

Drafting a Blueprint for Functional and Phylogenetic Diversity Conservation in the Brazilian Cerrado

Rodrigo Assis de Carvalho*, Marcus Vinicius Cianciaruso, Joaquim Trindade-Filho, Máira Dalia Sagnori, Rafael Dias Loyola

Departamento de Ecologia, Universidade Federal de Goiás – UFG, CP 131, CEP 74001-970, Goiânia, GO, Brasil

Abstract

Understanding how different aspects of biodiversity are covered by protected areas and how they could be used to derive efficient conservation actions remains little studied. We mapped mammal functional and phylogenetic diversity in the Cerrado Biodiversity Hotspots to pinpoint sites with high conservation value across the biome. Further, we overlapped sites with higher or lower diversity than expected by chance with the current network of protected areas. Northeast and midwest regions emerged as priority for bats, whereas southern sites were less critical. Midsouth region captured both aspects of non-flying mammals' diversity more than expected. Current network of protected areas covers 52% of sites with high diversity for non-flying mammals; this value being lower respective to bats (22%). Our approach provides a wall-to-wall picture on the effectiveness of the Cerrado protected areas in capturing different aspects of mammal biodiversity and points to new directions for future establishing conservation actions.

Keywords: Bats, Biodiversity Hotspots, Conservation Assessment, Diversity Gradients, Protected Areas, Mammals.

Introduction

Human activities are changing climate and landscapes worldwide, leading to a significant increase in extinction rates. Consequences of extinctions are not restricted to the loss of species *per se* but also to the erosion of phylogenetic diversity (i.e. species evolutionary history, von Euler 2001) and losses of functional diversity (i.e. the diversity of morphological, physiological and ecological traits within biological communities, Ernst *et al.* 2006, Petchey & Gaston 2006). Several studies have already demonstrated that phylogenetic and functional diversity might be lost faster than we lose species (e.g. Heard & Mooers 2000). Thus, preserving these different aspects of biodiversity poses a new and important challenge for conservation biology.

Previous global gap analyses pointed out that biodiversity coverage by networks of existing protected areas is inadequate (Rodrigues *et al.* 2004). But these studies focused in the effectiveness of protected areas to represent the species and, as far as we know, there is only one study highlighting the importance to evaluate the effectiveness of existing protected areas in capturing phylogenetic and functional diversity (Devictor *et al.* 2010). An evaluation of protected areas capability to represent different biodiversity aspects is a critical step for conservation because if sites with high

phylogenetic and functional diversity are not protected by existing reserves, human impacts on species and extinction risk can be higher than previously forecasted. Decrease in communities' phylogenetic and functional diversity lead to loss of species evolutionary history and as well as of future options to ensure provision of ecosystem goods and services (Díaz *et al.* 2007; Forest *et al.* 2007). Another important step for conservation is to identify places outside protected areas that can integrate future strategies and actions to preserve these different biodiversity aspects.

Here we mapped spatial patterns of phylogenetic and functional diversity from bats and non-flying mammals inhabiting the Brazilian Cerrado and evaluated the effectiveness of existing protected areas to represent these different biodiversity facets. Moreover we identified a set of sites that could play an important role in the future to maximize the protection of phylogenetic and functional diversity in the entire biome. We choose the Brazilian Cerrado as a study case because 1) the Cerrado is a Biodiversity Hotspot with high number of endemic and rare species (Mittermeier *et al.* 2004), 2) it is severely threatened by the expansion of agriculture and cattle-ranching activities (Machado *et al.* 2004), and 3) establishment of reserves in the biome often follows subjective criteria with political and economical having more weight than biological ones (Diniz-Filho *et al.* 2008).

*Send correspondence to: Rodrigo Assis de Carvalho
Departamento de Ecologia, Universidade Federal de Goiás,
CP 131, CEP 74001-970, Goiânia, GO, Brasil
E-mail: rodrigoassisscarvalho@gmail.com

We addressed the following questions: 1) Are protected areas from the Brazilian Cerrado capable to protect bats and non-flying mammal functional and phylogenetic diversity? 2) Which sites outside actual protected areas hold high levels of community functional and/or phylogenetic diversity?

