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Formulating conservation targets for a gap analysis of endemic lizards in a biodiversity hotspot

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ABSTRACT

Species gap analyses that adopt conservation targets based on individual species attributes recognize that some biodiversity features need more protection than others and should lead to better outcomes than uniform conservation targets. In the Brazilian Cerrado hotspot, 4 of the 30 endemic lizard species are included in the IUCN or Brazilian red lists of threatened species. For 18 species with more than 5 occurrence records, we produced distribution models using Maxent and for 12 species with less than 5 occurrence records we used a 5 km radius around the records to indicate distributions. For all species, we estimated habitat loss after discounting cleared areas from indicated distributions. Non-modeled species were considered as truly restricted-range endemics and had conservation targets set a priori as 100%. We formulated conservation targets for 18 modeled species based on three characteristics: natural rarity, vulnerability, and life-history. We estimated vulnerability from a model of future habitat loss across the Cerrado, derived with Maxent. We then performed a gap analysis considering strictly protected conservation areas. We applied percentage targets (between 12% and 23%) to estimated species distributions prior to habitat loss and evaluated the targets against the presence of the species within strictly protected conservation areas. Disturbingly, only one species is adequately protected by the current system of protected areas. We also found that one species is a minor conservation gap, whereas the remaining 28 species are either major (13) or total (5) conservation gaps. Habitat loss has erased a significant fraction of the original distribution of Cerrado endemic lizards and the existent network of protected areas is wholly inadequate to ensure their conservation. The use of conservation targets based on natural rarity, vulnerability, and life-story will support more defensible conservation guidelines than commonly used uniform targets for this threatened Neotropical savanna biome.

1. Introduction

The protection of natural areas is a historical concern of humankind. However, the effectiveness of many protected areas (PAs) around the world is questionable, because they have often been established for reasons unrelated to biodiversity conservation, such as their scenic value or lack of competing interests (Andelman and Willig, 2003; Pressey and Tully, 1994; Rodrigues et al., 2004b; Rouget et al., 2003a; Scott et al., 2001). To be effective, a PA system should be composed of reserves that complement each other in their biodiversity attributes, minimizing redundancy across space (Margules and Pressey, 2000; Pressey and Nicholls, 1989). They should also be representative, containing samples of these attributes at adequate levels to ensure their long-term permanence and viability (Pressey and Nicholls, 1989); otherwise, gaps in regional biodiversity conservation will occur (Jennings, 2000; Scott et al., 1993). Among the several tools to make PA systems more representative (Margules and Pressey, 2000), gap analysis has been successfully used in conservation planning (Catullo et al., 2008; De Klerka et al., 2004; Oldfield et al., 2004; Paglia et al., 2004).

To detect whether a PA system adequately protects a given species or taxonomic group of interest, a gap analysis requires: (1) an estimate of its distribution in the region, (2) the identification of protected sites (Scott et al., 1993), and (3) the definition of explicit

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conservation targets necessary to ensure acceptably small extinction risks (Pressey et al., 2003). Conservation targets represent "the minimum amount of a particular biodiversity feature that we would like to conserve through one or several conservation actions" (Carwardine et al., 2009). Targets lend accountability and defensibility to the process of conservation planning (Pressey et al., 2003), even recognizing the inevitable uncertainty inherent to the process of target definition, since most species are insufficiently studied. We are usually not sure about species distributions, population sizes, metapopulation dynamics, gene flow, and other important biological and ecological factors that could accurately indicate the area requirements for species conservation. Nevertheless, it is important to use the best available information and, in the absence of an adequate knowledge of the species full distribution, species distribution models (SDMs) can be useful, especially when sampling bias can be controlled (Costa et al., 2010; Elith et al., 2006; Phillips et al., 2006).

Integrating vulnerability estimates is also valuable in systematic conservation planning (Pressey et al., 2003), as indications of how much and how urgently protection is needed. Populations in more threatened regions have less chance of persisting outside PAs (Pressey and Taffs, 2001) and vulnerability can be estimated by modeling threats across species distributions. For example, Rouget et al. (2003b) used rule-based and statistical models to identify areas likely to be transformed in the future by agriculture, urbanization, and alien species, and also to formulate conservation targets for different habitat types in the Cape Floristic Region of South Africa. The most commonly-used targets in biodiversity conservation planning exercises are uniform targets for all species considered (Urbina-Cardona and Flores-Villela, 2010) or for groups of species with equivalent distributions (Catullo et al., 2008; Marini et al., 2009). Problems with uniform targets include potentially favoring widespread species (Vimal et al., 2011) and failing to acknowledge that some species need more extensive protection than others for a variety of reasons (Pressey et al., 2003).

The South American Cerrado, the largest and richest savanna on Earth (Eiten, 1971; Ribeiro and Walter, 1998), has a large core distribution in central Brazil with isolated patches in Amazonia and the Atlantic Forest (Fig. 1a). It is characterized by a highly heterogeneous landscape, with vegetation patches ranging from grasslands to forests (Eiten, 1971; Ribeiro and Walter, 1998) and a marked wet–dry seasonality. The Cerrado supports a rich and unique biota (Diniz et al., 2010; Oliveira and Marquis, 2002; Werneck, 2011), but has been extensively transformed by agriculture, livestock, and other anthropogenic activities (Klink and Machado, 2005); thus, it is considered a global biodiversity hotspot (Mittermeier et al., 2000; Myers et al., 2000). Integral protection areas in Brazil, which correspond to Category Ia of IUCN Protected Areas Categories System, currently occupy only 3% of the Cerrado (Fig. 1a). To date, conservation gaps in the Cerrado PA system have been identified only for odonates (Nóbrega and De Marco, 2011) and birds (Marini et al., 2009).

Lizards are often considered model organisms for ecological and evolutionary studies (Camargo et al., 2010; Pianka and Vitt, 2003). Nevertheless, lizards are at risk of global and regional extinction (Gibbons et al., 2000; Sinervo et al., 2010), with about one in every five species being threatened (Böhm et al., 2013). There is critical need for a rigorous evaluation of their conservation status, accounting for life-history characteristics, differential area requirements, vulnerability, and natural rarity. At least 30 endemic species of lizards occur in the Brazilian Cerrado (Nogueira et al., 2011), most of which are associated with specific habitat features (Mesquita et al., 2006; Nogueira et al., 2009). Herein we formulate conservation targets based in three different characteristics likely to influence the conservation needs of lizard species: natural rarity, vulnerability, and life-history, and report on a gap analysis for the endemic lizards of the Brazilian Cerrado.

2. Materials and methods

2.1. Study area

We adopted boundaries of the Cerrado following Instituto Brasileiro de Geografia e Estatística (IBGE, 1993; Silva, 1995; Silva and Bates, 2002). We obtained data on federal, state, and municipal PAs from Ministério do Meio Ambiente – MMA (available from http://mapas.mma.gov.br/i3geo/datadownload.htm) and Instituto Brasileiro do Meio Ambiente – IBAMA (available from http://siscom.ibama.gov.br/). We included only integral protected areas in analyses, considering the unpredictable consequences of permitted activities in sustainable use areas for Cerrado biodiversity. The latter chiefly correspond to large areas (6% of the Cerrado) with very little regulation on permitted uses, potentially reducing their contribution to biodiversity conservation. We also used information on Cerrado remnants, habitat loss (available from http://siscom.ibama.gov.br/monitorabiomas/cerrado/index.htm), and first-order rivers (available from http://www.ana.gov.br/bibliotecavirtual/solicitacaoBaseDados.asp) to model the probability of future habitat loss and to assess the vulnerability of species to further habitat loss.

2.2. Species distributions

We obtained distribution records for 30 endemic species of Brazilian Cerrado lizards (Nogueira et al., 2011) from the Global Biodiversity Information Facility (GBIF), the literature, and specimens deposited at Coleção Herpetológica da Universidade de Brasília (CHUNB), the largest scientific collection with emphasis on the Cerrado herpetofauna (Table 1). We are confident this represents the best available data on the distribution of the species of Cerrado lizards.

2.3. Spatial analyses

For 18 species with five or more distribution records (Table 1), we produced SDMs with Maxent 3.3.2 (Elith et al., 2006; Phillips et al., 2006, 2004). Maxent is a presence-only SDM algorithm that can produce robust distribution estimates even with small sample sizes (Hernandez et al., 2006; Wisz et al., 2008). We used the bioclimatic variables of mean annual temperature (BIO1), standard deviation in annual temperature (BIO4), and annual and wettest quarter precipitation (BIO12 and BIO17, respectively) from Worldclim (Hijmans et al., 2005). We also included two non-climate environmental correlates that are likely to influence the species: the Normalized Difference Vegetation Index – NDVI (mean, from Terra MODIS, MOD13 product) and slope. We chose this small set of variables to avoid a reduction in model accuracy due to overparameterization (Warren and Seifert, 2011), to minimize collinearity, because they represent different aspects of the climate, and because they are relevant to the life-histories of ectothermic animals in general and Cerrado lizards in particular (e.g., Colli, 1991; Colli et al., 2002b, 2003b, 1997; Garda et al., 2012; Meiri et al., 2013; Mesquita and Colli 2003a,b; Wiederhecker et al., 2002). All environmental layers had a spatial resolution of 1 km^2 and were continuous for our study region with a 1-degree ($\sim$100 km) buffer. We ran Maxent with the default settings and randomly selected background (10,000 locations) across the study area. To assess SDM performance, we used AUC, the area under the receiver-operating-characteristic (ROC) curve (Fawcett, 2006;

