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An integrated trait-based framework to predict extinction risk and guide conservation planning in biodiversity hotspots

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A B S T R A C T

Determining species extinction risk and its drivers is a major goal for conservation biology. The IUCN Red List is widely used for classifying extinction-risk and prioritizing conservation action. However, this system has been acknowledged as biased and complementary approaches are strongly recommended to achieve more reliable conclusions on conservation priorities. Species traits, often perceived as determinant for resiliency to disturbances, have been used to identify potentially vulnerable species, even when data are scarce (e.g. Data Deficient species). We provide an integrative and cost-effective framework for predicting species extinction-risk using data on 195 anurans from the Brazilian Cerrado. We used IUCN population trend and expert-perceived vulnerability to habitat alteration as response variables, to identify traits associated to increased extinction-risk. We used species traits, threat pressure and geographic range to determine which species and areas should have higher conservation priority. We found the IUCN extinction-risk to be underestimated, as many species categorized as LC or DD are actually sensitive and/or declining. We identified breeding site, habitat and clutch size as predictors of anuran extinction risk. We found that >70% of the biome's anurans have major protection gaps, incurring in high extinction-risk. The southwest and central regions of the biome are the main hotspots for high extinction-risk species and should be prioritized for conservation. Our framework may be particularly valuable to assess extinction-risk and prioritize conservation action regarding less studied taxa and regions with high anthropogenic pressure, but weak government support and scarce funding.

1. Introduction

Vulnerability to disturbance differs across species and many systems have been devised to determine extinction risk, aid in conservation planning and raise public awareness. The most prevalent of these systems is the IUCN Red List of Threatened Species (henceforth "Red List"), developed by the Species Survival Commission of the World Conservation Union (IUCN; http://www.iucn.org). The Red List highlights species at greater risk of extinction, aiming to prioritize conservation action. The Red List classifies species based on quantitative data on population size and geographic range (IUCN, 2001). If population size or range has been shown to decline, species are classified as threatened (Critically Endangered (CR), Endangered (EN) or Vulnerable (VU)). If threat criteria are not met, species are classified as not threatened (Near Threatened (NT), Least Concern (LC)) or, when there is no sufficient data for categorization, as Data Deficient (DD). The Red List has been paramount for establishing protection priorities and justifying conservation funding (Baillie et al., 2008; Mace and Baillie, 2007; Young et al., 2014). However, conservation status is more relative than absolute, in the sense that a classification of CR does not imply that the species is almost extinct, but only that it is in greater danger of becoming extinct – even if by stochastic events – compared to a species that is classified in any other category.

The Red List's reliability stems from its criteria, which are objective and relatively easy to apply when adequate information is available (IUCN, 2001). These criteria were, however, defined based on the requirements of large vertebrate species, causing the system to be putatively biased towards larger and easily sampled taxa (Cardoso et al., 2011; Régnier et al., 2015; Triantis et al., 2010). Hence, even if enough information could be gathered, they may not be appropriate for many taxa. Furthermore, decade-long re-evaluation periods may render the Red List unable to detect shifts in extinction-risk for fast-declining species, further compromising its effectiveness. Despite its unarguable value for conservation, the Red List should not be used as the sole means of setting priorities for conservation measures (IUCN, 2001). This recommendation is rarely appreciated and, due to the system's importance in current conservation circles, its bias is often pervasive in species inventories (Cardoso et al., 2011), reintroduction projects (Seddon et al., 2007), invasive species studies (Pyšek et al., 2008), legally protected species lists and conservation funding (Cardoso et al., 2011). Although there is a considerable degree of classification

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consistency, the Red List does not take into account species life histories, causing under- or over-estimated extinction-risks in certain cases (IUCN, 2001). Hence, threat category provides only a relative assessment of the extinction-risk under current circumstances, and should not be used in isolation. A system for assessing priorities for action should include numerous other factors to guide conservation action, such as biological characteristics of the subject, costs, logistics and chances of success (IUCN, 2001).

Our understanding of which species are most at risk remains poor, especially for inconspicuous taxa, for which natural histories have not been well documented and population changes are hard to detect (Cardoso et al., 2011). For example, according to the Red List, 32.4% of the world's amphibians are threatened or extinct, and 24.4% are unclassified (DD), due to insufficient information (IUCN, 2008). Amphibians are among the least studied vertebrates when compared to birds and mammals (Hecnar, 2009), due to their inconspicuous nature and small size (Wells, 2007). In a highly anthropogenic world, with alarming climate change predictions and limited funding for conservation, it is vital to develop more accurate and case-specific frameworks to prioritize conservation actions and aid mitigation.

Differences in species extinction risk have been partially attributed to variation in biological traits (Pearson et al., 2014; Van Allen et al., 2012). Indeed, habitat preferences, ecological traits and demographic characteristics have been successfully used to predict species' extinction risk (e.g. Cardillo et al., 2005; Davies et al., 2004; Lee and Jetz, 2011; Pearson et al., 2014). Therefore, understanding how species traits interact to determine extinction-risk may help identify species at greater risk and prompt cost-effective and timely conservation measures.