Material and Methods

We divided the Brazilian Cerrado into 181 equal-area grid cells of $1^\circ \times 1^\circ$ degree of spatial resolution, excluding isolated and peripheral savanna areas in Amazonian region (see Diniz-Filho *et al.* 2008, for details). Then we overlaid extent of occurrence maps of 187 mammal species inhabiting the biome (retrieved from natureserve.com). We updated species list from Marinho-Filho *et al.* (2002) and constructed range maps based on both primary and secondary literature. Extent of occurrence maps entail their own limitations; therefore using a 1° grid cell recognizes the limitations of the data, reflecting a compromise between data quality and spatial resolution. It may also provide guidelines for detailed studies at finer spatial scales (see Hulbert & Jetz 2007). Recording mammals' presence in each cell we constructed two binary matrices separating mammals into bats and non-flying mammals. We considered this division because bats are functionally very distinct from non-flying mammals, so conservation assessment and actions must be different for these two groups.

For each grid cell we calculated values of functional and phylogenetic diversity associated to bat and non-flying mammal species composition. Based on these values we built maps with the spatial patterns of phylogenetic and functional diversity in the Cerrado. Phylogenetic diversity was based on the phylogeny proposed by Bininda-Emonds *et al.* (2008) and we used phylogenetic diversity (henceforth PD, Faith 1992) as phylogenetic diversity index. PD is obtained by summing branch lengths of a phylogenetic tree from species that compounds a community. PD is therefore a function of species number and phylogenetic differences among species (Faith 1992). The non-flying mammals, *Calomys tocantinsi*, *Philander frenata*, *Rhipidomys emiliae*, *Rhipidomys macrurus*, and *Thylamys velutinus* were not present in the phylogeny used and, thus, we did not consider them in PD calculation. All bat species were present in the phylogeny.

We calculated functional diversity (henceforth, FD) using the protocol proposed by Petchey & Gaston (2006): i) construction of a species-trait matrix; ii) conversion of species-trait matrix into a distance matrix; iii) clustering distance matrix into a dendrogram; and iv) calculating functional diversity by summing dendrogram branch lengths of community species. Here we used the method proposed by Pavoine *et al.* (2009), using Gower distance to create the distance matrix and UPGMA to build up the dendrogram. We collected trait information from the PanTHERIA database (Jones *et al.* 2009) updated with data collated from Marinho-Filho *et al.* (2002) and Reis *et al.* (2006). When trait values were not available for a given species we used

genus/family average values. Traits compiled for bats and non-flying mammals are summarized in Tables S1 and S2 (see on-line Supplementary Material).

For each grid cell we tested if observed FD and PD were higher, equal or lower than expected by chance, assuming a null-model in which every species could occupy any grid cell in the biome. For each grid cell we fixed the observed species richness, randomized species composition without replacement, and then calculated expected FD and PD values. We repeated this procedure 1000 times for each grid cell producing a distribution of random FD values and another for PD. Finally, we checked whether observed FD and PD values for each cell were within the empirical 95% confidence interval of its simulated distribution. This approach allowed us to identify sites harboring higher or lower values of FD and/or PD than expected by chance and overlap them to existing protected areas; hence, we were able to identify if protected cells are capable to preserve these different aspects of biodiversity. We considered a grid cell as protected if it contained a reserve of at least 10 ha included in IUCN categories I-IV. All analyses were done using the R software (R Development Core Team 2009).

Results

The Brazilian Cerrado has several sites with high values of FD and PD for bats (Figure 1a, b) and non-flying mammals (Figure 1c, d). Few sites had low values of mammal FD and/or PD. However, when compared with expected values of functional and phylogenetic diversity different patterns emerged. For bats, the midwest region had sites harboring more FD than expected by chance (Figure 2a) whereas for PD these areas were located in the northeast region (Figure 2b). On the other hand, the southern region had a great number of sites with lower PD than expected (Figure 2b). For non-flying mammals, both aspects of biodiversity achieved higher values than expected by chance in the midsouth region of the biome (Figure 2c, d). Further, two sites had lower values of FD than expected by chance, while four other sites had PD values lower than expected (Figure 2c, d).

Given the criteria used we considered 27 sites to be currently protected in the Brazilian Cerrado. For bats, six of them had higher FD than expected by chance, while 21 did not differ from the null expectation (Figure 3a). Two protected cells had higher values and eight lower values of PD than expected (Figure 3b). When considering the protection of both aspects of biodiversity any protected cell represented them at the same time and just three unprotected cells appears as important (Figure 3c). For non-flying mammals 14 and 12 protected cells had higher values of PD and FD, respectively, than expected by chance (Figure 3d, e). Finally, 12 protected cells had higher values of both biodiversity aspects than expected by our null model (Figure 3f).

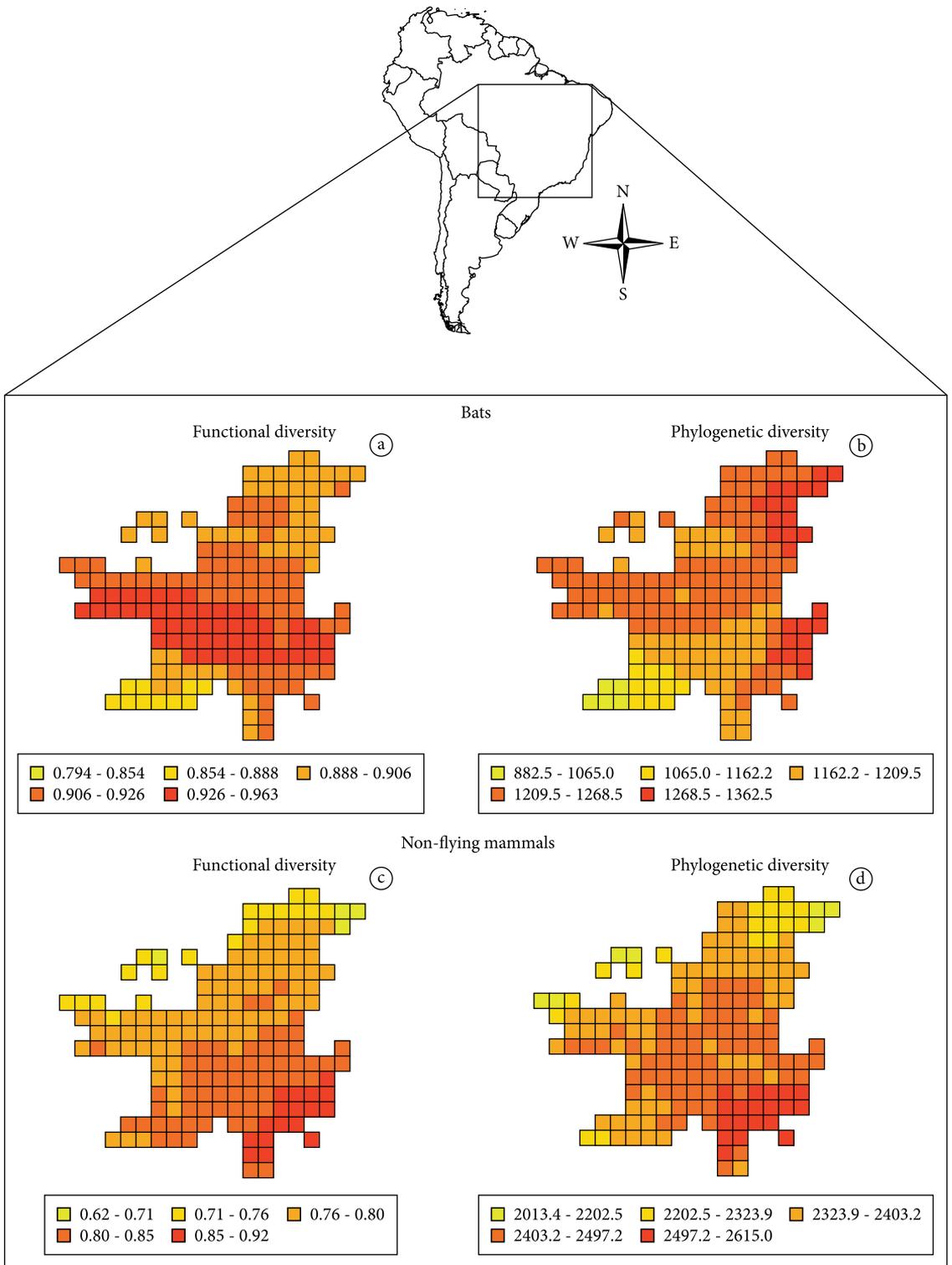


Figure 1. Spatial patterns of functional (a, c) and phylogenetic (b, d) diversity for bats and non-flying mammals occurring in the Brazilian Cerrado.

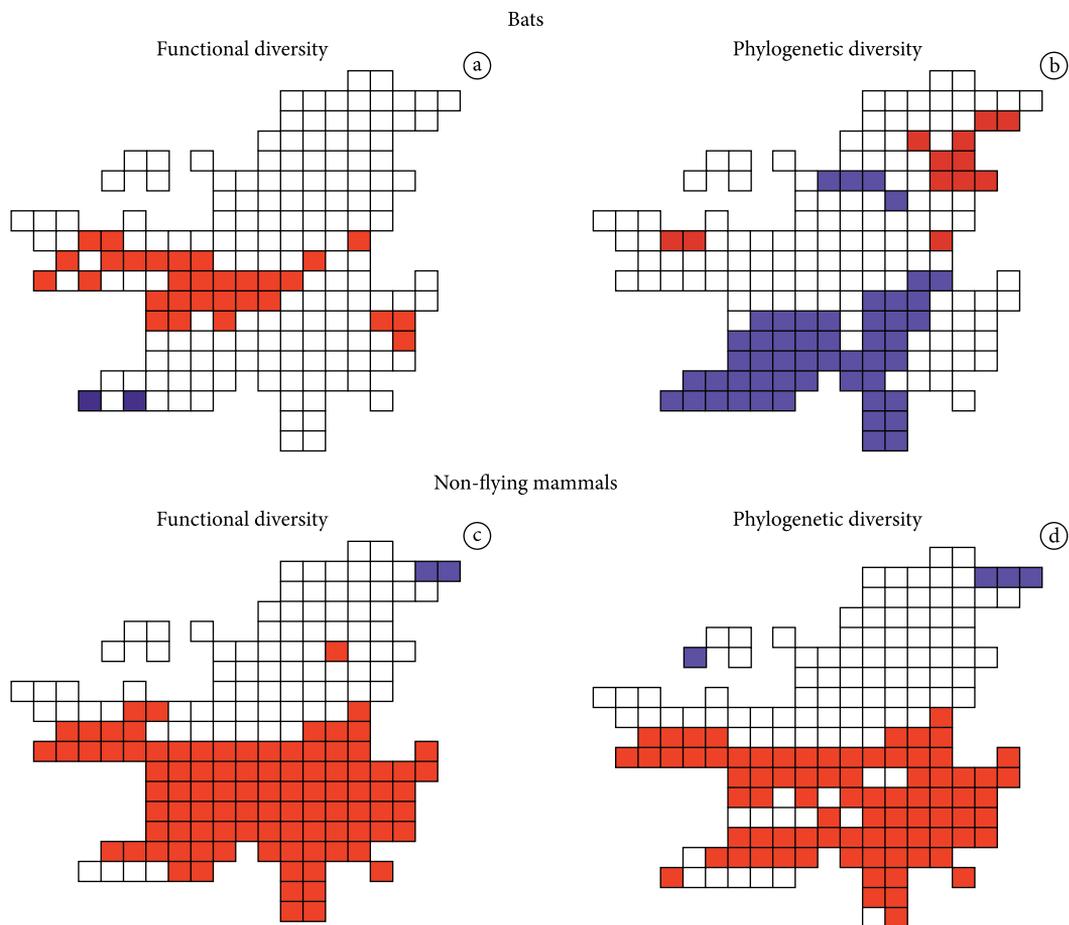


Figure 2. Sites with observed functional (a, c) and phylogenetic (b, d) diversity higher (red cells) or lower (blue cells) than expected by chance for bat and non-flying mammal species pool inhabiting the Brazilian Cerrado.

