that could be analyzed (had at least one species in the Red List category).

Red List	Category	Brazilian States				Sites			
		% Lower	% Equal	% Higher	N	% Lower	% Equal	% Higher	N
IUCN	NT	83.3	16.7	0	6	12.2	87.8	0	41
	VU	16.7	83.3	0	6	4.3	95.7	0	23
	EN	0	100	0	6	0	100	0	8
	CR	16.7	83.3	0	6	NA	NA	NA	0
Brazilian	VU	0	100	0	6	0	100	0	22
	EN	0	100	0	6	25	75	0	4
	CR	16.7	83.3	0	6	0	100	0	1
Regional	NT	0	100	0	2	0	100	0	20
	VU	0	100	0	6	2.3	95.4	2.3	44
	EN	0	100	0	6	0	100	0	29
	CR	0	100	0	6	0	100	0	13

**Table 2.** Percentage of analyzed Brazilian States and sites with threatened birds in categories of the IUCN, Brazilian and respective States Red Lists which had values of observed phylogenetic diversity lower, equal or higher than expected by chance (see Supplementary Material for more information). %N+ represents the number of States or sites that could be analyzed (had at least one species in the Red List category).

Red List	Category	Brazilian States				Sites			
		% Lower	% Equal	% Higher	N	% Lower	% Equal	% Higher	N
IUCN	NT	83.3	16.7	0	6	9.7	90.3	0	41
	VU	33.3	66.7	0	6	21.7	78.3	0	23
	EN	33.3	66.7	0	6	0	100	0	8
	CR	16.7	83.3	0	6	NA	NA	NA	0
Brazilian	VU	16.7	83.3	0	6	22.7	72.7	4.5	22
	EN	0	100	0	6	25	75	0	4
	CR	0	100	0	6	0	100	0	1
Regional	NT	0	100	0	2	0	95	5	20
	VU	50	50	0	6	20.4	77.3	2.3	44
	EN	50	50	0	6	20.7	79.3	0	29
	CR	33.3	77.7	0	6	7.7	92.3	0	13

ories (NT and VU) from the IUCN Red List assembled birds that were functionally more similar than one would expect by chance, while all categories in the Brazilian Red List had a random loss of FD (see Table S2 for details). Also, all categories on the IUCN Red List and one category from the Brazilian Red List gathered birds that were phylogenetically more similar than expected by chance (see Table S3 for details). Moreover, when considering IUCN, National and regional Red Lists, we found that most analysed regions and sites had threatened birds with FD equal to that expected by chance.

Indeed, at the regional scale, only the NT category of the IUCN Red List assembled birds that represented losses in FD and PD less than those expected by chance in most regions (83.3%). For regional Red Lists, when considering NT species, 10.4% of sites had less FD than expected by chance. When considering the VU category, 66.7% of regions and 18.75% of sites had less PD than expected by chance. Nevertheless, at the local scale, we found greater FD than expected by chance for VU species in only one site (located in São Paulo), and greater PD than expected by chance for NT species in another site in São Paulo. Likewise, we found that one site located in Rio Grande do Sul had VU species, listed in both in the Brazilian and Rio Grande do Sul Red Lists, with greater PD than expected by chance.

Not surprisingly, we found that, on average, IUCN categories gathered species that had FD and PD levels similar to what one might expect by chance (Table 3 and Table 4). Indeed, most of the Mann-Whitney results showed no difference between the observed FD and PD and the mean of randomized values for the categories on both the regional and local scales. However, we found that for the analysed regions, birds

ist were, on average, more similar in relation to their ecological traits than expected by chance (i.e., functional clustering). Likewise, among local lists, birds in the EN category of the regional Red Lists were, on average, more similar in relation to their evolutionary history than expected by chance (i.e. phylogenetic clustering).

**Table 3.** Results for the Mann-Whitney tests comparing values of observed functional diversity and mean of randomized functional diversity of the analyzed Brazilian States and sites with threatened birds in categories of the IUCN, Brazilian and respective States Red Lists (see Supplementary Material for more information). %N+ represents the number of States or sites that could be analyzed (had more than two species in the Red List category). Statistically significant values are underlined.

Red List	Category	Brazilian States			Sites		
		U	P	N	U	P	N
IUCN	NT	<u>4,000</u>	<u>0.025</u>	6	740.000	0.351	41
	VU	13.000	0.423	6	244.000	0.652	23
	EN	13.000	0.423	6	14.000	0.059	8
	CR	10.000	0.200	6	NA	NA	0
Brazilian	VU	13.000	0.423	6	237.000	0.907	22
	EN	15.000	0.631	6	4.000	0.248	4
	CR	13.000	0.423	6	NA	NA	1
Regional	NT	NA	NA	2	197.000	0.935	20
	VU	14.000	0.522	6	962.000	0.960	44
	EN	15.000	0.631	6	401.000	0.762	29
	CR	16.000	0.749	6	70.000	0.457	13

is comparing values of observed phylogenetic diversity and of the analyzed Brazilian States and sites with threatened birds in categories of the IUCN, Brazilian and respective States Red Lists (see Supplementary Material for more information).  $N+$  represents the number of States or sites that could be analyzed (had more than two species in the Red List category). Statistically significant values are underlined.

Red List	Category	Brazilian States			Sites		
		U	P	N	U	P	N
IUCN	NT	7,000	0.078	6	734.000	0.323	41
	VU	15.000	0.631	6	206.000	0.199	23
	EN	16.000	0.749	6	26.000	0.529	8
	CR	10.000	0.200	6	NA	NA	0
	VU	17.000	0.873	6	216.000	0.542	22
Brazilian	EN	12.000	0.337	6	6.000	0.564	4
	CR	13.000	0.423	6	NA	NA	1
Regional	NT	NA	NA	2	191.000	0.808	20
	VU	12.000	0.337	6	817.000	0.208	44
	EN	15.000	0.631	6	<u>293.000</u>	<u>0.047</u>	29
	CR	15.000	0.631	6	66.000	0.343	13

## Discussion

There is an increasing body of evidence that FD is positively related to ecosystem functioning and stability [14, 30, 60]. Also, PD is often a proxy for FD [61-63] and for species evolutionary potential, known as the potential capabilities of species to evolve given environmental changes [64]. Thus, the conservation of such components of biodiversity might be important for maintaining ecosystem processes and services, and must be set as a goal in conservation planning [14, 25, 37, 64, 65].

We found, however, that Red List categories did not capture greater FD or PD than expected by chance. Because the objective of Red Lists is species and population recovery as opposed to the conservation of other aspects of biodiversity (e.g. functional or phylogenetic diversity), it is no surprise that species within given IUCN

or PD than expected by chance. This is a crucial point, because Red Lists (and therefore rarity) are often the only information considered in national conservation assessments and planning [10, 66]. Still, we only found greater FD for VU species in a single site in São Paulo, and greater PD for NT species in another site in São Paulo, and for VU species in a site in Rio Grande do Sul (Table S2 and Table S3). Despite not being much threatened today, these species have important ecological and evolutionary roles. This is the typical case where species with important ecological roles that might suffer rapid population declines [67, 68] are probably not appropriately targeted for conservation purposes. For example, it has been demonstrated that common species with important ecological roles in their native ranges, like the common starling (*Sturnus vulgaris*) in Europe, suffered from dramatic population losses in recent decades [67]. If most of the national budget for biodiversity conservation is allocated to the protection of threatened species, we may face the risk that, in the long term, we will lose ecosystem functions and services because we neglected the functional role of species when defining our national conservation action and policy.

Extinctions are not expected to occur at random [36, 69]. Indeed, Szabo et al. [70] found that extinctions were disproportionately concentrated in species-poor bird families. Then, some ecological traits can be more closely related than others to the extinction of species, revealing patterns of functional vulnerability among Red List categories. We found that the NT category of the IUCN Red List represented fewer losses of FD and PD than expected by chance in most of the regions. In other words, this category concentrates species that share most of their ecological traits and evolutionary history. These ecologically ~~redundant~~ species are sometimes referred

them functioning, and thereby are important from a conservation perspective [71]. Species with similar evolutionary histories may share a large number of ecological traits [72], so a portion of these results can be explained by a phylogenetic signal in species traits already captured by our previous finding for FD (see above). When considering the VU category on regional Red Lists, we also found that 66.7% of regions had less PD than expected by chance. In this way, at the regional scale, the NT and VU categories concentrated, in general, more recent species that share a large amount of their evolutionary history and might have high evolutionary potential, which is the ability of species to evolve in the face of environmental changes [62]. This finding is contrary to Purvis et al. [36], where the simulated extinction of endangered species represented a greater loss of PD than expected by chance for mammals, birds and primates at the global scale. We observed Red List categories with threatened species that have similar traits and share a large amount of their evolutionary history, which are the likely intrinsic biological drivers of their extinction. Hence, that reinforces our need to identify which traits are more related to a species's probability of extinction [24] and which clades are more likely to disappear in the future [36].

Species are more likely to interact with each other on local scales [39, 40]. Therefore, broad-scale analysis can produce models in which species are ~~falsely~~ complementary to each other in relation to their functional traits or evolutionary history. For example, when considering all the birds in Brazil for analysing the functional or phylogenetic diversity of threatened species, birds from different ecoregions or biomes are treated as if they would always occur together. If these species are ecologically or phylogenetically similar and some of them become



will compensate for the functional/phylogenetic losses. Thus, narrow scales would better represent the consequences of losing endangered species. Indeed, we only found greater FD and PD than expected by chance in a few categories of less concern at the local scale (as we discussed previously). However, even after reducing the effect of false complementarity among species in relation to their ecological traits and evolutionary history at narrow scales, Red Lists, in general, were still not able to protect more functional and phylogenetic diversity in any of the analysed scales.

Brito et al. [6] found for Brazil, China, Colombia and Philippines a considerable number of species that were listed as threatened by the IUCN, but were not listed nationally (average of 14%) or that were listed as threatened nationally but not assessed by the IUCN (average of 20%). Moreover, it is known that the overall IUCN threat status of the birds of the world has deteriorated since 1988 [73], meaning that species from categories of less concern have been moved to ones of greater concern. We observed that different assessments, independent of their categories, were equally incapable of protecting more FD or PD than expected by chance. We observed that categories in the IUCN, national and regional Red Lists did not contain the same species (see Table S1). In fact, the similarity within categories among these lists ranged from 0 to 76%. This reinforces our finding that these categories did not capture bird FD and PD, and also highlights that our congruent results for FD and PD were not due to a possible high species similarity among categories from different Red Lists.

Evolutionary dissimilarity can be implemented into extinction risk assessments [21, 64, 65, 74]. They represent the relative contribution of threatened species to the PD and FD of assemblages. For example, there is an initiative for protecting species that are evolutionarily distinct and globally endangered according to the IUCN Red List, known as EDGE [11]. Also, it is known that indicator groups that represent the dissimilarities in both ecological traits and evolutionary history should be conserved, maintaining ecosystem processes and evolutionarily distinct species [16]. These studies can bring us cost-effective shortcuts for conserving assemblagesq ecological and evolutionary dissimilarity while protecting globally or regionally threatened species. However, as noted by Winter et al. [74], we still need a guideline for including species PD in conservation, and other components of biodiversity, such as FD, should be included whenever possible. In that way, there is some debate on whether and how we should target less or more FD and PD. We found several cases in which Red List categories protected sets of functionally redundant (less FD than expected by chance) and closely related species from more recent clades (less PD than expected by chance). It is important to note that these species might be able to protect both the maintenance of ecosystem functions and services [71] and the evolutionary history of recent clades due to their high evolutionary potential [62].

As resources directed to conservation are finite, it is important that both proactive and reactive actions consider multiple variables, like costs, benefits (e.g., ecosystem functions and evolutionary history), species extinction probability, and likelihood of management success [26, 27]. The failure of Red Lists to capture PD and FD highlights our need for new methods for prioritizing speciesq ecological and

27] and inform us about the consequences of species loss to ecosystem processes instead of using only demographic variables to understand which species are more likely to disappear first.

**Acknowledgments:** We thank two anonymous reviewers for critical comments on the text. We are also grateful to Daniel Brito and Joaquim Trindade Filho for helping us with the data.

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**Table S1.** Richness and similarity of species composition of similar categories among IUCN, Brazilian and regional red lists. IUCN categories have the following species richness: NT=95; VU=65; EN=35; CR=21. Categories that share more than a half of their species have values in bold.

**Table S2.** Relation between observed functional diversity values and the mean of randomized functional diversity values for six Brazilian regions and 48 sites; and the reference for the sites and the status of conservation of these areas, as well as the total number and the number of threatened birds within each Red List category for Brazil, each State and each site.

**Table S3.** Relation between observed phylogenetic diversity values and the mean of randomized phylogenetic diversity values for six Brazilian regions and 48 sites; and the reference for the sites and the status of conservation of these areas, as well as the total number and the number of threatened birds within each Red List category for Brazil, each State and each site.

O material suplementar pode ser encontrado no site da PLoS ONE:  
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## **CAPÍTULO 2**

### **EcoEDGE: Identifying Ecologically and Evolutionarily Distinct and Globally Endangered Species**

**Trabalho submetido para a revista Diversity and Distributions**

Hidasi-Neto, J., Loyola, R.D. & Cianciaruso, M.V. EcoEDGE: Identifying Ecologically  
and Evolutionarily Distinct and Globally Endangered Species.