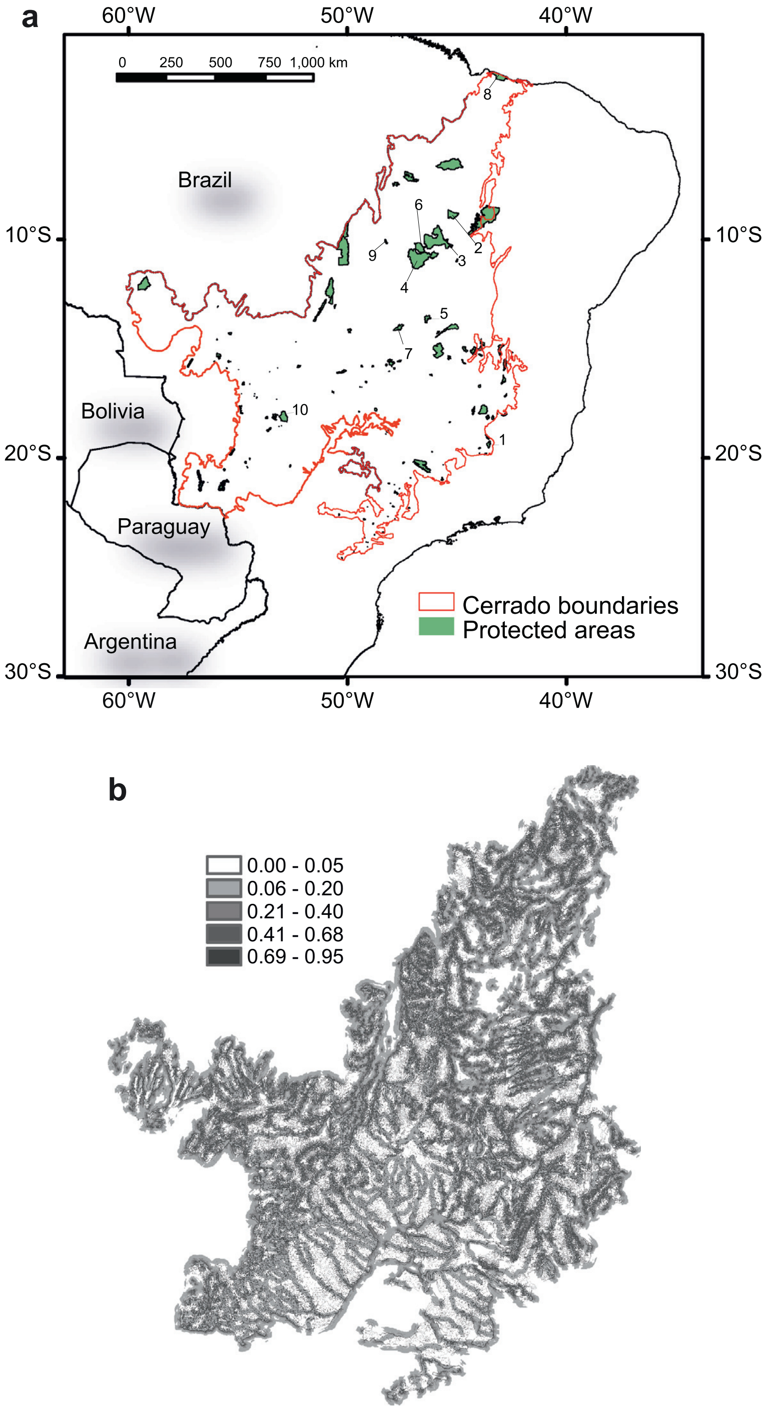

Fig. 1. (a) Boundaries of the Brazilian Cerrado (core area) and integral (strict) protected areas. 1: PARNA da Serra do Cipó, 2: ESEC de Uruçuí-Una, 3: PARNA Nascentes do Rio Parnaíba, 4: ESEC Estação Serra Geral do Tocantins, 5: PE de Terra Ronca, 6: PE do Jalapão, 7: PARNA Chapada dos Veadeiros, 8: PARNA dos Lençóis Maranhenses, 9: PE do Lageado, 10: PARNA das Emas. (b) Probability of future habitat loss across the Cerrado in areas currently with native vegetation.

Lasko et al., 2005; Peterson and Birdsall, 1953; Peterson et al., 1954; Phillips et al., 2004), based on 10-fold cross-validation, and considered AUC values above 0.7 as indicative of good models (Swets, 1988). We reclassified each SDM raster file as binary (presence–absence), using the 10th percentile training presence of the logistic threshold of the SDM, following Urbina-Cardona and Flores-Villela (2010). We checked SDMs for overprediction by visual inspection of each SDM against the Cerrado boundaries and the distribution records and using our field experience with the Cerrado herpetofauna. This procedure, although subjective, can help reduce the occurrence of errors (Pineda and Lobo, 2012). The resultant SDMs indicated areas with suitable conditions for species presence or colonization. To account for habitat loss and give a more realistic picture, we intersected initial SDMs with Cerrado remnant vegetation detected up to 2008, assuming that species were absent from cleared areas; hereafter we call the resultant areas as SDMs*. For the 12 species with less than five occurrence records, we estimated SDMs by delimiting a 5-km buf-

Table 1
Spatial statistics for 30 species of lizards endemic to the Brazilian Cerrado. N: number of distribution records, AUC: area under the receiver–operator curve, SDM: area of the binary species distribution model, SDM*: SDM minus cleared areas, loss: ($\text{SDM}_i - \text{SDM}^*_i$)/$\text{SDM}_i \times 100$, NR: natural rarity, measured as ($\text{SDM}^*_{max} - \text{SDM}^*_i$)/$\text{SDM}^*_{max}$. #For species with less than 5 records, SDM indicates the sum of the areas of 5-km buffers around each record. NA indicates values not applicable to these 12 species. Species are ordered according to their predicted SDM areas.

Species	*N*	AUC	SDM (km^2)	SDM*	Loss (%)	NR
Kentropyx vanzoi	15	0.81	1,801,580	923,798	49	0.00
Tupinambis duseni	9	0.81	1,601,022	713,254	55	0.23
Hoplocercus spinosus	51	0.84	1,584,894	757,490	52	0.18
Anolis meridionalis	52	0.86	1,455,812	656,128	55	0.29
Coleodactylus brachystoma	14	0.82	1,454,170	743,692	49	0.19
Bachia bresslaui	15	0.74	1,206,297	486,457	60	0.47
Tupinambis quadrilineatus	25	0.89	1,201,546	606,779	50	0.34
Mabuya guaporicola	25	0.86	1,161,303	486,593	58	0.47
Micrablepharus atticolus	33	0.90	1,136,032	470,271	59	0.49
Gymnodactylus carvalhoi	31	0.92	1,070,808	556,279	48	0.40
Tropidurus itambere	59	0.92	874,923	270,763	69	0.71
Kentropyx paulensis	23	0.90	873,370	259,408	70	0.72
Cercosaura albostrigata	25	0.94	528,898	164,436	69	0.82
Stenocercus quinarius	5	0.95	256,541	139,433	46	0.85
Stenocercus sinesaccus	6	0.98	156,041	59,506	62	0.94
Tropidurus montanus	17	0.99	38,087	19,543	49	0.98
Bachia oxyrhina	6	0.99	37,828	29,132	23	0.97
Cnemidophorus mumbuca	5	1.00	19,181	13,512	30	0.99
Eurolophosaurus nanuzae	3	NA	276#	273	1	1.00
Rhachisaurus brachylepis	3	NA	276#	194	30	1.00
Heterodactylus lundii	3	NA	274#	259	5	1.00
Cnemidophorus japalensis	3	NA	271#	270	0	1.00
Tropidurus insulanus	2	NA	191#	191	0	1.00
Bachia didactyla	2	NA	188#	9	95	1.00
Bachia cacerensis	2	NA	185#	92	50	1.00
Bachia micromela	1	NA	96#	96	0	1.00
Bachia psammophila	1	NA	95#	52	45	1.00
Ameiva parecis	1	NA	94#	94	0	1.00
Gymnodactylus guttulatus	1	NA	92#	77	16	1.00
Placosoma cipoense	1	NA	91#	91	0	1.00

fer around each record and, when buffers overlapped, we merged them. This buffer area is somewhat arbitrary, but reflects what we consider to be a local lizard assemblage in the Cerrado.

2.4. Parameters used in the formulation of conservation targets

Natural rarity can be perceived in different ways, resulting from the combination of geographic range size, population size, and habitat specificity (Rabinowitz, 1981; Rabinowitz et al., 1986). Due to the paucity of data on population size and habitat specificity for most species of Cerrado lizards, we used only geographic range information to measure rarity. Among different forms of rarity, geographic range played the primary role in the extinction of fossil marine animals spanning the past 500 million years (Harnik et al., 2012). Our procedure gave larger targets for species with smaller distributions, recognizing the increased risks that relatively large impacts present for unprotected portions of their distributions (Bedward et al., 1992; Davis et al., 1999; Pressey et al., 2003). We measured natural rarity of each species *i* as:

$$NR_i = \left(\text{SDM}^*_{max} - \text{SDM}^*_i\right)/\text{SDM}^*_{max},$$

where SDM^*_{max} is the largest SDM* among all species (Pressey and Taffs, 2001).

To estimate vulnerability, we produced a model of future habitat loss threat with Maxent, according to proximity to rivers, as a proxy for water availability, and proximity to cleared areas, as a proxy for infrastructure. While the former accounts for the need of water access for human activities (e.g., agriculture), the latter accounts for the facilitated access to natural areas and desirability for conversion related to already-cleared areas. Since habitat loss in Cerrado is primarily driven by agriculture expansion (Brannstrom et al., 2008; Jepson, 2005; Jepson et al., 2010), we assume these parameters accurately predict future habitat loss as they did for other regions (Green et al., 2013). As habitat loss records (dependent variable), we converted 100,693 polygons of recently cleared areas into points, representing locations disturbed between 2002 and 2008. Despite having presence-absence data here, we opted for the Maxent algorithm because of uncertainties with the absence data, given the difficulties in correctly classifying Cerrado vegetation and also in tracking habitat loss in Cerrado (e.g., Brannstrom et al., 2008; Jepson, 2005; Jepson et al., 2010; Sano et al., 2008, 2010, 2009). As predictors, we used the Euclidean distance to cleared areas by converting polygons representing habitat loss detected up to 2002 into points, and the Euclidean distance to first-order rivers. For each SDM* (online Appendix Fig. 2A and B), we extracted values of the resulting threat model and estimated the probability of future habitat loss to the species as the mean probability of habitat loss for all pixels within its present distribution. Vulnerability accounted for extrinsic threats, calculated for each species *i* as:

$$VL_i = 1 - [(\text{Threat}_{max} - \text{Threat}_i)/\text{Threat}_{max}],$$

where Threat_{max} is the highest threat value among all species and Threat_i is the threat value for the species under consideration. We estimated threat values as the product of habitat loss threats (see above) and an estimate of extinction threat, which we derived from the IUCN Red List Categories (IUCN, 2013) and Lista Nacional das Espécies da Fauna Brasileira Ameaçadas de Extinção (Machado et al., 2005). Categories of both lists as applied to Brazilian Cerrado lizards are primarily based on assessments of inferred population reduction, population fragmentation, and extent of occurrence (GRC, pers. comm., IUCN Standards and Petitions Subcommittee, 2013). The extinction threat was ranked as: Not Assessed = 1, Least Concern = 1.1, Near Threatened = 1.2, Vulnerable = 1.4, Endangered = 1.6, and Critically Endangered = 1.9.

The life-history component accounts for area requirements and vulnerability linked to life-history traits, being represented by two factors: habit and body size. We estimated habit from the microhabitat where the species are generally found, stressing the link between habitat specialization and vulnerability, and addressing the need of more extensive protection for more specialized species. The body-size factor recognizes the common trend of larger species tending to have larger home ranges (Perry and Garland, 2002), therefore requiring larger protected areas than smaller species. Body size also accounts for ecological vulnerability, since large-bodied lizards tend to be more conspicuous, which imposes higher predation risks especially in fragmented habitats. We used four habit categories, ordered in specialization from terrestrial (0.25), leaf litter (0.50), semi-arboreal (0.75), and fossorial (1.00). We used three body-size (snout-vent length, SVL) categories, ordered as small, <71 mm SVL (0.33), medium, 71–120 mm SVL (0.66), and large, >120 mm SVL (1). We calculated the mean of habit and body size values (*LHM*), then calculated the sensitivity due to life-history for each species *i* as:

$$LH_i = 1 - (LHM_{max} - LHM_i)/LHM_{max}),$$

where LHM_{max} is the *LHM* value of the most sensitive species.

2.5. Formulation of conservation targets

For the 12 species with less than 5 distribution records, we set targets as 100% of their SDMs on the basis that their small sizes (all <300 km^2) predispose them to significant depletion in this rapidly developing region. For the 18 modeled species, we defined targets as a function of natural rarity, vulnerability, and life-history, which we recognize as key characteristics that determine conservation requirements. We tuned the formula for calculating conservation targets to guarantee a minimum theoretical value of about 10% of the SDM* for all species, a value that has been widely used as a uniform target (Pressey et al., 2003). We weighted the natural rarity component twice as much as the other two criteria, to avoid putting too much emphasis on the conservation of widespread species and also recognizing the prominent role of range size (spatial rarity) in determining the risk of extinction (Harnik et al., 2012; IUCN Standards and Petitions Subcommittee, 2013). We calculated the conservation target for each species *i*, as:

$$T_i = 0.065 + 0.1NR_i + 0.05VL_i + 0.05LH_i,$$

where *NR* is natural rarity, *VL* is vulnerability, and *LH* is sensitivity due to life-history characteristics. To explore the possible outcomes from the formula output (T_i), and estimate its probability distribution and dependency on different combinations of parameters, we conducted a global sensitivity analysis (SA), a fundamental step prior to using the model in management decisions (Bart, 1995). SA conducts a parameter space exploration, aiming to determine the influence of uncertainty in model input upon the uncertainty in model output (Saltelli, 2002, 2005). We generated 10,000 samples from the 3-dimensional parameter space (*NR*, *VL*, *LH*) using the Latin Hypercube Sampling and assuming a uniform distribution *U*(0, 1) for each parameter, with package *pse* (Chalom and Prado, 2014) of R (R Core Team, 2014).

Following Pressey et al. (2003), we applied percentage targets to the SDM of each species, without accounting for habitat loss. The rationale was to account for past range reductions through habitat loss and to decouple the size of targets from further reductions. The overlap between SDMs* and PAs provided the area under protection for each species. We calculated the percentage of target area currently achieved as the area under protection and as a percentage of the target area. We regarded species with 50% or more of the target achieved as minor gaps and those with less than 50% of the target achieved as major gaps.

3. Results

All SDMs (online Appendix Fig. A1a and b) had AUC values above 0.70 (Table 1) and attained very good performances. SDMs averaged 548,682 ± 646,193 km^2 and had a skewed distribution towards narrow ranges, with most SDMs being smaller than average (Table 1). Half of the species have very small SDMs (<40,000 km^2), whereas the SDM of ten species was larger than 1,000,000 km^2 (Table 1). SDMs*, the intersection of SDMs with Cerrado remnant vegetation detected up to 2008, averaged 245,272 ± 303,938 km^2, being much less variable than SDMs (online Appendix Fig. A2a and b). Up to 2008, endemic species of Cerrado lizards lost, on average, 39.8 ± 26.4% of their SDMs, with some species having lost up to 95% of their SDMs (Fig. 2a). The correlation between SDM area and absolute habitat loss was very high ($r = 0.99$, $df = 28$, $p < 0.001$) (Fig. 2b). However, the relationship between percentage habitat loss and SDM was clearly non-linear, with drastic variation in the percentage habitat loss of restricted-range species (Fig. 2c). Natural rarity values ranged from 0 in *Kentropyx vanzoi* to 0.99 in *Cnemidophorus mumbuca*, representing the species with largest and smallest SDM*, respectively (Table 1).

The model of future habitat loss threat (Fig. 1b) had good performance (AUC = 0.83), with distance to previously cleared areas and distance to first-order rivers having similar contributions (56.3% and 43.7%, respectively). Mean species threat was 0.35 ± 0.08 and threat was primarily correlated with percentage habitat lost in the SDM ($r_S = 0.80$, $df = 16$, $p < 0.001$, Fig. 2d), since *Bachia bresslaui* is the only modeled species currently included in a threat category (Table 2). Accordingly, *B. bresslaui* had the highest vulnerability. Mean species vulnerability was 0.64 ± 0.14 and, except for *Tropidurus montanus*, *Cnemidophorus mumbuca* and *B. oxyrhina*, all species had vulnerability values higher than 50% (Table 2). The highest values of life-history sensitivity were attributed to *B. bresslaui* and *B. oxyrhina*, two fossorial species, followed by *Tupinambis quadrilineatus* and *T. duseni*, the two largest species (Table 3).

Our analysis indicates that endemic species of Cerrado lizards require, on average, that 50.87 ± 40.88% of their SDMs is protected for adequate conservation, corresponding to 90,170 ± 101,254 km^2 (online Appendix Table A1). Restricted-range species (SDM < 40,000 km^2) had higher percentage requirements (84.27 ± 32.58%) but lower area requirements (1 523 ± 2 960 km^2). The global sensitivity analysis revealed a null expectation of 16.5 ± 3.5% for the conservation target (T_i). As such, and considering the range of observed values, only those species with T_i larger than 23, i.e., *Bachia oxyrhina* and all restricted-range species (online Appendix Table A1), deviated significantly from the null expectation (*Z*-test, $p < 0.05$). This should be interpreted as these species being at a higher extinction risk than expected by chance, given the model constraints.

On average, endemic species of Cerrado lizards have currently 14,099 ± 16,593 km^2 of their SDMs in protected areas, corresponding to only 24.0 ± 24.8% of the target achieved (online Appendix Table A1). For restricted-range species, these estimates change to 976 ± 2 509 km^2 and 31.9 ± 33.12%. SDM*s were at least 1.5 (*Cercosaura albostrigata*) and at most 4.5 (*Kentropyx vanzoi*) times the corresponding species' target areas (Table 1, online Appendix Table A1). Across the modeled species, the lowest target was assigned to *K. vanzoi* (12%) and the highest to *Bachia oxyrhina* (23%) (online Appendix Table A1), corresponding, respectively, to 10% and 0.4% of the Cerrado's original area. Five non-modeled species (17%) are total conservation gaps, since no portion of their SDMs overlaps with integral protection PAs (online Appendix Table A1). Twenty-three species (77%) are major gaps, since less than 50% of their SDMs overlaps with integral protection PAs

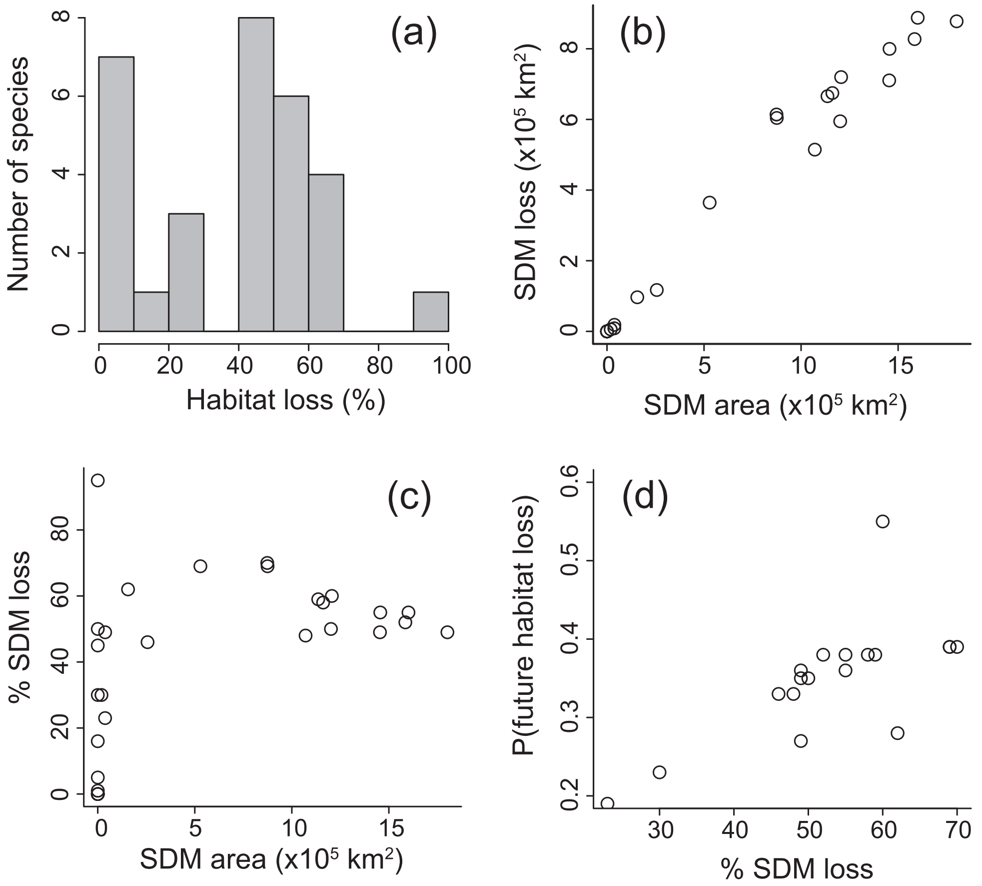

Fig. 2. Habitat loss and risk due to habitat loss to Cerrado endemic lizard species. (a) Frequency distribution of Cerrado species according to percentage of loss of suitable habitats according to species distribution models (SDMs). (b) Scatter graph of raw SDM loss versus SDM area. (c) Scatter graph of percentage SDM loss versus SDM area. (d) Scatter graph of the probability of future habitat loss versus percentage SDM loss.

Table 2
Parameters used in the assessment of the vulnerability (VL) of lizard species endemic to the Brazilian Cerrado with modeled distributions. DT: future habitat loss threat, IUCN: classification in IUCN Red List, LN: Lista Nacional das Espécies da Fauna Brasileira Ameaçadas de Extinção, ET: extinction threat. VU = vulnerable, NA = not assessed. None of the species are listed in the LN. Threat was obtained by the product DT × ET. Values were calculated only for species with more than five distribution records.

Species	DT	IUCN	LN	ET	Threat	VL
Bachia bresslaui	0.39	VU	–	1.4	0.55	1.00
Cercosaura albostrigata	0.39	NA	–	1	0.39	0.72
Tropidurus itambere	0.39	NA	–	1	0.39	0.72
Kentropyx paulensis	0.39	NA	–	1	0.39	0.71
Anolis meridionalis	0.38	NA	–	1	0.38	0.70
Mabuya guaporicola	0.38	NA	–	1	0.38	0.70
Hoplocercus spinosus	0.38	NA	–	1	0.38	0.69
Micrablepharus atticolus	0.38	NA	–	1	0.38	0.69
Tupinambis duseni	0.36	NA	–	1	0.36	0.66
Kentropyx vanzoi	0.36	NA	–	1	0.36	0.65
Coleodactylus brachystoma	0.35	NA	–	1	0.35	0.63
Tupinambis quadrilineatus	0.35	NA	–	1	0.35	0.63
Gymnodactylus carvalhoi	0.33	NA	–	1	0.33	0.60
Stenocercus quinarius	0.33	NA	–	1	0.33	0.59
Stenocercus sinesaccus	0.28	NA	–	1	0.28	0.51
Tropidurus montanus	0.27	NA	–	1	0.27	0.48
Cnemidophorus mumbuca	0.23	NA	–	1	0.23	0.42
Bachia oxyrhina	0.19	NA	–	1	0.19	0.35

(online Appendix Table A1). One species, *Placosoma cipoense*, is a minor gap, with more than 50% of its SDM under integral protection, and only one species, *B. oxyrhina* can be considered protected with the conservation target having being achieved (online Appendix Table A1). The SDM of *B. oxyrhina* (online Appendix Table A1) fully overlaps with the ESEC de Uruçuí-Una, PARNA Nascentes do Rio Parnaíba, ESEC Estação Serra Geral do Tocantins, PE de Terra Ronca, PE do Jalapão, PARNA Chapada dos Veadeiros, PARNA dos Lençóis Maranhenses, and PE do Lageado (Fig. 1a). *Placosoma cipoense* is included in the Brazilian species list (Lista Nacional das Espécies da Fauna Brasileira Ameaçadas de Extinção) as endangered and, despite its apparent rarity, *P. cipoense* has 91% of its distribution protected by the PARNA da Serra do Cipó (Cunha, 1966). Overall, these results indicate a critically poor conservation status for endemic lizards of the Cerrado.

4. Discussion

We modeled the distribution of all lizard species endemic to the Cerrado biodiversity hotspot. Our results revealed that half of the species have very few distribution records and narrow SDMs. Two main reasons can account for the paucity of records for these species: real rarity, due to small range size or low local abundance (Gaston, 1996; Gaston et al., 1997; Lawton, 1993), and poor knowledge of the distributions of Cerrado lizards. Considering that the knowledge on the Cerrado herpetofauna has advanced significantly in the past decades (Colli et al., 2002a; Costa et al., 2007; Nogueira et al., 2010, 2011) and that all SDMs overestimate the actual species distribution, as a result of species interactions and dispersal constraints (Araújo and Luoto, 2007; Soberón, 2007), we advocate these species are truly restricted-range endemics. Most of them have specific habitat requirements, being either saxicolous (*Eurolophosaurus nanuzae*, *Rachisaurus brachylepis*, *Heterodactylus lundii*,

Table 3
Habit, maximum snout-vent length (SVL, mm) and sensitivity due to life-history (LH) of lizard species endemic to the Brazilian Cerrado. Values were calculated only for species with more than five distribution records.

Species	Habit	SVL	LH	Source
Bachia bresslaui	Fossorial	106	0.83	Colli et al. (1998b)
Bachia oxyrhina	Fossorial	80	0.83	Rodrigues et al. (2008)
Tupinambis duseni	Terrestrial	370	0.62	Campos et al. (2011)
Tupinambis quadrilineatus	Terrestrial	260	0.62	Colli et al. (1998a)
Stenocercus quinarius	Leaf-litter	90	0.58	Nogueira and Rodrigues (2006)
Stenocercus sinesaccus	Leaf-litter	90	0.58	Nogueira and Rodrigues (2006)
Anolis meridionalis	Semi-arboreal	54	0.54	Vanzolini and Williams (1970)
Hoplocercus spinosus	Terrestrial	90	0.46	Garda (2000)
Mabuya guaporicola	Terrestrial	90	0.46	Pinto (1999)
Tropidurus itambere	Terrestrial	95	0.46	Van Sluys (1998)
Tropidurus montanus	Terrestrial	80	0.46	Cassimiro et al. (2009)
Cercosaura albostrigata	Leaf-litter	52	0.42	Freitas et al. (2011)
Coleodactylus brachystoma	Leaf-litter	60	0.42	Moretti (2009)
Cnemidophorus mumbuca	Terrestrial	59	0.29	Colli et al. (2003a)
Gymnodactylus carvalhoi	Terrestrial	49	0.29	Cassimiro and Rodrigues (2009)
Kentropyx paulensis	Terrestrial	65	0.29	Gallagher and Dixon (1980)
Kentropyx vanzoi	Terrestrial	65	0.29	Gallagher and Dixon (1980)
Micrablepharus atticolus	Terrestrial	43	0.29	Rodrigues (1996)

Tropidurus insulanus, *Gymnodactylus guttulatus*, and *Placosoma cipoense*) or psammophilous (*Ameiva parecis*, *Bachia didactyla*, *B. micromela*, *B. oxyrhina*, *B. psammophila*, *Cnemidophorus jalapensis* and *C. mumbuca*). Further, many of the restricted-range endemics have small population sizes (e.g., *R. brachylepis*, *H. lundii*, *G. guttulatus*, and *P. cipoense*) or are understudied due to their fossorial habits (e.g., *Bachia* spp). Habitat loss up to 2008 reduced suitable areas for Cerrado endemic lizards by ca. 40%. The average SDM loss is close to the total percentage of habitat lost in the Cerrado up to 2008, estimated to be 47.84% (source: http://siscom.ibama.gov.br/monitorabiomas/cerrado/index.htm). SDM loss was proportional to SDM area; nevertheless, the percentage of SDM lost was highly variable among restricted-range endemics. As a consequence of their narrow ranges and ecological specialization, these species are particularly vulnerable to land-use and climate change (Gilpin and Soulé, 1986; Malcolm et al., 2006; Ohlemuller et al., 2008; Schwartz et al., 2006; Thomas et al., 2004). Indeed, three of them are included in endangered list species: *Eurolophosaurus nanuzae* is "Near Threatened" in the IUCN Red List, while *Heterodactylus lundii* is "Vulnerable" and *Placosoma cipoense* is "Endangered" in the Brazilian endangered species list (Lista Nacional das Espécies da Fauna Brasileira Ameaçadas de Extinção). Considering the accelerated pace of habitat loss in the Cerrado (Jepson, 2005; Klink and Machado, 2005; Sano et al., 2010), the extinction risk of restricted-range, endemic lizard species might increase seriously in the near future.