Amphibians play keystone roles in ecosystem functioning, acting as both predators and prey, and enabling nutrient transport between aquatic and terrestrial systems (Blaustein et al., 2011; Wells, 2007). Furthermore, amphibians are among the most diverse and abundant vertebrates, comprising species from a variety of habits, breeding strategies and dispersal abilities (Wells, 2007). Due to their biphasic life cycle, highly permeable skin and ectothermic physiology, amphibians are very dependent on environmental quality and vulnerable to its change (Niemi and McDonald, 2004). Hence, amphibian extinction risk can be used as a surrogate for ecosystem resilience (Davic and Welsh, 2004) and a suitable model for conceiving a new framework to informatively predict extinction risk.

The Cerrado is the world's largest and most biodiverse savanna. It is also Brazil's new agricultural frontier, hosting the country's largest bovine herd and a percentage of crop area larger than that of the Amazon. About 40% of the biome has been converted into crops and pastures (Sano et al., 2010) and only 6.48% is under protection (Arruda et al., 2008; Overbeck et al., 2015). The anuran assemblage of this biome has high endemicity (ca. 50%) (Valdujo et al., 2012), but low official extinction risk, as only 3 amphibians are considered threatened (IUCN; 2014, MMA, 2014), while 22% remain Data Deficient. Discrepancy between low extinction risk, high endemicity (Valdujo et al., 2012) and intense anthropogenic pressure may be explained by historical biases towards Neotropical forest biomes, such as the Amazon or the Atlantic Forest. For example, sixteen Atlantic Forest anurans are threatened, but a Web of Science (apps.webofknowledge.com, accessed on April 2015) search using "Atlantic Forest" or "Cerrado" in combination with "amphibians" retrieved 3 times more journal articles on the Atlantic Forest than on the Cerrado.

With the ever-increasing anthropogenic pressure on biomes worldwide, many species may be unrecognizably endangered. There is a need for integrative, predictive and spatially explicit models capable of accurately identifying species at higher risk, evaluating the consequences of disturbances for biodiversity and guiding conservation actions, especially in biodiverse, highly disturbed and scarcely studied regions. Herein we assess amphibian extinction risk and identify its drivers in a highly disturbed biodiversity hotspot. We propose an integrative and cost-effective method for accurately assessing and predicting extinction risk, considering species rarity, threat pressure and trait-based vulnerability to disturbances. We compiled an extensive database with 12 biological traits (e.g., activity, habits) and 4 variables describing threat pressure (e.g., percentage of a species' range occupied by crops) for 195 Cerrado anurans. First, to identify traits associated to increased extinction risk across species, we used two proxies for extinction risk as response variables: IUCN population trend and expert-perceived vulnerability to habitat alteration. This analysis allowed us then to (i) predict population decline and vulnerability to habitat alteration for every species; (ii) use our results to calculate integrative species-specific conservation targets; (iii) perform a gap analysis to evaluate how effective the network of the biome's protected areas (PA) is, and which species have more urgent conservation needs, and (iv) build maps representing areas with increased extinction-risk.

2. Methods

Our framework is composed of 3 steps, initially requiring (i) proxies for extinction-risk obtained mostly from the IUCN online database, (ii) data on 12 biological traits, (iii) distribution maps for every species and (iv) quantification of threat pressure on each species' range. In the second step, we analyze this data using random forest and classification tree models, to (i) identify traits associated to increased extinction-risk and (ii) predict population trend and vulnerability to habitat alteration for every species, including species for which there is no information on those parameters. In the final step of the framework, we use (i) the traits associated to increased extinction risk, (ii) species' geographic range and (iii) predicted susceptibility (population trend and vulnerability) to calculate conservation targets and identify high priority species and areas (Fig. 1).

2.1. Data collection

We compiled intrinsic biological traits and extrinsic environmental variables for 195 species of anurans extant in the Brazilian Cerrado. We used the species list from Valdujo et al. (2012) and crossed it with the IUCN distribution maps (IUCN, 2008). This data crossing motivated us to exclude species for which we could not find satisfactory distribution maps, and include others not considered by Valdujo et al. (2012), with mapped occurrence in the Cerrado. The biological traits we considered for this study were anuran activity, adult snout–vent length (SVL), geographic range size, habitat, habit, fossorial behavior, breeding site, breeding strategy, clutch size, parental care, breeding season and breeding pattern. We also considered 4 variables quantifying extrinsic environmental variables, namely the percentage of range area in Cerrado, and percentage of natural vegetation, crops and pastures within each species' geographic range in the Cerrado (Table A1, Supplementary material). Trait data were compiled from the literature, AmphibiaWeb and IUCN online databases. If published data were unavailable, we relied on expert opinion. External threats were quantified using species distribution maps (IUCN, 2008) and a shapefile of land use in the Cerrado (e.g., agriculture, urban areas) provided by the Brazilian Ministry of Environment (MMA, 2007). We determined the percentage of each species' range occupied by crops, pastures and natural vegetation using program QGIS v.2.6.1 Brighton. Predictor variables were chosen based on our perception of their importance for determining species responses to anthropogenic disturbances, and also on data availability.

To identify which traits are associated with increased extinction risk across species, we used two proxies for extinction risk obtained from the IUCN Red List online database, as response variables. Due to the relatively low percentage of threatened amphibians (CR, VU, EN) among the 195 known from the Cerrado, we used other two variables provided by IUCN: (i) population trend, and (ii) expert-perceived vulnerability to habitat alteration. Both population trend and expert-perceived vulnerability were obtained from each species' fact sheet on the IUCN Red List database. This information is based on empirical data collected by