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Geographic range-scale assessment of species conservation status: A framework linking species and landscape features

Ludmila Rattis[a,b,*], Ricardo Dobrovolski[c], Maurício Talebi[d], Rafael Loyola[e]

[a] *Ecology Graduate Program, State University of Campinas, P.O. Box 6109, CEP 13083-970 Campinas, São Paulo, Brazil*
[b] *Woods Hole Research Center, Falmouth, MA Zip Code 02540, USA*
[c] *Laboratório de Ecologia e Conservação, Instituto de Biologia, Universidade Federal da Bahia, CEP 40170-180 Salvador, Bahia, Brazil*
[d] *Departmento de Biologia, Universidade Federal de São Paulo, Rua Professor Artur Riedel, 275, Campus Diadema, CEP 09972-270 São Paulo, Brazil*
[e] *Laboratório de Biogeografia da Conservação, Departamento de Ecologia, Universidade Federal de Goiás, Avenida Esperança s/n, Campus Samambaia, CEP 74.690-900 Goiânia, Goiás, Brazil*

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ABSTRACT

The concept of habitat and spatial extent are key features in landscape ecology. A non-precise definition of habitat and the wrong choice of the scale can affect model outcomes and our understanding about population conservation status. We proposed a framework and applied to five species representing different ecological profiles (1) to model species occurrences and (2) to evaluate habitat structure at nine different scale extents from local landscapes to entire species range. Then, we (3) evaluated the scale sensitivity of each metric and (4) assessed if the scale sensitivity of each metric changed according to species. Our model was succesfull in predicting species occurrence for all species. When we applied deductive suitability models, the total area of remaining habitat varied from 83% to 12% of the original extension of occurrence. On average, the proportion of habitat amount, fragmentation, and carrying capacity decreased and functional increased as scale extent increased. Habitat amount and fragmentation assessed locally would show the same pattern across species' range, but carrying capacity and functional connectivity – which consider biological features – were affected by the choice of scale. Also, the inclusion of species preferences on habitat modeling diminished commission errors arising from landscape-scale underestimation of species' occurrences. Local landscapes samples were not able to represent species' entire range feature and the way that individuals reach the remaining habitat depends on species' features. Species conservation status should be assessed preferably at the range scale and include species biological features as an additional factor determining species occupancy inside geographic ranges.

Introduction

The consequences of land use changes on biodiversity have been addressed by studies at different levels of ecological organization and geographic scales. These studies range from metapopulation established in fragmented landscapes (Ovaskainen and Hanski, 2003; Burkey, 1997), to the investigation of landscape features that modulate the species-area relationship (Benchimol and Peres, 2013; Hanski et al., 2013; Rybicki and Hanski, 2013). Also, the consequences of land use changes have been addressed by studies focusing on the perceived effects of habitat loss on biodiversity at regional and broader geographic scales (Banks-Leite et al., 2014; Brooks et al., 2002; Gaston et al., 2003; Pfeifer et al., 2017).

Given the Wallacean shortfall, i.e. lack of information about species' distribution, habitat suitability models have been suggested as a tool to refine information on species distribution and help guiding conservation assessment and decision more precisely (da Fonseca et al., 2000; Ottaviani et al., 2004; Rondinini et al., 2011). Habitat is defined as the set of resources and conditions present in an area that produce occupancy, including survival and reproduction by a given organism (Krausman, 1999). Habitat suitability models are important tools to evaluate species distribution based on their potential habitat remnants. They rely on the Hutchinson's concept of ecological niche (Hirzel and Arlettaz, 2003) and are designed to predict species' occurrence based on environmental data and species habitat preferences. Among several possible applications, these models have been used (1) to assess

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[*] Corresponding author at: Woods Hole Research Center, 149 Woods Hole Road, Zip Code 02540, Falmouth, MA, USA.
E-mail address: ludmilarattis@gmail.com (L. Rattis).

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species recovery (Cianfrani et al., 2013); (2) to estimate extinction debt when coupled with species-area relationships (Olivier et al., 2013); (3) to map the potential distribution of invasive species (Crall et al., 2013); (4) to evaluate global patterns of species richness (Rondinini et al., 2011); and (5) to propose global priority areas for conservation efforts (Brum et al., 2017).

However, habitat suitability models by itself lack information about the interaction between species features and spatial structure of habitat patches. Thus, a set of methods to assess the effects of landscape structure on species responses have been developed (McGarigal and Cushman, 2005). Nonetheless, those methods employed to study the effect of patch size and isolation on biodiversity usually 1) lack information on species' ecological features and their ecological meaning (for instance, classic landscape metrics describing landscape structure by itself, like habitat amount, edge length, shape index, etc.); 2) do not consider species-specific responses to landscape change; 3) are not able to transpose the results obtained from one scale to another; or 4) require a large amount of data. Considering this, Vos et al. (2001) proposed two indices linking species to habitat, both called Ecologically Scaled Landscape Indices: $ESLI_c$ and $ESLI_k$. $ESLI_c$ associates patch area, pairwise distance between patches, and species' movement ability resulting in an index that reflects landscape functional connectivity. $ESLI_k$ associates patch area and individual area requirement, resulting in an index that describes the landscape carrying capacity for a given metapopulation.