Discussion

Mammals compose a diversified group that play key roles in ecosystems and provide important benefits to humans (Schipper *et al.* 2008). Given the current biodiversity crisis, conservation actions must be taken fast if we want to preserve these species, their evolutionary history and the ecological processes shaping communities and driven diversity at different spatial scales. Here, we presented a first approach that accounts for FD and PD to shed light on how these biodiversity aspects are protected and how to apply them for future conservation actions under a conservation biogeography approach (*sensu* Whitakker *et al.* 2005).

In the last decades, ecologists, macroecologists and conservation biologists developed analytical tools and methods that made possible a critical evaluation of the differences among species to better understand community structure and composition (Devictor *et al.* 2010). PD and FD are measures that quantify such differences within and among communities. While the former measure focuses in the historical biogeographical events to depict the evolutionary history of local and regional assemblages (Webb *et al.* 2002) the later reflects the role of species interactions and trait diversity of communities that are

supposed to be linked to ecosystem functioning (Petchey & Gaston 2006). Thus, preserving phylogenetic and functional diversity may, respectively, guarantee the maintenance of evolutionary processes and features, as well as the continuity in goods and ecosystem services provision. Conservation of functional and phylogenetic diversity in the Brazilian Cerrado is threatened by the expansion of agriculture and cattle ranching, leading to loss of natural habitats. If no action is taken, the biome is likely to disappear until 2030 (Machado *et al.* 2004), putting in jeopardy species that hold unique evolutionary features, as well as important ecological traits that maintain ecological processes or, in the worst scenario, all of these aspects of biodiversity.

We found that the current network of protected areas established in the Cerrado is not entirely capable to represent mammal functional and phylogenetic diversity. For non-flying mammals 52 and 44% of protected sites represent FD and PD, respectively, better than one would expect by chance alone. The situation is worse for bats, as only 22 and 7.4% of protected sites overlap with sites of higher FD and PD, respectively. Moreover, there is an aggravating factor: 30% of the protected sites carry lower PD than expected.

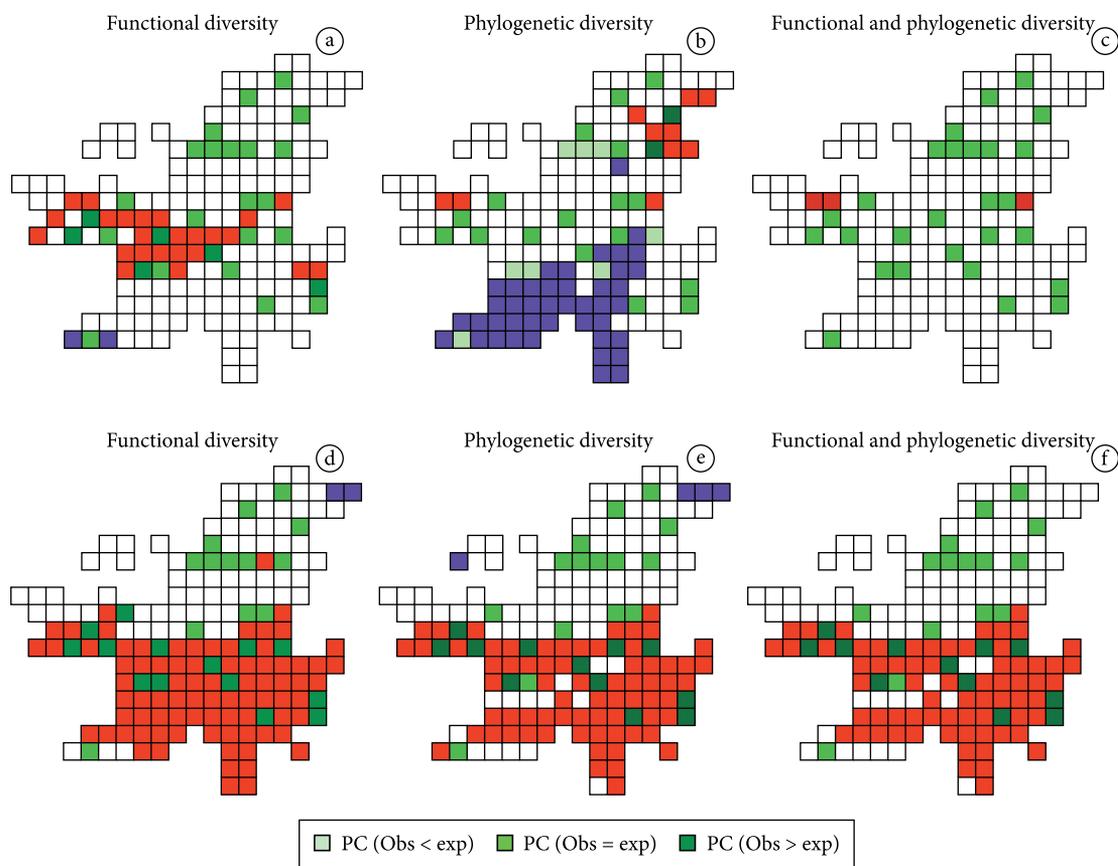


Figure 3. Spatial overlap of existing protected cells (green cells) and sites with observed functional (a, d) and phylogenetic (b, e) diversity higher (red cells) or lower (blue cells) than expected by chance for bat and non-flying mammal species pool inhabiting the Brazilian Cerrado; (c) and (f) stands for the spatial overlap of protected areas and sites showing, at the same time, higher functional and phylogenetic diversity. Color codes as above. PC: Protected Cell.

Inefficiency of existing protected areas in the Brazilian Cerrado for these two biodiversity aspects reflects the consequences of government opportunistic old-fashion way to establish nature preserves, choosing sites for conservation under political and economical criteria (Diniz-Filho *et al.* 2008) or just for their scenic value. Such policy for establishing protected areas is surely not exclusive from the Brazilian Government, being commonly applied worldwide (Margules & Pressey 2000). As a consequence, species evolutionary history and the diversity of ecological traits, which should have a close link to ecosystem processes, may be more threatened than we expect. Under this scenario selecting new areas to maximize the representation of phylogenetic and functional diversity is essential for conservation purposes. In fact, recent attempts to include species evolutionary history (*e.g.* Forest *et al.* 2007, Loyola *et al.* 2008a) and biological traits (*e.g.* Loyola *et al.* 2008b, 2009) in conservation planning have been published elsewhere.

In the Brazilian Cerrado, in particular, three sites are crucial for conserving higher values of bat FD and PD at the same time (see Figure 3c); non-flying mammal PD and FD could be well conserved in the biome focusing in the midsouth region (see Figure 3d, f). We suggest these areas should

be the focus of future studies aimed at applying a spatial conservation prioritization for the Cerrado. Although we indicate these regions as priority sites for mammal FD and PD conservation we call attention that other sites are also important to the persistence of species. For example, if we consider complementarity, a key concept in spatial conservation prioritization (Moilanen *et al.* 2009), maybe the northern sites appears as important for non-flying mammals because they have species not represented in current network of protected areas. But if systematic conservation plans built on complementarity indicate priority sites both in northern and southern regions, conservation investments should be first placed in the South because this region captures higher values of FD and PD than expected by a site from the north. In a nut-shell, spatial patterns of different biodiversity facets can add important information to guide decisions of where start to invest aiming to maximizing conservation of all biodiversity.

Finally, our study reinforces the idea proposed by Devictor *et al.* (2010), which is to avoid strategies using a single biodiversity aspect as a cure-all. Despite several areas with high values of FD and PD for non-flying mammals are congruent, bats are not in the same situation. While good areas to preserve FD of bats are in midwest region,

northeast concentrates better sites for conserving PD. Hence, effective conservation strategies may emerge with biodiversity assessments done under integrative approaches connecting biogeography, evolutionary and functional ecology (Johnson & Stinchcombe 2007).

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References

- Bininda-Emonds ORP *et al.*, 2008. The delayed rise of present-day mammals. *Nature*, 446:507-512.
- Devictor *et al.*, 2010. Spatial mismatch and congruence between taxonomic, phylogenetic and functional diversity: the need for integrative conservation strategies in a changing world. *Ecology Letters*, 13:1030-1040.
- Díaz S *et al.*, 2007. Incorporating plant functional diversity effects in ecosystem service assessments. *Proceedings of the National Academy of Science*, 104:20684-20689.
- Diniz-Filho JAF *et al.*, 2008. Spatial patterns of terrestrial vertebrate species richness in the Brazilian Cerrado. *Zoological Studies*, 47:146-157.
- Ernst R, Linsenmair KE & Rodel MO, 2006. Diversity erosion beyond the specie level: Dramatic loss of functional diversity after selective logging in two tropical amphibian communities. *Biological Conservation*, 133:143-155.
- Faith DP, 1992. Conservation evaluation and phylogenetic diversity. *Biological Conservation*, 61:1-10.
- Forest F *et al.*, 2007. Preserving the evolutionary potential of floras in biodiversity hotspots. *Nature*, 445:757-760.
- Heard SB & Mooers AØ, 2000. Phylogenetically patterned speciation rates and extinction risks change the loss of evolutionary history during extinctions. *Proceedings of the Royal Society B*, 267:613-620.
- Hulbert AH & Jetz W, 2007. Species richness, hotspots, and the scale dependence of range maps in ecology and conservation. *Proceedings of the National Academy of Science*, 104:13384-13389.
- Johnson MTJ & Stinchcombe JR, 2007. An emerging synthesis between community ecology and evolutionary biology. *Trends in Ecology & Evolution*, 22:250-257.
- Jones KE *et al.*, 2009. PanTHERIA: a species-level database of life history, ecology, and geography of extant and recently extinct mammals. *Ecology*, 90:2648.
- Loyola RD *et al.*, 2008a. Conservation of Neotropical carnivores under different prioritization scenarios: mapping species traits to minimize conservation conflicts. *Diversity and Distributions*, 14:949-960.
- Loyola RD *et al.*, 2008b. Hung out to dry: choice of priority ecoregions for conserving threatened Neotropical anurans depend on their life-history traits. *PLoS ONE*, 3:e2120.
- Loyola RD *et al.*, 2009. Integrating Economic Costs and Biological Traits into Global Conservation Priorities for Carnivores. *PLoS One*, 4:e6807.
- Machado RB *et al.*, 2004. *Estimativas de perda da área do cerrado brasileiro*. Brasília: Conservation International.
- Margules CR & Pressey RL, 2000. Systematic conservation planning. *Nature*, 405:243-253.
- Marinho-Filho J, Rodrigues FHG & Juarez KM, 2002. The Cerrado mammals: Diversity, Ecology and Natural History In: Oliveira PS & Marquis RJ, ed. *The Cerrados of Brazil: ecology and natural history of a Neotropical savanna*. New York: Columbia University Press. 266-284 p.
- Mittermeier RA *et al.*, 2004. Hotspots Revisited: Earth's Biologically Richest and Most Endangered Ecoregions. CEMEX, Mexico City, Mexico.
- Moilanen A, Wilson KA & Possingham HP, 2009. *Spatial conservation prioritization: quantitative methods & computational tools*. Oxford: Oxford University Press. 304 p.
- Pavoine S *et al.* 2009. On the challenge of treating various types of variables: application for improving the measurement of functional diversity. *Oikos*, 118:391-402.
- Petchey OL & Gaston KJ, 2006. Functional diversity: back to basics and looking forward. *Ecology Letters*, 9:741-758.
- R Development Core Team, 2009. *R: A language and environment for statistical computing*. Vienna: R Foundation for Statistical Computing. Available from: <<http://www.R-project.org>>.
- Reis NR *et al.*, 2006. *Mamíferos do Brasil*. Londrina. 437 p.
- Rodrigues ASL *et al.*, 2004. Effectiveness of the global protected area network in representing species diversity. *Nature*, 428:640-643.
- Schipper J. *et al.*, 2008. The Status of the World's Land and Marine Mammals: Diversity, Threat, and Knowledge. *Science*, 322:225-230.
- von Euler F, 2001. Selective extinction and rapid loss of evolutionary history in the bird fauna. *Proceedings of the Royal Society B*, 268:127-130.
- Webb CO *et al.*, 2002. Phylogenies and community ecology. *Annual Review of Ecology and Systematics*, 33:475-505.
- Whitaker RJ *et al.* 2005. Conservation Biogeography: assessment and prospect. *Diversity and Distributions*, 11:3-23.

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