### Endangered Species

José Hidasi-Neto, Rafael Dias Loyola, Marcus Vinicius Cianciaruso

## ABSTRACT

### Aim

Species ecological and evolutionary dissimilarities have gained attention in the scientific community in the past years as they have important roles in the functioning and stability of ecosystems. However, Conservation Science is in urgent need of objective methods to integrate both ecological and evolutionary components of biodiversity into the conservation of threatened species. To address this need, we developed an approach to identify which species are the most **Ecologically and Evolutionarily Distinct and Globally Endangered**(EcoEDGE).

### Location

Global.

### Methods

We used a recent phylogeny and life history traits to calculate values of ecological and evolutionary distinctiveness for the mammals of the world. Furthermore, we combined these values into one measure by standardizing both the phylogeny and the dendrogram and attributing similar weights to ecological and evolutionary distinctiveness values. Then, we mapped the spatial distribution of species to locate regions with high numbers of ecologically and evolutionarily distinct threatened mammals.

### Results

In general, EcoEDGE species tended to be the most threatened ones, while ecological and evolutionary dissimilarities tended to be complementary rather than redundant. Evolutionarily distinct threatened species were mostly concentrated in the tropics, while ecologically distinct threatened species were distributed both on tropical and temperate regions. In addition, both ecologically and

overlapped their distribution with the areas of some  
est, Cerrado, Guinean forests of West Africa, Indo-Burma  
and Sundaland. The ecologically and evolutionarily distinct threatened mammals were highly  
concentrated in the tropics, but as it retained patterns from ecologically distinct species distribution, it  
had a considerable expansion in direction to temperate regions.

### Main Conclusions

EcoEDGE represents a further step to include ecological traits into a species-focused prioritization  
approach and, thus, to guide the conservation of ecosystem processes and services in multiple scales  
using global, regional or local Red Lists.

**Keywords:** biodiversity; conservation; extinction risk; functional diversity;  
phylogenetic diversity; threatened species.

## INTRODUCTION

There is a consensus among scientists that several human activities are accelerating  
the extinction rate of species, pruning the tree of life and, thus, leading our planet to  
a biodiversity crisis (Pereira et al., 2010; Barnosky et al., 2011). In face of finite  
conservation funds, decision and policy makers will not be able to protect all  
threatened species (Vane-Wright et al., 1991). Therefore, it is necessary to choose a  
set of species that would, if conserved, minimize the loss of different components of  
biodiversity (Bottrill et al., 2008).

The perception of the relevance of species evolutionary history to conservation  
approaches is not new (Erwin, 1991; Faith, 1992), but there has been a growing  
interest in that topic in the last decade. This is mainly because of the increasing  
availability of phylogenies for a large number of species (Diniz-Filho et al., 2013) and

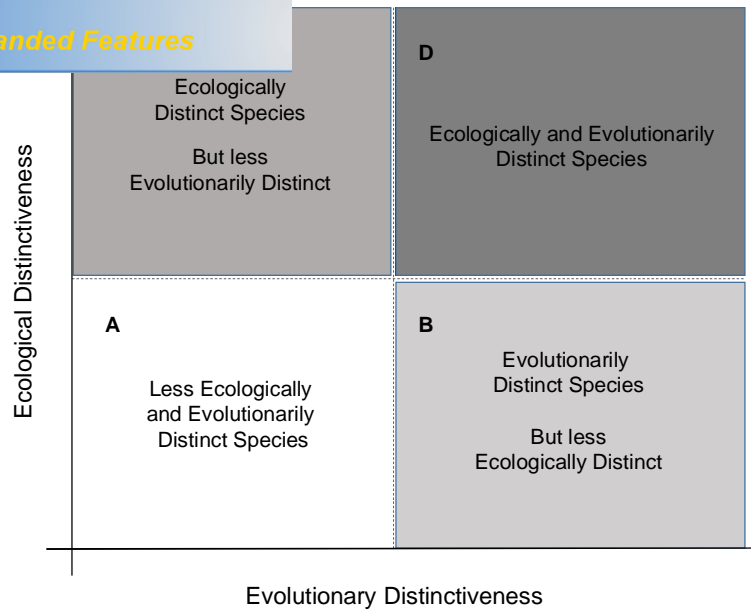
to capture the phylogenetic diversity of species (Cadotte et al., 2010). From a conservation perspective, species which are very unique in relation to their evolutionary history are usually rare and clumped in clades with few species (McKinney, 1998; Heard & Mooers, 2000). Also, the loss of threatened species can lead to a higher loss of closely related species than it would be expected by chance (Purvis et al. 2000). Thus, we could expect that entire clades will be rapidly lost in a short time (McKinney, 1998; Purvis et al., 2000; Jono & Pavoine, 2012).

Another component of biodiversity that has gained attention in conservation planning is the functional diversity or the ecological trait dissimilarity among species (Becker et al., 2010; Strecker et al., 2011). Functional diversity is often positively related to ecosystem function and stability (Díaz & Cabido, 2001; Petchey et al., 2004; Cadotte et al., 2011; Clark et al., 2012; but see Cadotte et al., 2012), and can also determine changes in a variety of ecosystem services (Díaz et al., 2007; Sekercioglu, 2012). It has been suggested that both phylogenetic and ecological dissimilarities among species can contribute to our understanding of the consequences of losing species to ecosystem functioning (Flynn et al., 2011). Also, linking these two components within an integrative conservation approach would help to preserve the continuity of the Tree of Life while maintaining or promoting ecosystem stability, goods and services (Wiens & Graham, 2005; Devictor et al., 2010; Loyola et al., 2011). For example, depending on the conservation purpose, one would prioritize species that are simultaneously evolutionary and ecologically distinct (Fig. 1D), only ecologically distinct (Fig. 1C), or only evolutionarily distinct (Fig. 1B). Species that are simultaneously less ecologically and evolutionary distinct (Fig. 1A) could receive less

ing the threat status of each species decisions may not be straightforward. This is because, conservation strategies focused only on threatened species will not necessarily capture most of phylogenetic and functional diversity of natural communities (Hidasi-Neto et al., 2013).

In 2007, the Zoological Society of London started a conservation programme entitled Evolutionarily Distinct and Globally Endangered species (EDGE; Isaac et al. 2007). The main premise of this programme is to protect species that are not only endangered, according to IUCN Red List categories, but also distinct in relation to their evolutionary history (Isaac et al., 2007, 2012). On the other hand, few conservation initiatives have focused on the ecological dissimilarity among species (Carvalho et al., 2010; Lucifora et al., 2011; Strecker et al., 2011; Trindade-Filho et al., 2012). Hence, we face the risk that we might be losing several ecosystem processes and services that are maintained by ecologically unique species (Srivastava & Vellend, 2005; Devictor et al., 2008; Hidasi-Neto et al., 2013). Now we need methods for species prioritization that not only focus on species evolutionary history and threat status, but also on the ecological differences among these species. Here, following the steps of the EDGE initiative (Isaac et al., 2007), we developed a new species prioritization method for identifying both ecologically and evolutionarily distinct endangered species. This is the first time that ecological and evolutionary dissimilarities are considered together with species extinction probability in a species-focused prioritization approach. The method allows one to weight the relative contribution of the ecological and evolutionary information in a flexible framework that can be adapted to distinct conservation purposes.





**Figure 1** A framework to prioritize species according to their ecological and evolutionary distinctiveness. In this scheme species that are simultaneously less ecologically and evolutionarily distinct, that is, they are highly related and ecologically similar (A); others can be only evolutionarily (B) or ecologically (C) distinct. Finally, some species can be both evolutionarily and ecologically very distinct (D). These four dimensions can be combined to each species threat status in order to conserve evolutionarily and/or ecologically distinct threatened species.

To show the benefits of our method we applied it to all the mammals of the world using life-history traits and a phylogeny of extant mammals to evaluate globally endangered species that are both ecologically and evolutionarily distinct. This is also the first time that the spatial distribution of ecologically and evolutionarily distinct endangered species is mapped at the global scale. We then discussed how this method could be used at smaller geographical extents and the future consequences of not considering ecological and evolutionary processes in conservation planning.

## (A) MATERIAL AND METHODS

### (B) Data

We compiled information on ecological traits for the mammal species of the world (excluding Sirenia and Cetartiodactyla). We selected traits which indicate how much

use and how and when they acquire them (Safi et al., 2011). We used information on body mass (in grams), diet (vertebrates, invertebrates, foliage, stems and bark, grass, fruits, seeds, flowers, nectar and pollen, roots and tubers; presence/absence), habit (aquatic, fossorial, ground dwelling, above ground dwelling, aerial; presence/absence), and activity period (catemeral, crepuscular, diurnal, nocturnal; presence/absence). We only considered species for which we had information for body mass and at least four categorical variables. We ended up with 3364 mammals, which we classified into categories based on the International Union for Conservation of Nature (IUCN 2012). We considered four IUCN categories: Near Threatened (NT), Vulnerable (VU), Endangered (EN) and Critically Endangered (CR).

## **(B) Calculating species scores**

We produced a functional dendrogram for the mammals of the world using the above-mentioned ecological traits. To build the dendrogram, we used a modification of Gower's distance (Pavoine et al., 2009) to create a distance matrix from qualitative and quantitative traits, and the unweighted pair-group method using arithmetic averages (UPGMA) clustering method. Also, we used a dated mammalian supertree (Bininda-Emonds et al., 2007; Fritz et al., 2009) for pruning a phylogenetic tree to our species.

First, for the mammalian phylogeny, we used the fair proportions method (Isaac et al., 2007) to calculate the evolutionary distinctiveness (ED) of each species (`evol.distinct` function from `Picante` package; Kembel et al. 2010), which is comparable to the one presented by Isaac et al. (2007). However, because

es are not in the same unity and dimension (i.e., evolutionary distances are in millions of years and ecological distances depend on the distance measure used) some standardization was necessary. Thus, we relativized the branches of the phylogeny and the functional dendrogram to calculate, respectively, new ED values and ecological distinctiveness (EcoD) values, which we multiplied by 100 (respectively EDz and EcoDz for now on). We did this multiplication to approximate EDz and EcoDz to the original EDGE values (Isaac et al., 2007) for comparison purposes. To certify that such standardization did not deviate from the original ED measure we calculated a Pearson correlation coefficient between ED and EDz values (as expected they had a perfect positive correlation; see results). The original phylogeny had branch lengths dated in million years, but when we relativized these branches (proportional to the number of divergences) the phylogeny became an undated tree. This procedure was essential to define similar weights to the phylogenetic (EDz) and ecological (EcoDz) measures.

To answer if there was redundancy between the evolutionary and ecological distinctiveness of species, we also correlated EDz and EcoDz. If they were highly correlated this would indicate that evolutionary distances would be enough to capture both historical and ecological aspects of mammalian biodiversity (i.e., a scenario of strong niche conservatism; Wiens & Graham, 2005). As we show in the result section that was not the case, thus, based on Isaac et al. (2007), we used EDz and EcoDz to calculate scores for each mammal species as:

$$\text{Score} = \ln(1 + \text{DistMeasure}) + \text{GE} \times \ln(2)$$

ness measure used (EDz or EcoDz), and GE is the Red List category in which the species is categorized (LC = 0, NT = 1, VU = 2, EN = 3 or CR = 4). Accordingly, depending on the distinctiveness measure used we have the following metrics: EDGEz and EcoDGEz. These measures indicate the priority species for conservation based on their extinction risk and, respectively, their evolutionary distinctiveness (Isaac et al. 2007) or ecological distinctiveness (this study). They can be used alone depending on which biodiversity component one would like to prioritize.

To produce a metric capable of determining which species are the most Ecologically and Evolutionarily Distinct and Globally Endangered (EcoEDGE) we did the following modification on EDGE (Isaac et al. 2007):

$$\text{EcoEDGE} = \ln[1 + (\text{EDz} \times 0.5 + \text{EcoDz} \times 0.5)] + \text{GE} \times \ln(2)$$

where the evolutionary (EDz) and ecological (EcoDz) distinctiveness have the same weight when calculating species scores. Notice that by using this equation one could change the relative contribution of the evolutionary and ecological components of EcoEDGE. Species scores calculations and correlations were done in R software (R Development Core Team, 2013).

## **(B) Spatial analysis**

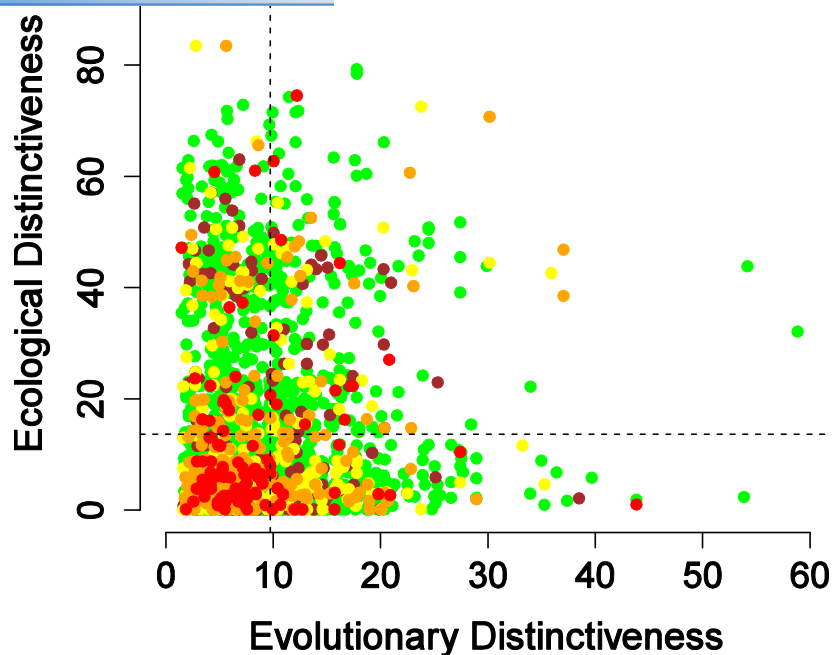
To identify regions containing species with high EDGEz, EcoDGEz and EcoEDGEz values, we overlaid extent of occurrence maps (available at <http://www.iucnredlist.org/technical-documents/spatial-data>) for the species within the

itions (841 species) onto a grid of one degree of latitude and longitude. Then, we produced three occurrence maps (one for each measure) that we used to identify spatial changes occurred with the inclusion of species ecological dissimilarity to the EDGE approach. We also used the maps to identify areas with highest numbers of most ecologically and evolutionarily distinct endangered species. The occurrence maps were done in SAM software (Rangel et al., 2006).

## **(A) RESULTS**

### **(B) Species scores**

We calculated score values for 3364 species (see Appendix S1). As expected, we found a perfect positive correlation ( $r = 1.0$ ;  $p < 0.001$ ;  $df = 3362$ ) between ED and EDz. Therefore, we used the standardized functional dendrogram to calculate EcoDz values. Moreover, EDz and EcoDz were not related to each other (Fig. 2) and thereby may be used together on the calculation of EcoEDGE scores. Most species have low EDz and/or EcoDz values and, consequently, only a few mammals are both evolutionarily and ecologically distinct. Also, there are species from all IUCN categories into this group of evolutionarily and ecologically distinct mammals.



**Figure 2** Relationship between species evolutionary (EDz) and ecological (EcoDz) distinctiveness (Pearson correlation;  $r = 0.054$ ;  $p = 0.001$ ;  $df = 3362$ ). The colors represent the different IUCN categories of threat status: LC= Green, NT = Yellow, VU = Orange, EN = Brown, and CR = Red. Dashed lines indicate the upper quartiles.

### (B) Spatial distribution

We observed that species with high EDGEz, EcoDGEz, and EcoEDGE scores were distributed all over the world (Fig. 3). First, analyzing the species in the upper quartile of EDGEz distribution, there is a concentration of priority species for conserving evolutionary history in the tropics (Fig. 3a), especially in the Indo-Malayan region of the Oriental Biogeographic realm (sensu Holt et al., 2013). For EcoDGEz, we observed that both tropical and temperate areas held more ecologically distinct threatened species. Noteworthy, the United States, Europe, Andes, Amazon Basin, Cerrado, Atlantic Forest, Afromontane, Himalaya, Indo-Burma, and (again) Indo-Malayan regions presented high number of these priority species (Fig. 3b). Comparing the distributions of the highest EDGEz and EcoDGEz values, we observed an expansion of high ecologically distinct and endangered



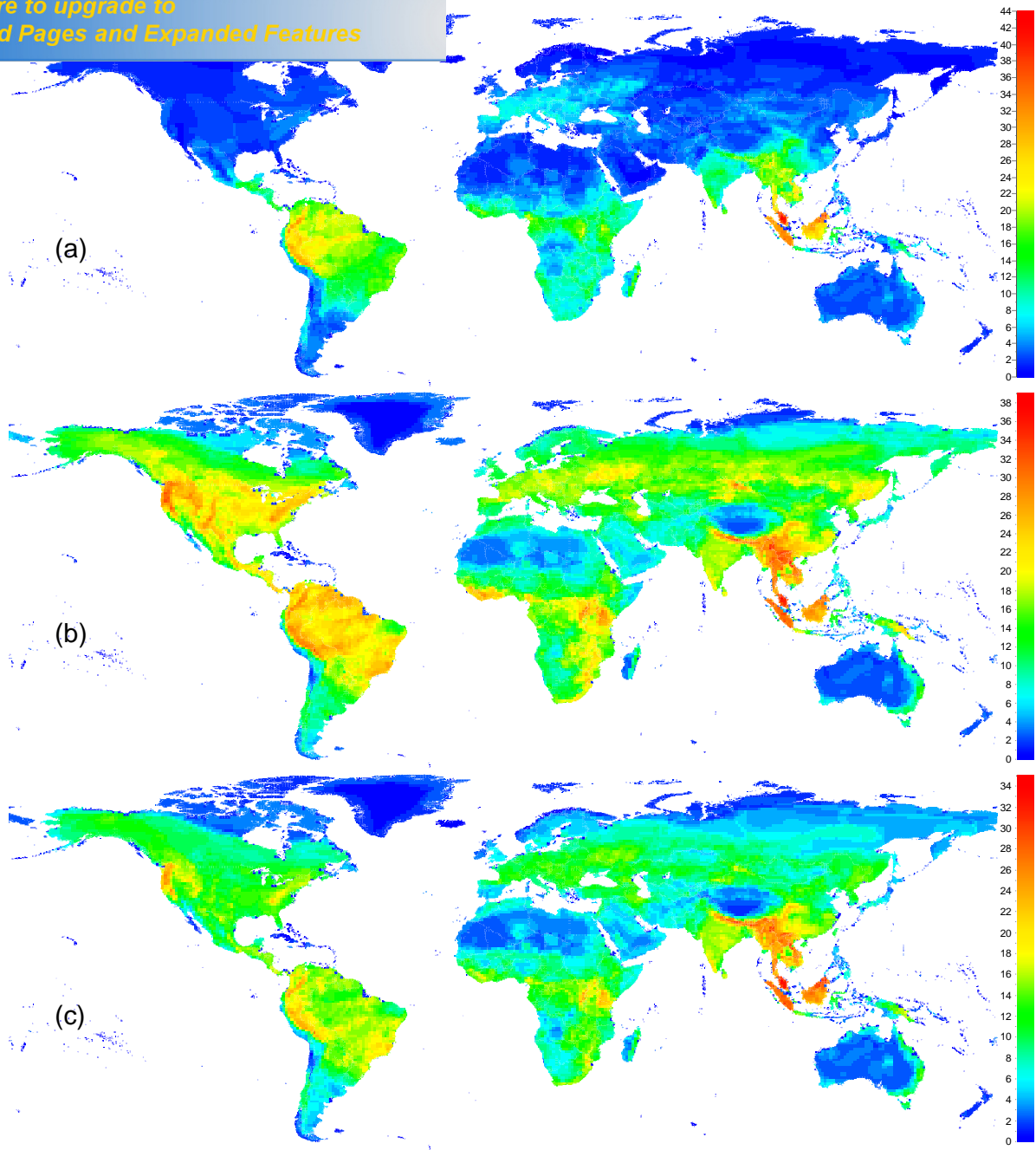
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though tropical regions also held a high amount of these mammals). When we mapped the distribution of species with highest EcoEDGE scores, the most ecologically and evolutionarily distinct endangered species were highly concentrated in the tropics (Fig. 3c). However, it is also notable that western United States and European regions presented high numbers of these species. As expected, EcoEDGE species distribution captured both EDGEz and EcoDGEz distribution patterns.





**Figure 3** Species richness maps for 25% (841) of species with highest (a) EDGEz scores, (b) EcoDGEz scores, and (c) EcoEDGE scores. Warmer colors indicate higher species richness.

The EDGE initiative (Isaac et al., 2007) was an important and innovative development for conservation assessment, as it highlights the inclusion of species relative contribution to evolutionary history into large conservation programmes. However, it ignores another important aspect of biodiversity that is the ecological dissimilarity among species. It has been shown that this component is closely related with ecosystem processes and stability (Díaz, 2001; Cadotte et al., 2011; Clark et al., 2012) and, therefore, conservation planning studies are starting to consider it as a main concern (Loyola et al., 2009; Becker et al., 2010; Carvalho et al., 2010; Strecker et al., 2011). Based on that, the EcoEDGE metric focuses on identifying ecologically and evolutionarily distinct endangered species using phylogenetic and trait dissimilarities as well as species threat status. In that way, EcoEDGE represents the differential importance of species in evolutionary and ecological processes, weighted by how much they are near to extinction.

Whereas the inclusion of evolutionary history is slowly becoming a regular practice in conservation planning and discussion (Faith et al., 2004; Faith & Baker, 2006; Isaac et al., 2007, 2012; Rolland et al., 2012; Winter et al., 2013), the inclusion of ecological dissimilarity is rather recent and still has several gaps (Díaz et al., 2007; Carvalho et al., 2010; Strecker et al., 2011; Trindade-Filho et al., 2012). For example, there is a debate on whether species evolutionary distances are a good surrogate to ecological dissimilarities (Winter et al., 2013). Although this is frequently thought to be true, assuming that closely related species usually share similar traits (Webb et al., 2002; Blomberg et al., 2003; Revell et al., 2008), a variety of studies does not corroborate this idea (Flynn et al., 2011; Cianciaruso et al., 2012; Swenson et al.,

l., 2013). We observed that mammalsqecological (EcoDZ) and evolutionary (EDZ) distinctiveness were not related to each other, and thus they could be used in EcoEDGE without adding redundant information (Fig. 2). Indeed, we observed that evolutionarily distinct species are not necessarily ecologically distinct, and vice versa. In addition, some species are both ecologically and evolutionarily distinct but are not threatened in the present (Fig. 2). Here we have a clear example on how our metric can aid to help one to implement proactive conservation actions to assure that these species will not become threatened in the near future, considering their latent extinction risks. This highlights our need for integrative approaches to the conservation of the functional and phylogenetic components of biodiversity (Loyola et al., 2011; Arponen, 2012).

There is little information about the spatial distribution of species or assemblages that have relevant importance for ecological and evolutionary processes. Some studies have demonstrated that often high numbers of ecologically and evolutionarily distinct species do not share the same areas (Carvalho et al., 2010; Devictor et al., 2010). We generated spatial distributions for 25% of species with highest EDGEz, EcoDGEz and EcoEDGE scores, and we found some interesting patterns. First, species-rich tropical zones as Amazonian, Indo-Malayan and Oriental regions (sensu Holt et al. 2013) have high concentrations of evolutionarily distinct threatened mammals. A possible explanation for that is the movement of basal groups of mammals to the tropics during the Pleistocene period (MacFadden, 2006). These regions would, therefore, bear a high number of evolutionarily distinct species. Second, we also observed a more expansive distribution of ecologically distinct threatened species in direction to higher-latitude zones. It has been observed that

community functional diversity in temperate regions in relation to their amount of evolutionary history likely due to environmental limitation, high habitat heterogeneity and rapid trait evolution (see Safi et al., 2011). Moreover, Buckley et al. (2010) observed that these areas are rich in young mammal clades, and that their origin dates back to the expansion of temperate climate zones in the late Eocene. Indeed, we found a considerable spatial mismatch in our EDGEz and EcoDGEz distributions, especially in temperate regions, in which ecologically distinct threatened species were more concentrated than phylogenetically distinct species. As expected by combining EDGEz and EcoDGEz, these areas had moderate concentrations of species with highest EcoEDGE scores.

Jenkins et al. (2013) recently mapped the distribution of threatened species around the world. They observed that threatened mammals are mainly concentrated in tropical regions, which is a pattern similar to what we found for mammals with highest EDGE scores. However, as stated earlier, the distribution of priority species expanded from tropical to temperate regions when we included ecological dissimilarity into the prioritization method. It is of great concern that Indo-Malayan region has not only high richness of threatened mammals (Jenkins et al., 2013), but also of both ecologically and evolutionarily distinct threatened mammal species. Therefore, more attention should be directed to this area in the following years. On the other hand, it is notable that the distribution of ecologically distinct, evolutionarily distinct, and both ecologically and evolutionarily distinct species overlapped their areas with some hotspots, like Atlantic forest, Cerrado, Guinean forests of West Africa, Indo-Burma and Sundaland (Mittermeier et al., 2005). This is a good sign that



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have good applications to regions already considered of great conservation and, consequently, political importance.

The complementarity of species ecological characteristics may have several implications to conservation assessments. For example, it has been suggested that land use changes can determine the composition of species ecological dissimilarities, altering the provision of diverse ecosystem services (Díaz et al., 2007). Including these dissimilarities into the EcoEDGE approach produces a method that not only takes into account species evolutionary processes, but also ecological processes related to species ecological traits. Moreover, it is known that species assembly and interactions depend on the scale considered (Lortie et al., 2004; Brooker et al., 2009), and that this can also have important implications to biodiversity conservation (Faith et al., 2004; Loyola et al., 2008; Devictor et al., 2010; Hidasi-Neto et al., 2013). EcoEDGE could be calculated for different scales, using regional red lists and traits that are more important in specific scales or situations.

Because species are more likely to interact at finer scales (Lortie et al., 2004; Brooker et al., 2009), these could better reflect functional and phylogenetic relationships among species (see Hidasi-Neto et al., 2013). For example, at the local scale, EcoEDGE can be used with ecological traits of pollinator species in order to conserve their functions while prioritizing the most threatened and ecologically distinct ones. Recently, it has been observed that agricultural production declines resulting from domesticated pollinator bee losses can be buffered by the maintenance of native bee fauna (Winfree et al., 2007). Thus, local conservation actions could aim specific traits related to pollinators' success to identify locally

ly evolutionarily, but also ecologically distinct .  
capable of providing ecosystem services useful to human well-being (see Cardinale  
et al., 2012).

Species distinctiveness is a valuable information to be included in conservation prioritization approaches (Pavoine et al., 2005). Indices that capture this aspect have been widely proposed (Pavoine et al., 2005; Isaac et al., 2007; Steel et al., 2007), although most of them have the focus on the species evolutionary history. Nevertheless, their relevance for conservation science has been widely discussed (Pavoine et al., 2005; Redding & Mooers, 2006; Isaac et al., 2007). This is the first time that both evolutionary and ecological distinctiveness, along with threat status, are considered in a species-focused prioritization method. Furthermore, we did a step forward to incorporate ecological and phylogenetic components into the conservation of the threatened biodiversity. There is a growing concern on the importance of phylogenetic and functional diversity to conservation biology and a way to improve conservation efforts is to take into account the relative contribution of species to evolutionary history and ecological trait diversity in conservation planning. This would be, at least, a relief on the agony of choice.

**ACKNOWLEDGMENTS:** We thank D.M.C. Alves, R. Dobrovolski, L. Jardim and B. Vilela for the help and the discussion about the analyses present in this manuscript. We are grateful to CAPES for the scholarship granted to the first author. Rafael Loyola's research is supported by CNPq (project #563621/2010-9), Conservation International Brazil, O Boticário Group Foundation for Nature Conservation and by a



ed by CNPq (grant #304703/2011-7). Marcus

Glanciaruso also has a productivity grant awarded by CNPq (grant #306843/2012-9).

Paper # of the SISBIOTA - Top Predators network. The authors thank Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) for financial support.

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Table S1 (mammal species with their respective IUCN threat status and values of EDz, EcoDz, EDGEz, EcoEDGEz, and EcoEDGE.)

O material suplementar pode ser adquirido por meio do contato com o autor pelo email: [hidasineto@gmail.com](mailto:hidasineto@gmail.com).

## BIOSKETCH

José Hidasi-Neto is a Master's degree candidate who studies patterns of phylogenetic and functional diversity of assemblages and the conservation of species in face to their phylogenetic and ecological dissimilarities. This article is a product of Hidasi-Neto's Master's thesis under the supervision of Marcus V. Cianciaruso and Rafael D. Loyola.

Marcus V. Cianciaruso is an ecologist interested in the factors responsible for the origins and maintenance of biodiversity. He investigates how species traits, phylogeny and environment are linked and how they can help us to understand biodiversity patterns at different scales.

Rafael D. Loyola works with conservation biogeography. His interests range from theoretical and methodological aspects of ecological niche models (and their applications in conservation biology) to how inclusion of functional and phylogenetic diversity, along with economic costs of biodiversity protection, improves conservation assessment and planning.

Author contributions: MVC and JHN designed the study. MVC, RDL, and JHN collated the data. JHN did the analyses. JHN wrote the first draft of the manuscript and all authors contributed substantially to revisions.





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## **Conclusões Gerais**

### **Definindo Prioridades para a Conservação da Biodiversidade**

**Trabalho submetido para concorrer ao I Prêmio SBPC/GO de Popularização da  
Ciência, promovido pela Secretaria Regional de Goiás da Sociedade Brasileira  
para o Progresso da Ciência**

Hidasi-Neto, J., Cianciaruso, M.V. Definindo Prioridades para a Conservação da  
Biodiversidade.



### Introdução

Desde a metade do século passado, cientistas tentam compreender o quão próximos os seres vivos estão da extinção para entender quais seriam os impactos causados caso eles desaparecessem. O maior projeto mundial voltado para a resolução deste problema é conduzido pela União Internacional para a Conservação da Natureza (International Union for Conservation of Nature . IUCN). Além de avaliar a ameaça das espécies em âmbito global, a IUCN incentiva e providencia normas para a avaliação do risco de extinção em nível regional (por exemplo, países ou estados). Assim, são criadas listas vermelhas que respondem a seguinte questão: quanto as espécies estão ameaçadas de extinção. Entretanto, estudos apontam que as características dos organismos (por exemplo, tamanho do corpo, dieta etc) estão relacionadas à contribuição que estes possuem para o funcionamento dos ecossistemas e, portanto, são essenciais para a manutenção de processos ecológicos (como a polinização de plantas). Além disso, a história evolutiva (parentesco) das espécies tem sido vista como indicadora da diversidade de características dos organismos. Por exemplo, um conjunto de plantas pouco aparentadas (pouco similares) poderia ser mais resistente a perturbações ambientais (como queimadas) do que um conjunto de plantas muito aparentadas, pois necessitaria de mais tipos de perturbação para extinguir suas espécies. Contudo, as diferenças ecológicas e evolutivas entre as espécies não são consideradas na criação das chamadas Listas Vermelhas. Portanto, em face ao cenário de perda de biodiversidade, precisamos determinar quais espécies são

os recursos (dinheiro e pesquisadores) limitados disponíveis para a conservação do meio ambiente.

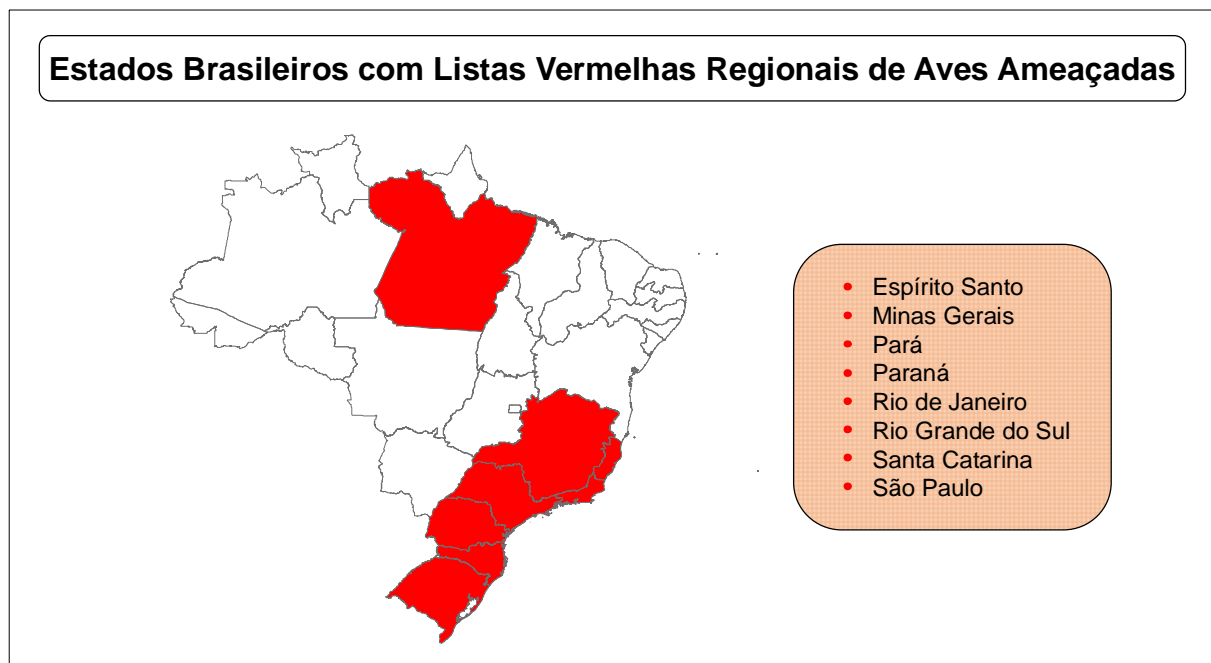
### **Avaliando o grau de ameaça das espécies**

A IUCN determina o grau de ameaça de espécies verificando as mudanças que ocorrem em suas populações (por exemplo, se elas estão diminuindo ao passar do tempo) e nas áreas onde podem viver (IUCN, 2012). Desta forma, espécies são classificadas nas Listas Vermelhas em diferentes categorias de ameaça: Menor Preocupação, Quase Ameaçada, Vulnerável, Ameaçada, Criticamente Ameaçada, Extinta na Natureza e Extinta. Uma espécie também pode ser considerada Deficiente de Dados, quando não há informações suficientes na literatura científica sobre ela, ou como Não Avaliada, quando ainda não houve avaliação sobre se existe ou não informações sobre ela. Essas duas últimas categorias são importantes indicadores das espécies que precisam ser mais estudadas. Além disso, pesquisas recentes discutem como considerar esses organismos no planejamento de ações conservacionistas (TRINDADE-FILHO et al., 2012).

### **Espécies ameaçadas nacional e regionalmente?**

A Lista Vermelha da IUCN determina a ameaça das espécies em escala global. Quando queremos avaliar as ameaças em escalas mais regionais, como em países ou estados, devemos considerar algumas mudanças durante a avaliação da categoria de uma determinada espécie. Dessa forma, uma espécie poderia estar pouco ameaçada em nível global, mas muito ameaçada em nível regional. Um exemplo disso é o lobo-guará (*Chrysocyon brachyurus*), que não está globalmente ameaçado, mas está ameaçado no Brasil. Sendo assim, a criação de uma Lista

modificações pertinentes à mudança da escala espacial considerada na análise das espécies. Uma preocupação notável que devemos ter é quanto à concentração de estudos em regiões economicamente mais desenvolvidas. Por exemplo, as aves representam um dos grupos de organismos mais bem estudados. No Brasil, existe um padrão perceptível da existência de Listas Vermelhas regionais de aves ameaçadas em estados das regiões Sul e Sudeste (Figura 1). Portanto, regiões economicamente desfavorecidas necessitam de mais incentivos para a criação de Listas Vermelhas em suas regiões. Notavelmente, o estado de Goiás e o Distrito Federal atualmente não possuem Listas Vermelhas.



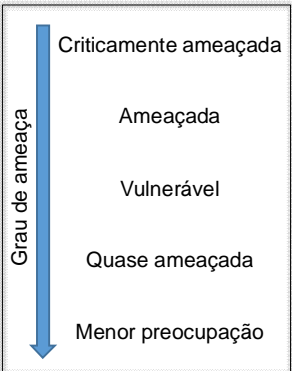
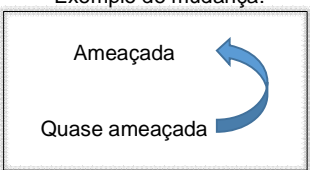
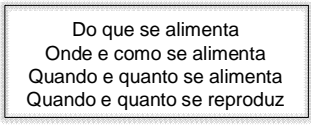
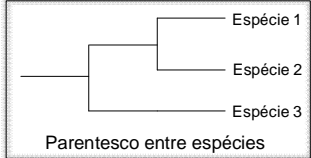
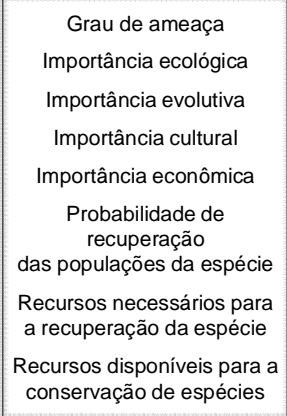
**Figura 1.** Estados brasileiros que possuem Listas Vermelhas regionais de aves ameaçadas de extinção.

### A agonia da escolha

Uma grande dificuldade está relacionada à escolha do que conservar. Por exemplo, uma espécie de abelha pode estar muito ameaçada, mas não polinizar muitas espécies de plantas. Por outro lado, uma outra espécie pode estar menos

grande variedade de plantas. Se você tivesse recursos financeiros para conservar uma delas, qual escolheria? Essa dificuldade em escolher é muitas vezes referida como a *agonia da escolha* (VANE-WRIGHT et al., 1991). Uma possível solução é identificar a contribuição das espécies para o funcionamento dos ecossistemas (diversidade funcional) e para a história evolutiva (diversidade filogenética) dos grupos biológicos. Nós encontramos, por exemplo, que conservar aves brasileiras listadas nas categorias de Lista Vermelhas da IUCN, do Brasil e de estados brasileiros não protege mais diversidade funcional e filogenética do que conservar aves quaisquer (HIDASI-NETO et al., 2013). Sendo assim, precisamos incluir a contribuição que cada espécie possui nesses aspectos funcional e filogenético durante o planejamento de ações conservacionistas (CARVALHO et al., 2010). Precisamos também de maneiras de incluir nesse planejamento a importância que cada espécie possui na economia e na cultura humana, sempre pensando nos recursos disponíveis e necessários para a conservação dos organismos. Nessa perspectiva, uma espécie pode não ser muito importante ecologicamente ou evolutivamente, mas ser usada em muitas atividades econômicas ou trazer bem-estar humano. Por fim, é necessário avaliar se existe a possibilidade real de recuperar as populações destas espécies à maneira como eram antes da ação do homem (Figura 2).

## ção de espécies ameaçadas de extinção

Passo 1	Passo 2	Passo 3	Passo 4
Identificar espécies próximas da extinção	Atualizar a lista constantemente	Conhecer a ecologia e história evolutiva das espécies ameaçadas	Priorizar a conservação de certas espécies ameaçadas
Listá-las de acordo com o grau de ameaça:	Utilizar novas metodologias para avaliar possíveis mudanças no grau de ameaça de espécies	Incentivar estudos sobre:	Selecionar espécies de acordo com:
	Exemplo de mudança: 	Características das espécies  Evolução 	

**Figura 2.** Passos para identificar e priorizar a conservação de espécies ameaçadas de extinção.

### Conclusão

Conservar a biodiversidade pode ser muito mais difícil do que parece. Precisamos conhecer a variedade de organismos do nosso planeta, país e estado. Devemos elaborar e seguir regras para saber quais são as ameaças desses organismos em diferentes escalas espaciais. Além disso, devemos entender o que temos em mãos (como dinheiro e número de pesquisadores) para conservar espécies. Em face a esses desafios, ainda devemos entender o que cada uma dessas espécies representa no funcionamento dos ecossistemas, na história evolutiva e nos padrões socioeconômicos atuais. Somente assim poderemos passar pelo último e inacabável passo de escolher quais espécies conservar.

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### **Fonte Financiadora**

O autor foi bolsista da Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) durante a realização deste trabalho.