We employed an approach that classifies species according to their response to environment, specifically to habitat fragmentation and habitat amount sensitivity: the ecological profile. Such approach incorporates different colonization responses to environment when empirical data is missing (Grimm et al., 1996). The strength of this approach is the employment of this concept in answering general questions about how a given group of organisms with some intrinsic features can respond to differences in the composition and configuration of natural environments. For instance, species with similar dispersal ability and similar total areas required to reproduce, belonging to different taxa, could be considered part of the same ecological profile.

Here, we propose a framework to evaluate connectivity and carrying capacity at species range scale, coupling deductive habitat suitability model and landscape connectivity and carrying capacity through *ESLIs*. Our framework includes an intuitive and realistic definition of habitat and it is a more factual way to know how much habitat is there based not only on remaining area, but also on species' habitat preferences. Also, it quantifies how much habitat would be potentially occupied by a metapopulation, given patches' carrying capacity that, even though isolated, would be connected by individual moving ability, and it allows one to perform a validation test for obtained models. Using this approach, we 1) modeled habitat suitability based on deductive habitat suitability modelling in order; 2) to evaluate habitat amount, fragmentation, functional connectivity and carrying capacity at nine different scale extents from local landscapes to species range; 3) to evaluate the scale sensitivity of each metric and 4) to assess if the scale sensitivity of each metric changed according to the species. To exemplify our approach, we applied it to five species that represent different ecological profiles distributed in different places around the world.

Methods

Case studies

We chose five species belonging to four different ecological profiles (*sensu* Vos et al., 2001) distributed around the world (Fig. 1): 1) *Aquila adalberti*; 2) *Brachyteles arachnoides*; 3) *Eulemur flavifrons*; 4) *Heloderma suspectum*; 5) *Sarcophilus harrisii*. These five species were choose based on the following criteria: 1) geographic regions: these five species are representing different regions around the world to assure that the geographical location is not a constraint; 2) conservation status: according to IUCN those species are classified in different threat categories, Near Threatened, Vulnerable to extinction, Endangered and Critically Endangered; 3) different reproductive units: groups, female, couples; 4) different taxa: three groups of vertebrates with different mobilities and area requirements; 5) different sources of occurrence data: specialists, GBIF (http://www.gbif.org/) and scientific groups; 6) different number of occurrences to work with: which varies from 11 (*E. flavifrons*) to 332 (*S. harrisii*).

The Spanish Imperial Eagle *A. adalberti* (Falconiformes, Accitripidae) is highly sensible to habitat fragmentation given its large individual area requirements and short dispersal ability. Other factors can increase its extinction risk, like sedentary habit, low reproductive rates (in average 0.75 offspring/reproductive unit), late reproductive maturity (reproductive age at 4–5 years), and high mortality caused by electrocution and illegal poisoning, the latest resulting in a decreasing fecundity of adults (Ferrer et al., 2013, 2003). In fact, according to the IUCN Red List of Threatened Species (IUCN, 2017), *A. adalberti* is Vulnerable to extinction (VU), though its population is increasing due to conservation initiatives (Ferrer et al., 2013).

The South American Muriqui *B. arachnoides* (Primates, Atelidae) would be theoretically placed at a low extinction risk level considering some features such as small individual area requirement and intermediary dispersal ability place. However, according to the IUCN Red List, *B. arachnoides* is assigned as Endangered (EN) (IUCN, 2017). The major threat to *B. arachnoides* is the residential and commercial development and agriculture especially annual and perennial non-timber crops (Mendes et al., 2008).

The Malagasy Blue-eyed Black lemur *E. flavifrons* (Primates, Lemuridae), also has small individual area requirement and intermediary dispersal ability. The major threat to *E. flavifrons* is forest conversion by slash-and-burn agriculture and hunting (Andriaholinirina et al., 2014). *E. flavifrons* living in disturbed habitat is usually under stress, as shown by parasitological analysis in areas with different levels of degradation (Schwitzer et al., 2010). This species is currently considered as Critically Endangered (CR) by the IUCN Red List (IUCN, 2017).

The North American Gila Monster *H. suspectum* (Squamata, Helodermatidae), which some features could make this species more robust to habitat disturbances. Among these features are the survival strategies that combine timing and duration of activity (predominantly diurnal during rainy periods and nocturnal activity during hot and dry conditions), ability to capitalize on pulsatile energetic resources when available, as well as an economical use of this resources and high tolerance to physiological disturbances (Davis and DeNardo, 2010). This species presents small individual area requirement and low dispersal ability. According to the IUCN Red List, this species is considered Near Threatened (NT) (IUCN, 2017).

The Tasmanian Devil *S. harrisii* (Marsupialia, Dasyuridae) presents large dispersal ability and large individual area requirement regardless of its habitat generalism. This species is victim of the devil facial tumor disease, a parasitic cancer that has rapidly annihilated local populations. According to the IUCN Red List, this species belongs to the Endangered category (EN) (IUCN, 2017).

Habitat suitability modelling

We built deductive habitat suitability models based on two spatial variables: land use and elevation. We extracted land use information from the Glob Cover 2.1, a global land use map

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