Our results clearly demonstrate the inadequacy of using a uniform 10% conservation target: since 50% of the endemic species of Cerrado lizards have less than 30,000 km^2 of their SDMs remaining (Table 1), the protection of 10% of these may simply not be enough. According to IUCN criteria, species with an extent of the occurrence <5000 km^2 coupled with a small number of known localities ($\leqslant 5$) and a continuing decline observed, estimated or inferred, fall in the Endangered category (IUCN Standards and Petitions Subcommittee, 2013). Therefore, we defined a uniform 100% target for the 12 restricted-range species (with less than five distribution records) and variable targets for the remainder, recognizing that species differ in their conservation requirements (Pressey et al., 2008). These targets considered various lizard traits with implications for their conservation and ensured a minimum 10% target framed in terms of their SDMs. Following Pressey et al. (2003), we applied percentage targets to the estimated original extent of the Cerrado (SDM), still allowing scope to fully achieve these targets in parts of the Cerrado with native vegetation remnants (SDM*). Our results indicated that 94% of the lizards endemic to Cerrado are either total or major conservation gaps and only two species had more than 50% of the target achieved. Therefore, the vast majority of the endemic Cerrado lizards lack adequate protection. Most critical, five restricted-range endemics have no part of their SDMs* intersected by PAs. These figures are much worse than those depicted in a global gap analysis for terrestrial vertebrate species (Rodrigues et al., 2004a). Similar results were obtained in gap analyses of Cerrado birds (Marini et al., 2009) and odonates (Nóbrega and De Marco, 2011), where conservation units were found highly inefficient to ensure species conservation and restricted-range species had a high probability to not occur in PAs. This is not surprising, since Integral PAs currently occupy only 3% of the Cerrado and most of them were established without adequate planning.

Future use of our targets to define a PA network for the conservation of Cerrado lizards may be difficult to implement, especially regarding widespread species. For example, the conservation of *Bachia bresslaui* would demand approximately 13% of the Cerrado's original total area (online Appendix Table A1), or 26% of the remaining vegetated area, given that habitat loss affected about half of the biome by 2008. Nonetheless, 13% is still lower than the 17% target agreed in the Aichi Biodiversity Targets established for the conservation of Brazilian biodiversity for 2020 during the 2012 Convention on Biological Diversity (http://www.cbd.int/). In any case, required percentages of regions or countries should emerge from, rather than constrain, the achievement of targets for individual features (Pressey et al., 2003). The identification of target areas for conservation is only the first step toward conservation strategies, and these strategies require a very complex process of policy negotiation and implementation. At the end, decisions should be based on comparing alternatives and considering the interests of all stakeholders; therefore, our analyses should be considered more indicative than prescriptive.

Definition of conservation targets is a crucial step in gap analysis (Vimal et al., 2011), having the potential to significantly alter the configuration and size of the PAs network. A 10% percentage is a well-known uniform target that, albeit arbitrary, has been used frequently (Pressey et al., 2003; Soulé and Sanjayan, 1998). However, the use of uniform targets has been widely questioned as they fail to acknowledge that some species need more protection than others (Jennings, 2000; Pressey et al., 2003; Rodrigues and Gaston, 2001; Svancara et al., 2005) and they tend to bias the results of gap analysis towards more widespread species

(Rodrigues et al., 2004b). Our results emphasize the need to formulate conservation targets based on relevant attributes of biodiversity features, such as natural rarity, vulnerability, and life-history, to produce more defensible and effective conservation guidelines to stakeholders. This is in agreement with previous works conducted with amphibians in the Brazilian Atlantic Forest, which found that incorporating detailed knowledge on the biology of species aids in understanding the sensitivity of amphibians to habitat change and also to more effective protection and restoration programs (Becker et al., 2010). We also recognize that it is necessary to revise targets with improved information on the pattern of biodiversity in a region (Pressey et al., 2003). SDMs, for example, will benefit from more occurrence records from species currently with few scattered occurrence data (e.g., *Tupinambis duseni*, *Stenocercus sinessaccus*, *S. quinarius*). Additionally, refined taxonomic assessments that commonly reveal instances of cryptic taxa should affect and be taken into account in future revisions of conservation targets for Cerrado endemic lizards. For example, Domingos et al. (2014) recovered eight deeply divergent clades within the widespread Cerrado endemic *Gymnodactylus amarali*. The split of a widespread species into independent cryptic species with smaller distribution ranges will likely affect its threats and vulnerability. The Cerrado threat model that we developed can equally be refined and applied to other biodiversity features. Cerrado endemic lizards have already lost significant percentages of their distributions as a result of habitat loss and the PA network is insufficient to minimize their extinction risks: only one species is fully protected and 94% of the species are either major or total conservation gaps. These results, and the continuing rapid loss of native vegetation in the Cerrado global hotspot, indicate the urgent need for extensive conservation measures.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.biocon.2014.09.016.

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