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Modeling the spatial distribution of the endemic and threatened palm shrub *Syagrus glaucescens* (Arecaceae)

Modelando a distribuição espacial da endêmica e ameaçada palmeira *Syagrus glaucescens* (Arecaceae)

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ABSTRACT

This study tests the use of accessible geoprocessing techniques to identify and describe the distribution of *Syagrus glaucescens*, a threatened palm shrub endemic to rupestrian fields (high-altitude grasslands) of the southern Espinhaço Range, in Minas Gerais, Brazil. A hundred and ninety five occurrence points and 24 absence points of *S. glaucescens* were recorded on a GPS device during field trips. Free databases of eight abiotic variables for the surveyed area were also used. Ninety-eight of the occurrence points were used to generate a spectral signature in ArcView to identify variables best characterizing *S. glaucescens'* distribution area and produce a probability map. The species' distribution was strongly associated to rocky outcrops whose geological composition is Quartzite Filite and Conglomerates, above 1.000 m of altitude, with declivities of 5-30%. When the accuracy of the probability map was tested, 87.63% of the 97 occurrence points used fitted areas of very high occurrence probability on the map, while 100% of the 24 non-occurrence points matched areas of null probability; therefore confirming the high accuracy of the model in predicting the occurrence of *S. glaucescens*. Although the altitudinal grasslands of Espinhaço are areas of great biodiversity and high degree of plant species endemism, they remain poorly studied. Thus, this model can be a helpful tool in designing management and conservation strategies not only for *S. glaucescens* but also for other species associated to rocky outcrops of such environment.

Key words: rupestrian fields, rocky outcrops, habitat modeling.

RESUMO

O presente estudo testou a utilização de ferramentas acessíveis de geoprocessamento na identificação e caracterização das áreas de ocorrência da palmeira *Syagrus glaucescens*, uma espécie de palmeira ameaçada de extinção e endêmica dos campos rupestres da Cadeia do Espinhaço de Minas Gerais, Brasil. Cento e noventa e cinco pontos de ocorrência e 24 pontos de ausência de *S. glaucescens* foram registrados com um GPS. Bases gratuitas de oito variáveis abióticas da área estudada também foram usadas. Noventa e oito dos pontos de ocorrência foram utilizados para gerar uma assinatura espectral no ArcView para identificar as variáveis que melhor caracterizassem a área de distribuição de *S. glaucescens* e produzir um mapa de probabilidades. Observou-se uma maior distribuição da espécie em áreas de afloramentos rochosos com composição geológica Quartzito Filito Metaconglomerados, acima de 1000 m de altitude e com declividade entre 5 e 30%. Quando testado o potencial preditivo do mapa de probabilidades, obteve-se 87,63% dos 97 pontos de ocorrência encontrados em áreas de altíssima probabilidade, enquanto que 100% dos 24 pontos de não ocorrência enquadrou-se em áreas de probabilidade nula, confirmando assim a alta eficácia do modelo em predizer as áreas de ocorrência da espécie. Embora os campos rupestres da Cadeia do

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Espinhaço sejam áreas de grande biodiversidade e alto grau endemismo de espécies de plantas, permanecem pouco estudados. Este modelo pode ser uma ferramenta útil para o delineamento de estratégias de manejo e conservação não apenas para *S. glaucescens* como também para outras espécies associadas a afloramentos rochosos de tal ambiente.

Palavras-chave: campos rupestres, afloramentos rochosos, modelagem de hábitat.

Introduction

The first requirement to asses a species' conservation status is to determine its occurrence. However, threatened species usually present narrow distribution, sparse populations or low abundance being, therefore, hard to detect (de Siqueira *et al*., 2009). For that reason, the prediction of species spatial distribution through niche modeling has been considered an important tool for management and conservation strategies (Peterson, 2001; Austin, 2002; Anderson *et al*., 2003; Sánchez-Cordero *et al*., 2005). Such is evidenced by the increasingly number of publications on species distribution modeling (Rushton *et al*., 2004).

The process of spatial modeling consists of converting primary data of species occurrence into maps of geographic distribution. Most of theses models work with the modern concept of fundamental ecological niche, proposed by Hutchinson (1957). It is defined as a set of ecological conditions and resources under which a species is able to maintain a viable population, regardless of competition and predation.

The ecological niche modeling can, among others, be used to: (i) recognize or predict the geographic distribution of taxa; (ii) better understand the role played by the different environmental parameters in the geographic distribution of species; (iii) help to take decisions on conservation subjects, such as native species reintroduction; (iv) monitor and predict the distribution of invasive species; (v) establish more suitable areas for conservation; and (vi) point out gaps in conservation and knowledge of biodiversity.

Due to the increasing use of Geographic Information Systems (GIS) and remote sensing tools, there has been vast advances in modeling species distribution, especially for larger areas (Rushton *et al*., 2004). These technologies have revolutionized the conservation biology, with applications ranging from the identification and description of habitat biophysical traits to the detection of environmental changes, both at small and large scales (Kerr and Ostrovsky, 2003; Turner *et al*., 2003). The interplay between these new tools and the ecological theory can breed the basic information to answer to a long-standing question in ecology: "why organisms are where they are?"

The aim of this study was to test the use of accessible geoprocessing techniques and free databases to identify and characterize the occurrence areas of the palm shrub *Syagrus glaucescens* Becc. (Arecaceae). It is an endemic threatened species from rupestrian fields (high-altitude grasslands) of the Espinhaço Mountain Range, in Minas Gerais, southeastern Brazil (Noblick, 2009 [1998]). The rupestrian fields are very rich environments with a high degree of endemism (Giulietti *et al*., 1987; 1997; 2000; Rapini *et al*., 2008) and, as for most of its endemic species, biological and ecological information for *S. glaucescens* are scarce at best.

Methods

Study area

Espinhaço is an old quartzite mountain range, extending 1100 km across the Brazilian states of Minas Gerais and Bahia (Ab'Saber, 1990). The studied area comprehended its southern portion, the so-called Serra do Espinhaço, in the Minas Gerais State. Field trips were directed to Serra do Cipó region, in the south, and Diamantina region, in the north (Figure 1a).

Above 900 m of altitude, this mountain range is dominated by rupestrian fields, a mosaic of communities associated to quartzite and filite derived substrates, including grassland, savannah, and forests (Vitta, 2002). A grassland matrix, growing on sandy or rocky-sandy stratum, surrounds islands of quartzite rocky outcrops, where some sparse shrubs and small trees grow-up fixing roots into the cracks, which are rich in organic material (Benites *et al*., 2003). The outcrops are the habit of many endemic species of Velloziaceae, Asteraceae and Melastomataceae (Medina and Fernandes, 2007), and also for palms such as *S. glaucescens* and *S. pleioclada*.

The area has a Köppen climate type Cwb, marked by dry winters and rainy summers, strongly influenced by latitude and altitude (Schulz and Machado, 2000). The average annual rainfall is around 1.250 - 1.550 mm, and average temperatures range from 18 to 19ºC (Maderia and Fernandes, 1999). Soil is sandy, shallow and nutrient poor, presenting low water holding capacity, low pH and high aluminum concentration (Ribeiro and Fernandes, 2000; Schulz and Machado, 2000; Negreiros *et al*., 2008).

Syagrus glaucescens

It is a small palm of up to 4 m height, presenting single individuals (Marcato and Pirani, 2001). It has a peculiar habitat, occurring, mostly, associated to quartzite rocky outcrops (Figure 1b). The species' limited distribution, allied to habitat change, has led it to integrate the list of threatened species of the International Union for Conservation of Nature and Natural Resources (Noblick, 2009 [1998]).

Glassman (1987) divided it into two species: (i) *S. glaucescens*, occurring at the northern portion of Espinhaço, in Diamantina, and (ii) *Syagrus duartei* in the southern portion, in Serra do Cipó. Nevertheless, here we used the criterion adopted by Marcato and Pirani (2001), which considers it as a single species, *S. glaucescens*, occurring in both locations.

Modeling

Modeling the spatial distribution of *S. glaucescens* consisted of locating and mapping points of occurrence using the physical characteristics of the study area, through the following steps: (i) collecting the occurrence points coordinates to determine the basic environmental attributes required for the species occurrence; (ii) Digital Image Processing (DIP) and data bank creation; (iii) spatial analysis and modeling.

(i) Data acquiring

Based on field observations and on previous works by Glassman (1987) and Marcato and Pirani (2001), altitude above 700 m and rocky outcrops were previously expected to be important attributes for the occurrence of *S. glaucescens*. Therefore, field trips were directed to rupestrian fields of the study regions, above 800 m altitude. Each population of *S. glaucescens* found had its geographic coordinates taken on a GPS (Global Positioning System) device of 10 m accuracy. Ninety-eight occurrence points were recorded to create the model. Other 97 presence and 24 absence points were collected to test the model.

(ii) Digital image processing and data bank creation

The software *SPRING* (INPE) was used to process the satellite digital imagery. The area of interest, Serra do Espinhaço, was delimited, processing the image clips from bands 5, 4 and 3 of the Landsat satellite (orbits/points: 217/72, 218/72, 218/73, 217/73, 218/74 and 217/74) with spatial resolution of 30 m, from September 2001. Once the images had been clipped, a radiometric adjust was performed between them and the georeferenced mosaic composition was made. The false color RGB543 was used to emphasize the rocky outcrops (Figure 1a). Such composition was, then, classified through the supervised method of verisimilitude, in which an applicative classifies the pixels according to criteria previously defined by the user for a set of samples. Five thematic classes were identified: rocky outcrops, grassland, non-grassland (Cerrado and forests), exposed land, and water. All variables (information layers) used to construct the data bank, with respective descriptions and sources are presented in Table 1.

(iii) Spatial analysis and model development

Ninety-eight occurrence points of *S. glaucescens* were converted into matricidal data and used to build a signature in the software ArcView 9.0. It consisted of crossing the layers of information of all occurrence points to recognize key variables for the species' occurrence (Moura, 2003). All bases were converted into matrix format, with 30 m resolution, even though it caused redundancy of lower resolution data. That was to enable the crossing of data from other sources with Landsat images. The averages and covariance of the signatures were used to create a map with the occurrence probabilities for the whole Serra do Espinhaço: null (0%), very low (1-20%), low (21-40%), medium (41-59%), high (60-79%) and very high (80-100%) (Figure 1c). Ninety-seven occurrence points of *S. glaucescens* plus 24 points of absence were plotted against the probability map to test the model.

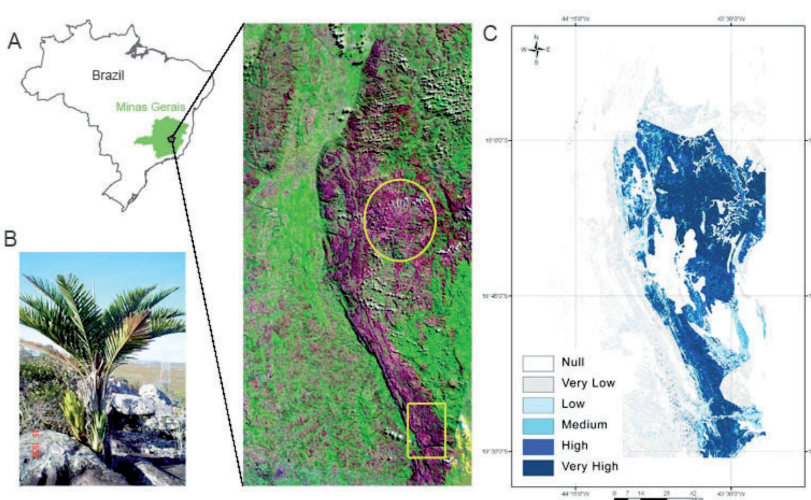

Figure 1. A) Study area. Serra do Espinhaço location in Minas Gerais, Brazil (star); Diamantina region (circle) and Serra do Cipó region (square). False color purple (RGB543) was used to emphasize the rocky outcrops; B) *Syagrus glaucescens* on rocky outcrop (Diamantina, MG); C) Occurrence probability map produced for *Syagrus glaucescens.*

Results

The greater frequency of *S. glaucescens* was found on rocky outcrops whose geological composition is Quartzite Filite and Conglomerates, in altitudes higher than 1000 m, with 5 to 30% of declivity and greater incidence of solar radiation (aspect variable) in the afternoon (Figure 2).
For the rest of the variables, though, there were clear differences between

Table 1. Variables used to create the data bank and characterize the habitat of *S. glaucescens*.

Layers	Description	Source
Altitude	Fourteen altitudinal classes were defined, from 100 to 100 m between 0 e 2100 m a.s.l.	Base derived from SRTM (NASA) radar image available at: http://srtm.usgs.gov. Resolution: 90 m.
Aspect	Periods of greater incidence of solar radiation on the vegetation. Three classes were predefined: (i) Higher incidence of solar radiation in the morning; (ii) Higher incidence of solar radiation in the afternoon; and (iii) Regular incidence of solar radiation throughout the day.	Base derived from SRTM (NASA) radar image available at: http://srtm.usgs.gov. