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ECOLOGICAL NICHE MODELING IN PRACTICE: FLAGSHIP SPECIES AND REGIONAL CONSERVATION PLANNING

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ABSTRACT

Conservation of rare or endemic species is a multifaceted matter, especially whenever knowledge gaps in species' distribution and anthropogenic pressures converge. We combined Geographic Information Systems and ecological niche modeling tools with field data to characterize the habitat types used for different behavioral activities and to identify important areas for conservation of a charismatic bird endemic to northeast South America, the Guianan cock-of-the-rock (*Rupicola rupicola*). Using species' occurrences and climatic, topographic, and remotely sensed vegetation variables we developed potential distribution models at two scales: (1) broad geographic scale (northern South America), based on georeferenced occurrences obtained from literature and natural history museum specimens, and (2) local scale, based on precise occurrences (GPS coordinates) recorded in the field (Caverna do Maroaga Protected Area, Amazonas, Brazil). We identified six priority areas for the conservation of the cock-of-the-rock corresponding to high environmental suitability and lowest anthropogenic pressure, measured as distance from urban areas and highways (>5 km). Protecting the areas identified in this study from anthropogenic threats such as hunting and selective logging will help to preserve not only the cock-of-the-rock, but also the biodiversity of the whole mosaic of habitats in the region. Our results were incorporated in a regional management plan developed by state agencies and non-governmental organizations. Geographic Information Systems and ecological niche modeling techniques combined with on the ground, local surveys can be useful in species conservation efforts, for planning new inventories, prioritizing areas to be protected, and for creating ecological corridors.
Keywords: Amazon; cock-of-the-rock; conservation priority area; GARP; Maxent.

RESUMO

Modelagem de nicho ecológico na prática: espécies bandeira e planejamento para conservação regional. Conservação de espécies raras ou endêmicas é uma questão multifacetada, especialmente quando as lacunas de conhecimento na distribuição das espécies e pressões antropogênicas convergem. Nós combinamos Sistemas de Informação Geográfica e ferramentas de modelagem de nicho ecológico com dados de campo para caracterizar os tipos de habitat utilizados para diferentes atividades comportamentais e identificar áreas importantes para a conservação de uma ave carismática e endêmica do nordeste da América do Sul, o galo-da-serra (*Rupicola rupicola*). Usando a ocorrência da espécie e variáveis climáticas, topográficas de sensoriamento remoto da vegetação foram desenvolvidos modelos de distribuição potencial em duas escalas: (1) escala geográfica (norte da América do Sul), com base em ocorrências georreferenciadas obtidas a partir da literatura e espécimes de museu de história natural, e (2) escala local, com base em ocorrências específicas (coordenadas GPS) registradas em campo (Área de Proteção Ambiental Caverna do Maroaga, Amazonas, Brasil). Foram identificadas seis áreas prioritárias para a conservação do galo-da-serra correspondente a alta adequação ambiental e menor pressão antrópica, medida como a distância das áreas urbanas e rodovias (> 5 km). Proteger as áreas identificadas neste estudo de ameaças antropogênicas, como a caça e a exploração seletiva madeireira vai ajudar a preservar não só o galo-da-serra, mas também a biodiversidade de todo o mosaico de habitats na região. Nossos resultados foram incorporados em um plano de gestão regional desenvolvido por agências estatais e organizações não-governamentais. Sistemas de Informação Geográfica e técnicas de modelagem de nicho ecológico combinados com variáveis ambientais e levantamentos locais podem ser úteis nos esforços de conservação das espécies, para planejamento de novos inventários, priorizar áreas a serem protegidas e na criação de corredores ecológicos.
Palavras-chave: Amazônia; galo-da-serra; área prioritária para conservação; GARP; Maxent.

INTRODUCTION

The distribution patterns of endemic species have been used to define priorities for biodiversity conservation under the premise that successful conservation actions depend partly on assessments of representativeness of species' distributions in priority areas (Kerr 1997, Stattersfield *et al.* 1998, Chapman *et al.* 2009). The Amazon Basin is recognized as one of the most important repositories of biodiversity in the world, with high rates of endemism (Myers *et al.* 2000, Barreto *et al.* 2005). Large areas are still intact, but it is estimated that deforestation and rapid conversion to other uses has affected about 17% of the Amazon forest (Ferreira *et al.* 2005).

The Guianan cock-of-the-rock (*Rupicola rupicola*, Linnaeus 1766) is an endemic bird of the oldest East Andean areas, north of the Amazonas river, found only in forests on steep terrain in Brazil, the Guianas, Venezuela, Colombia, and Suriname (Ridgely and Tudor 1994, Sick 2001). Males are found mostly on courtship display sites, spatially gathered in leks where males display for females (Trail 1985, Endler and Thery 1996). The courtship display perches are used to attract, court, and mate with females, and to defend roost sites and territory against other males. The females build the nest within cracks in rock walls and caves (Erard *et al.* 1989), using mainly mud mixed with saliva, vegetal fibers, and tree resins (Omena and Martins 2007).

Unfortunately, the species' remarkable morphological and behavioral characteristics draw the attention of poachers and wild animal traffickers (Giovanini 2001, Omena and Martins 2007). In general, the birds do not tolerate captivity and eventually die due to stress (Omena 2005). Bird capture along with increasing urbanization and frequent tourist disturbance of nesting areas represent the main threats to persistence and preservation of this species (Giovanini 2001, Omena and Martins 2007). Despite these anthropogenic pressures and its local rarity (Stotz *et al.* 1996), the species is not considered threatened because of its wide distribution in the Amazon (BirdLife International 2013). Consequently, from a conservation standpoint, it is important to fill in information gaps regarding the species' ecology, such as the environmental factors affecting its distribution, in order to predict relevant areas for focusing regional management plans.

Some of these information gaps can be addressed via applications based on ecological niche theory to predict potential distribution of species using environmental data and known occurrences (Soberón and Peterson 2005, Guralnick *et al.* 2007, Lorini *et al.* 2011). Two terms have been used almost interchangeably in the growing field of estimating potential distribution of species: ecological niche modeling and species distribution modeling. Here we use the former term, as we aim to fit the model in the environmental space which is considered the ecological domain, not geographic distribution domain, of a species (Peterson and Soberón 2012). Conservation applications of this methodology include (1) predicting a species' distribution to ensure reintroduction in areas within the fundamental ecological niche of that species to increase chances of survival (Martínez-Meyer *et al.* 2006), (2) predicting the distribution of species at risk of extinction (Godown and Peterson 2000), and (3) prioritizing areas to protect and to create ecological corridors (Papes and Gaubert 2007).

The objectives of our study were to model the potential distribution of *R. rupicola*, over its described geographical range, and locally in Caverna do Maroaga Protected Area within Presidente Figueiredo municipality, where the species represents a major tourist attraction (Omena and Martins 2007). We also differentiate models among habitats used for behavioral activities (e.g., lekking and nesting), and identify important areas for species' conservation. The results of this study were incorporated in a regional management plan developed by state agencies and non-governmental organizations (Associação de Levantamento Florestal do Amazonas 2010), and may be further used for monitoring and management of the species in the municipality, guiding environmental education work, and delineating complementary conservation areas to increase the effectiveness of the current system of conservation units in the region.

MATERIAL AND METHODS

STUDY AREA

Field observations were conducted in the Caverna do Maroaga Protected Area (APA Maroaga, authorization of the scientiûc research in private properties and Conservation Unit no 013/08, June 9th, 2008) and its surroundings (Figure 1). APA Maroaga, part of the Central Amazon Corridor, covers about 374,700 ha and is located in Presidente Figueiredo municipality, Amazonas state, Brazil. Two main vegetation types are present: dense upland forest and black water river flooded forest along riverbanks, lakes and streams, in addition to more open, savanna-like *campinas* and *campinaranas* (da Silva and da Silva 2006). The mean annual precipitation is over 2000 mm, distributed over two distinct seasons, high (November to May) and lower rainfall (June to October). Relative air humidity is uniform throughout the year, averaging 86 percent (SUDAM 1984, EMBRAPA 1998).

DATA COLLECTION

We georeferenced 23 natural history museum specimens from GBIF, ORNIS, and SpeciesLink online databases for broad scale ecological niche modeling (Figure 2). For local scale modeling, data points from foraging or breeding areas were collected in the field with a GPS unit (< 30 m accuracy) at point counts (Sutherland *et al.* 2004) set 250 m apart to prevent repeated counts of the same individuals, and conducted simultaneously by two observers to increase detectability. We established 140 census point counts distributed along eight 5-km transects (Figure 1). A 3-min stop was used at each point count to detect the presence of the bird either auditory or visually. If no individuals were detected, recorded vocalizations were played three consecutive times using a recorder and mini-amplifier, followed by an additional 3-min period for response verification. We also surveyed the region for nesting and lekking sites along existing trails and in areas with caves and rocky walls, and recorded GPS coordinates of all sites where the species was confirmed present (Figure 1). Both point counts and continuous censuses were performed for 15 consecutive days between 6:00 and 18:00 each month, from March to December 2008. In all, 81 presence points, obtained from the continuous (59) and point count (12) censuses, and from information provided by local guides (10) were used to model habitats associated with the species' foraging range; 31 points (8 leks and 23 nests) were used to model habitats within the species' breeding range. We independently confirmed (visually or via recorded vocalizations) the species' presence at the sites indicated by local guides.

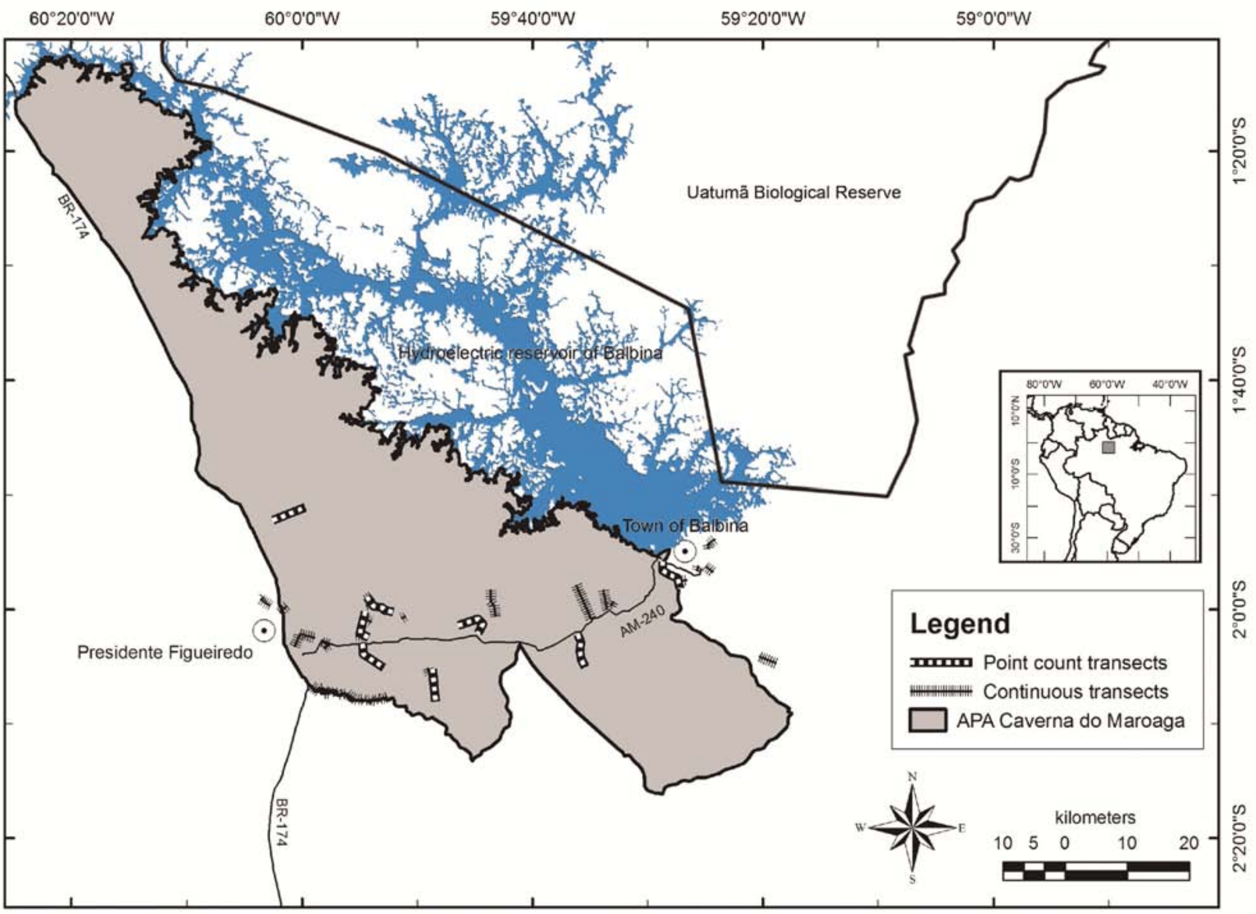

Figure 1. Map of the study area showing continuous and point count transects surveyed in 2008.

Occurrence data were combined with climatic variables at a resolution of 5 km covering northern South America for broad scale ecological niche modeling, and topographic variables and vegetation indices at a resolution of 250 m for local scale modeling. The climatic variables were obtained from WORLDCLIM database (http://www.worldclim.org), which includes annual trends as well as extreme quarterly values. The topographic elevation was obtained from Shuttle Radar Topography Mission (SRTM, http://www.jpl.nasa.gov/srtm/) and was used in ArcGIS 9.2 to derive orientation, slope, curvature, and hill shade variables. We also included two vegetation indices measuring photosynthetic activity, derived from MODIS (Moderate Resolution Imaging Spectroradiometer) satellite reflectance data: (1) normalized difference vegetation index (NDVI), which saturates over dense vegetation canopy, and (2) enhanced vegetation index (EVI), designed for high biomass regions like the Tropics (Huete *et al.* 2002). We downloaded NDVI and EVI 16-day data sets (https://lpdaac.usgs.gov) for July - November 2008 and used monthly averages, since extensive cloud cover over the study area in March - June and December prevented exact temporal match between field surveys and NDVI and EVI data.

ECOLOGICAL NICHE MODELING AND POTENTIAL DISTRIBUTION MAPPING

Since the climatic layers were obtained by interpolating data from meteorological stations scarcely scattered over the Amazon basin, they are not appropriate for local scale modeling in this region. We followed a two-scale modeling design approach: (1) construct a model at broad geographic scale, covering northern South America, using climatic variables with spatial resolution of 5 km and the occurrence dataset of 23 museum specimens, and (2) use resulting model in local scale analysis to mask out areas climatically unsuitable for occurrence of the cock-of-the-rock. This operation was performed in Spatial Analyst in ArcGIS 9.2 (ESRI, Redlands, CA, USA).

Our modeling experiments were also two-fold. First, we used the application Maxent 3.2.1 (Phillips *et al.* 2006) to build models using species' occurrence data and the original sets of 19 and 17 variables, for broad and local models, respectively, and to score each environmental variable in terms of contribution to the distribution model obtained (Maxent prediction). In the model iteration process, the algorithm modifies the coefficient for a single parameter (feature in Maxent application) and adds or subtracts the increase in model gain from the contribution of individual environmental variable. The gains are expressed as a proportion of contributions of all features. We applied a cut-off > 4 percent contribution to select variables for development of the final models. Maxent application uses the receiver operating characteristic analysis (ROC; Fielding and Bell 1997) to evaluate the predictive power of the models generated. The area under the curve (AUC) delimited by ROC represents the probability of correctly predicting presences as a function of the proportion of area predicted compared to probabilities corresponding to random models (Phillips *et al.* 2006, but see Lobo *et al.* 2008); AUC values closer to 1 indicate higher model accuracy.

Second, based on the selected environmental variables, we generated the potential distributions at broad and local scales using Desktop GARP application (Genetic Algorithm for Rule-set Production; Stockwell and Peters 1999). The program generates predictions of species' distributions based on non-random correlations between known presence points and environmental variables. It is an iterative process of generating and modifying rules (logistic regression, bioclimatic envelope, negated bioclimatic envelope, and atomic rules) regarding the species' environmental requirements (Stockwell and Noble 1992, Stockwell and Peters 1999). The set of rules that best fit the given data are projected onto geography to produce models of the species' predicted distribution.

Distributional predictions are subject to two types of errors: omission (false negatives), when known presences are predicted absent, and commission (false positives), when areas for which no presences are known are predicted present (Fielding and Bell 1997). To quantify model performance based on these two types of error, the occurrence data set is divided in two subsets, training and testing. We generated 100 GARP models, each based on a different random resampling of the original occurrence records into training dataset (80%) and testing dataset (20%). We selected ten models as best representing the species' potential distribution with < 10 percent omission error and 50 percent commission error based on the training dataset (Anderson *et al.* 2003), and used X^2 (chi-square) tests to determine if the proportion of the test points correctly predicted by the model was higher than random expectation. We summed in ArcGIS the selection of ten best models to provide a measure of GARP model agreement for each map pixel (0 - no model agreement to 10 - full model agreement). To avoid both high omission and commission errors, we analyzed areas that were predicted present by at least half of the models (model agreement threshold > 5).

In general, compared to Maxent, GARP algorithm appears to extrapolate more, *i.e.*, predict broader potential areas of distribution of the species' ecological niche (Papes and Gaubert 2007, Kumar *et al.* 2009), thus producing higher commission errors but lower omission errors (Peterson *et al.* 2007). The broader extrapolation is relevant for exploring larger areas potentially suitable for the species, particularly when the study area is relatively small and models may be validated in the field before conservation efforts are put in practice. Overall, the two methods have similar responses in model extrapolation situations and tend to produce similar results when general distribution patterns are examined (Pearson *et al.* 2007, Owens *et al.* 2013).

SELECTION OF PRIORITY AREAS FOR CONSERVATION OF THE GUIANAN COCK-OF-THE-ROCK

In order to identify candidate priority areas for conservation of the species in the study region, we overlaid its potential distribution with polygons representing urban areas and highways. As we were interested in regions of low anthropogenic influences, we applied a 5 km buffer to polygons in order to exclude the zone of anthropogenic influence, which was estimated by field observations. All spatial analyses were performed in ArcGIS 9.2.

We ranked priority areas for conservation of the cock-of-the-rock using the following criteria: largest contiguous area predicted (environmentally) suitable, overlap with known breeding and home ranges, smallest area lacking information (no data pixels), and distance from a confirmed species' occurrence point. For each criterion, a value of 1 (best) to 6 (worst) was assigned, and the overall ranking of priority areas was obtained by summing these values, the lowest figures indicating highest rank for conservation potential.

RESULTS

Environmental variable selection

All models produced with Maxent had AUC scores > 0.90. Of the 19 available variables, temperature seasonality, mean temperature of warmest quarter, mean precipitation of driest month, precipitation of driest quarter, and mean precipitation of coldest quarter contributed the most to constructing broad scale Maxent models. For local scale models, elevation, aspect, slope, and the NDVI and EVI monthly averages between July and November 2008 were selected, out of 17 variables available. When analyzing only the contribution of the selected variables to model generation, mean precipitation of coldest quarter and elevation presented the highest contribution at broad scale (37.9%) and local scale (51.4%), respectively.

BROAD AND LOCAL SCALE POTENTIAL GEOGRAPHIC DISTRIBUTIONS

The large scale GARP models (Figure 2) predicted suitable an area of 3,467,500 km^2 in northern South America, with two main regions: one extending from the southern border of Pará and Amazonas in Brazil to the coasts of Guiana and Suriname, through central-eastern Roraima in Brazil, and another one from northern Peru to south-central Venezuela, eastern Ecuador and Colombia, and extreme northwestern Brazil. The models built with the selected subset of environmental variables had higher omission errors but were statistically significant (Table 1).

The local scale models predicted an extent of 1,466 km^2 of potential home range and 1,405 km^2 of breeding habitat. The home range models did not improve when using the reduced set of environmental variables mainly due to an increase in the commission error; the omission error values were comparable between models obtained with the full set and the reduced set (Table 1). In general, the commission error values increased (and statistical significance decreased) when the subset of variables was used, most likely because fewer environmental dimensions allowed for broader models to be generated.

We overlaid home and breeding range models for an overall map of local scale potential distribution of the species (Figure 3). Three regions suitable for *R. rupicola* were predicted within the limits of APA Maroaga: (1) in the southern part, extending along highway AM-240, which connects the municipality of Presidente Figueiredo to the town of Balbina, (2) in the central region, and (3) to a smaller degree, in the northern region.

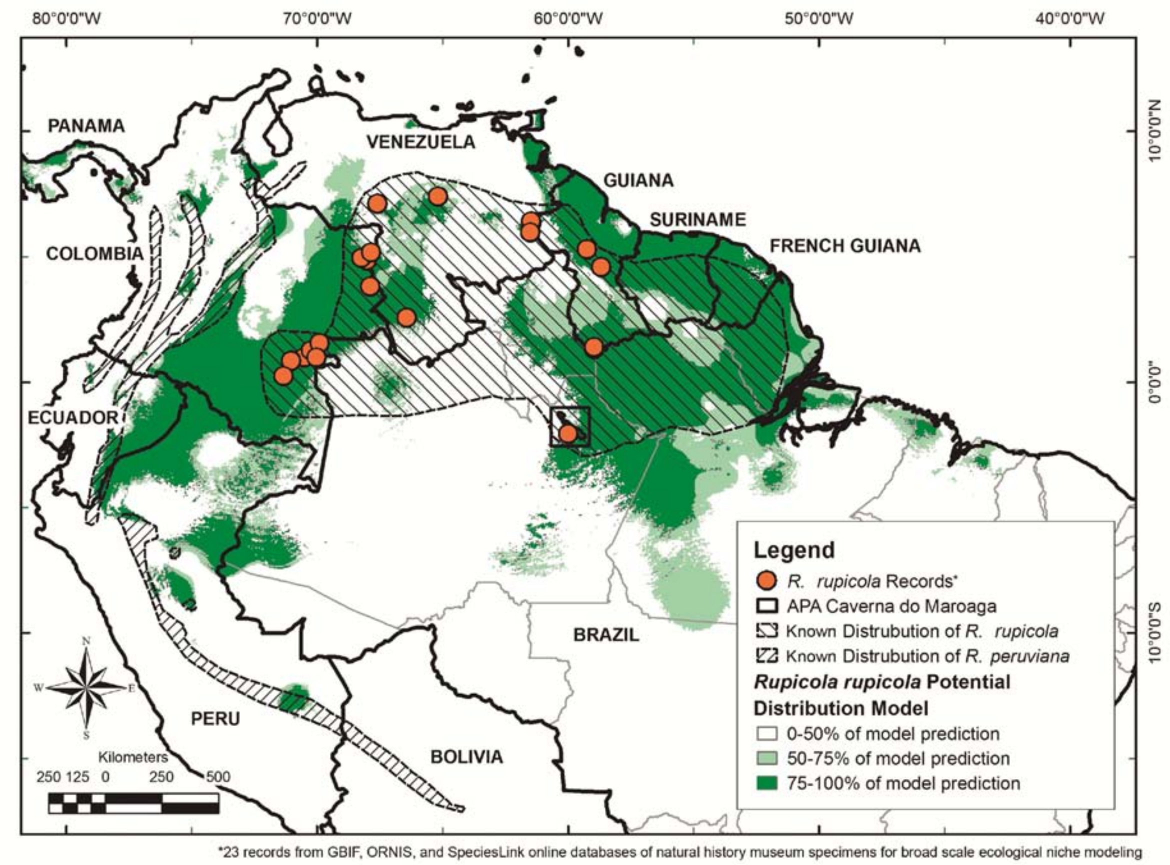

Figure 2. *Rupicola rupicola* broad scale GARP potential distribution, showing APA Maroaga borders, recorded presence points, and known range for the genus *Rupicola* (Ridgely and Tudor 1994).

Table 1. Summary of significance tests for broad and local distributional predictions, showing average omission and commission measures, and maximum X^2 and *P* values of the selected best ten GARP models. Omission represents percentage of presences predicted absent and commission is percentage of prediction area that exceeds presences. The environmental variables within datasets are given in Figure 2.

Dataset type	Extent	Training omission	Training commission	Testing omission	X^2	*P*
Full dataset	South America	0	21.65	0	19.54	<0.01
	Home range	0	53.89	6.25	28.78	<0.01
	Breeding range	0	36.05	0	14.49	<0.01
Subset	South America	3	26.81	5.45	21.53	0.09
	Home range	3.32	75.64	3.13	6.36	0.15
	Breeding range	6.88	41	0	12.02	0.02

PRIORITY AREAS FOR CONSERVATION

We identified six areas, ordered from higher to lower importance, with conservation potential for the cock-of-the-rock in APA Maroaga and its surroundings (Table 2, Figure 3). Area 1 is the largest area identified (979 km^2) and comprises the southern portion of APA Maroaga, south of highway AM 240, and in the southwest, outside APA Maroaga boundaries. Area 2 (747 km^2) is also located in the surroundings of APA Maroaga, near the Balbina Hydroelectric Plant, and between Uatumã river and Uatumã Biological Reserve. Area 3a (498 km^2) is located north of the highway AM 240 and west of the hydroelectric reservoir of Balbina. Area 3b (421 km^2), tied to 3a in rank, is located outside the western limits of APA Maroaga, and the closest area to Presidente Figueiredo urban center. Area 4 (137 km^2) is located in the central region of APA Maroaga, north of Area 3a. Area 5 is the smallest selected (84 km^2), located in the extreme north of APA Maroaga. The six areas cover cumulatively 2,866 km^2 and do not include urban areas, highways, or buffer zones considered under anthropogenic influences.

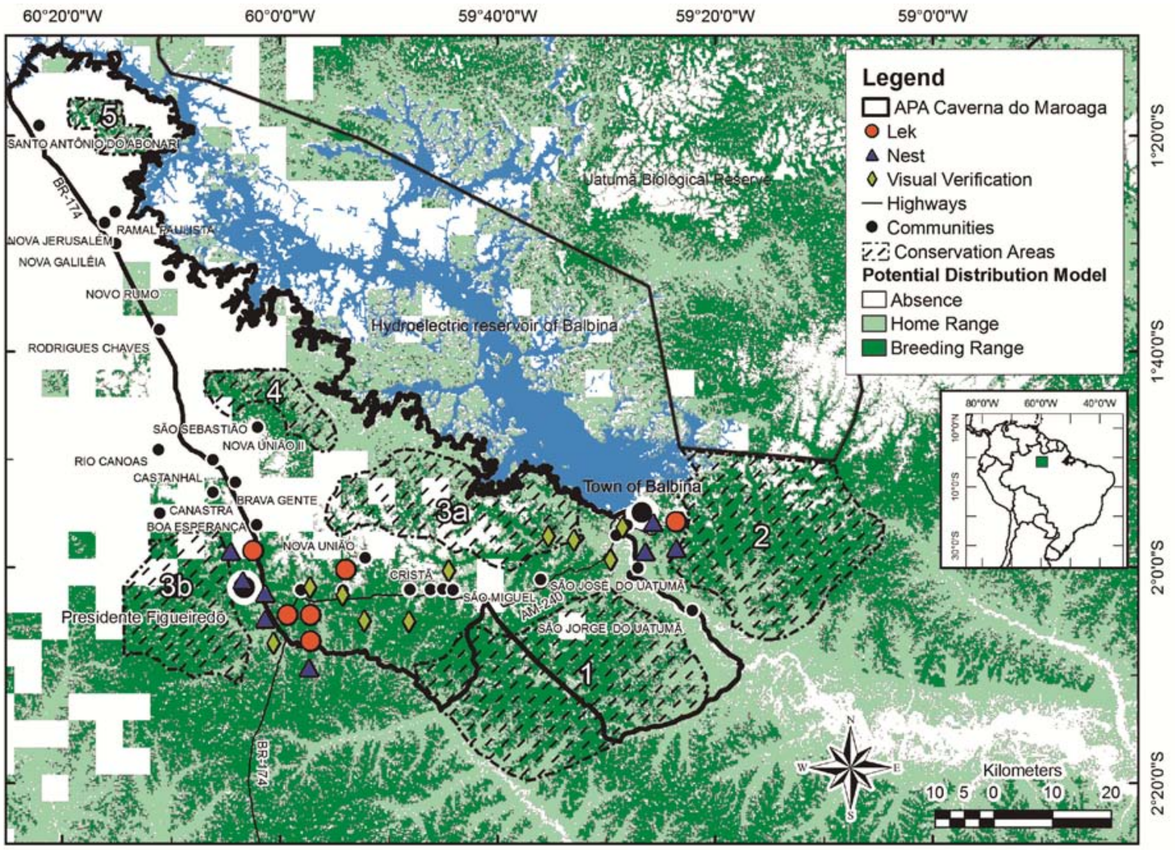

Figure 3. Potential GARP distribution map of the home and breeding ranges, observation points, and six priority areas (dashed area, numbered) for conservation of *Rupicola rupicola* in APA Maroaga.

Table 2. Priority areas ranked for overall conservation potential of the *Rupicola rupicola* in APA Maroaga.

Area rank	Size (km^2)	Number of pixels predicted suitable (resolution of 250 m)		Distance from closest presence point (km)
		Breeding range	Home range	
Area 1	979	10911	6379	5
Area 2	747	8848	3916	2.5
Area 3a	498	2836	3703	0
Area 3b	421	5331	1355	1.5
Area 4	137	1261	1268	19
Area 5	84	877	460	71

DISCUSSION

Ecological niche modeling has been used widely in recent years, including in conservation biology (Engler *et al.* 2004), and various techniques have been developed for this purpose (Guisan and Thuiller 2005). Generally, this research avenue is based on the assumption that the distribution of a species is, at least over a short period of time, in equilibrium with the environment (Guisan and Zimmermann 2000, Hirzel and Guisan 2002), and that it is correlated with one or more types of spatially-explicit habitats.

The accuracy of models is related to three main factors: quality of the species' occurrence data, selection of predictor variables, and algorithm or statistical method adopted (Araújo and Guisan 2006). We address below each of these components in the context of our modeling experiments.

We used locality information derived from museum specimens that may have georeferencing errors, as any historical data may present various degrees of accuracy. However, we used climate data at a resolution of 5km, and as such, we believe that the effects of inherent location errors associated with museum specimens were minimized at this scale (Graham *et al.* 2004, Pearson *et al.* 2007). For local-scale modeling, we collected GPS data points with a maximum error of 30 m, most of them within or adjacent to breeding areas.

Secondly, the variables selected for modeling experiments should ideally be those considered to directly influence a species' distribution. Due to sparse distribution of weather stations in the Amazon basin, and mainly due to lack of more refined environmental data for this region, we adopted a two-scale modeling design to exclude from the local scale models areas that were climatically unsuitable for the species. This approach was useful in our study, but more tests are needed to assess its value across different regions and taxa. We used the procedure implemented in Maxent to evaluate variable contribution to model generation and to select those variables that best explained the species' known presences. However, this selection was optimized for Maxent algorithm and did not produce more accurate GARP models when compared to those built using full sets of environmental variables.

Lastly, modeling algorithms can be based on markedly different statistical methods and thus algorithm selection may influence the outcome of ecological niche modeling experiments. Several studies compared the predictive power of various algorithms, with mixed results (Segurado and Araújo 2004, Elith *et al.* 2006, Papes and Gaubert 2007, Pearson *et al.* 2007, Peterson *et al.* 2007, Tsoar *et al.* 2007). Although we focused here on the applications of ecological niche modeling, we noted comparable distributional patterns obtained with two modeling algorithms. Models obtained with GARP algorithm were comparable with those obtained using Maxent, although GARP predicted larger areas and consequently recorded higher commission errors.

The models generated at broad scale and used to identify areas with climate conditions suitable for the cock-of-the-rock at local scale showed high coincidence with the species' described distribution (Ridgely and Tudor 1994, Sick 2001). In addition, the models predicted suitable a small area in the municipality of São Gabriel da Cachoeira, Amazonas, where the occurrence of the species has been recently confirmed (Charles Zartman pers. comm.). No presence records are known for the species south of the Amazon river. A possible explanation is that the river acts as a dispersal barrier for this species. In the Andean region between Colombia and Peru, our models also predicted suitable areas for the species within the known distribution of the sister species, *R. peruviana* (Latham 1790), suggesting partial ecological overlap without overlap in their geographic distributions (Figure 2). The observed allopatry could be the result of a split of ancestral populations by geographical or climatic barriers (Haffer 1969, Cracraft 1985), and more recently maintained through competitive exclusion in the Andean region (Terborgh 1971, MacArthur 1972, Terborgh and Weske 1975).

Our analysis showed that the cock-of-the-rock is distributed within environments exposed to uniform temperature regimes, in a relatively warm zone with high precipitation throughout the year, especially during the breeding season. The local scale models predicted suitable areas where high and low altitude converged and where vegetation indices values were lower, suggesting a preference for regions where less dense, short vegetation types occur (*e.g.*, *campinas* and *campinaranas*). These characteristics correspond to the species' habitat requirements observed during data collection: females use areas with abrupt elevation differences and rock outcrops. Moreover, females use nesting sites based on microhabitat conditions, selecting only caves and rocky walls that present high humidity, among other characteristics (Omena and Martins 2007).

At local scale, within APA Maroaga, a considerable area of the species' potential distribution occurs along highway AM-240, where the species is under significant anthropogenic pressure. In spite of our efforts to conduct censuses homogeneously distributed throughout the study region, accessibility was dependent on available roads. We extended our surveys up to 10 km away from roads to minimize correlation of occurrence data with location of highways. However, during our field surveys, we observed an increase in deforested and burned areas for subsistence farming, house building, and opening and improvement of side roads, thus the potential range of the species overlaps with increased anthropogenic pressures. The region also attracts tourists due to the presence of waterfalls and caves, and cock-of-the-rock observation sites, such as the Maroaga cave. It is therefore important to focus on environmental educational to raise awareness among local residents, and on creating additional protected areas in the region.

We present six areas with potential for the protection of this species based on the combined high likelihood of presence of breeding sites and adequate distance from anthropogenic influences, indicating less disturbed regions. However, the presence of individuals *in situ* remains to be determined via detailed field surveys.

The main goals of this study were to analyze the potential distribution of *R. rupicola*, especially in APA Maroaga area, and to indicate possible areas important for regional conservation of the species. To guarantee effectiveness, species conservation planning requires other investments and actions to reach its full potential. In the case of a protected area in particular, it is extremely important to work, through environmental education, with local residents and tourists, and moreover, to develop a participatory management plan with the local communities that make direct use of the resources. The results of this study were incorporated by state agencies and non-governmental organizations in a management plan for APA Maroaga, as part of a regional initiative of creating ecological corridors in central Amazonia (Associação de Levantamento Florestal do Amazonas 2010).

Protecting the areas identified in this study from anthropogenic threats such as hunting and selective logging will help to preserve not only the cock-of-the-rock, but also the biodiversity of the whole mosaic of habitats, which includes species of conservation concern, such as the Harpy eagle (*Harpia harpyja*), jaguar (*Panhtera onca*), margay (*Leopardus wiendii),* Amazonian manatee (*Trichechus inunguis*), Midas tamarin (*Saguinus midas*), and the endangered giant otter (*Pteronura brasiliensis*), among others.

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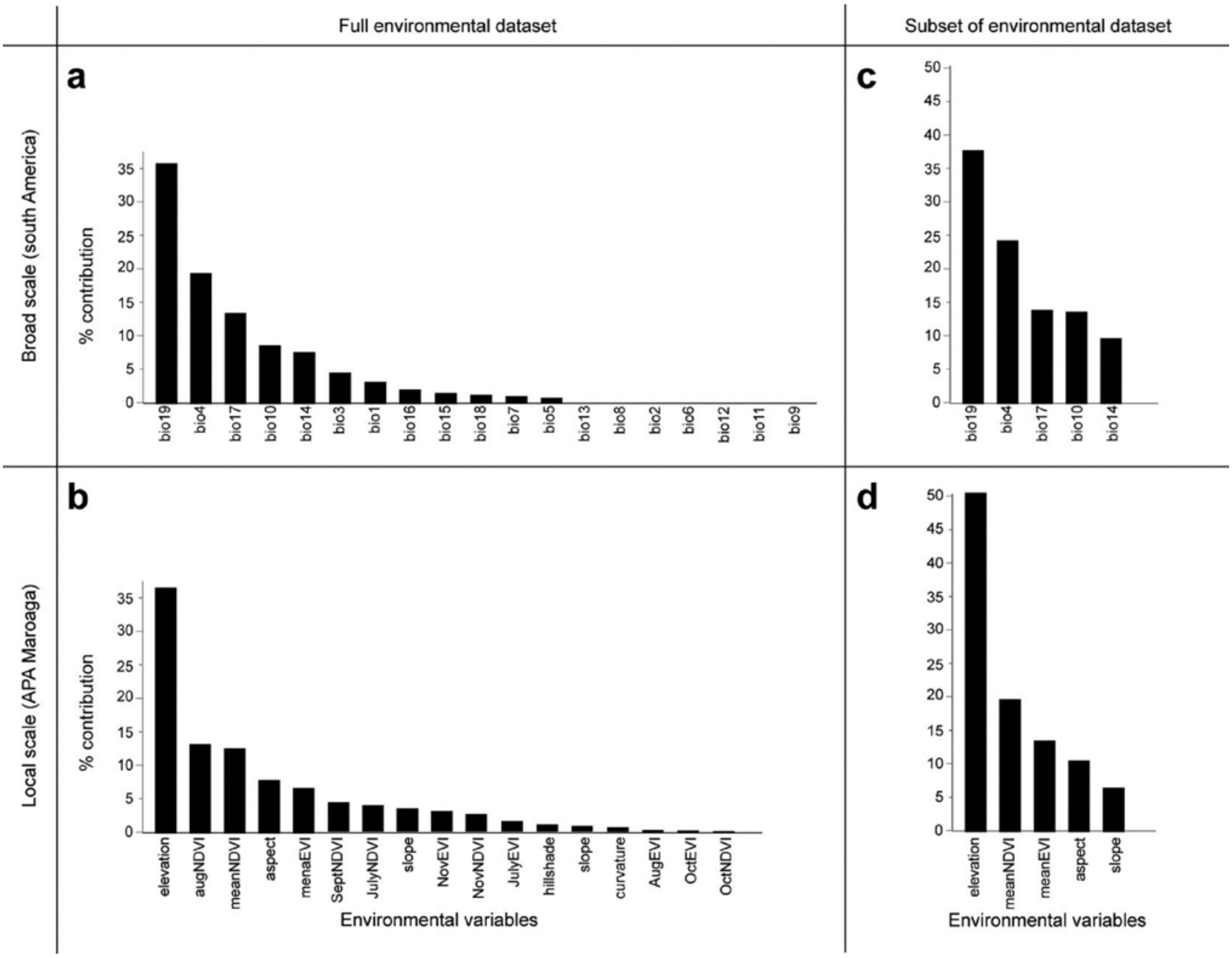
SUPPLEMENTARY FILE 1

Contribution (%) of the environmental variables to *Rupicola rupicola* Maxent potential distribution models using the entire dataset (a, c) and the subset (b, d), at broad scale in South America (a, b), and locally in APA Maroaga (c, d).



SUPPLEMENTARY FILE 2

List of environmental variables used in the broad and local scale modeling experiments.

MODELING SCALE	DATA SOURCE	VARIABLE	LABEL
Broad	WorldClim	Annual mean temperature	bio1
		Mean diurnal temperature range	bio2
		Isothermality	bio3
		Temperature seasonality	bio4
		Maximum temperature of warmest month	bio5
		Minimum temperature of coldest month	bio6
		Temperature annual range	bio7
		Mean temperature of wettest quarter	bio8
		Mean temperature of driest quarter	bio9
		Mean temperature of warmest quarter	bio10
		Mean temperature of coldest quarter	bio11
		Mean annual precipitation	bio12
		Mean precipitation of wettest month	bio13
		Mean precipitation of driest month	bio14
		Precipitation seasonality	bio15
		Mean precipitation of wettest quarter	bio16
		Mean precipitation of driest quarter	bio17
		Mean precipitation of warmest quarter	bio18
		Mean precipitation of coldest quarter	bio19
Local	SRTM	Elevation	elevation
		Aspect	aspect
		Slope	slope
		Curvature	curvature
		Hill shade	hillshade
	MODIS	July,2008 NDVI	JulyNDVI
		August 2008 NDVI	AugNDVII
		September 2008 NDVI	SeptNDVI
		October 2008 NDVI	OctNDVI
		November 2008 NDVI	NovNDVI
		July-November 2008 mean NDVI	meanNDVI
		July 2008 EVI	JulyEVI
		August 2008 EVI	AugEVI
		September 2008 EVI	SeptEVI
		October 2008 EVI	OctEVI
		November 2008 EVI	NovEVI
		July-November 2008 mean EVI	meanEVI

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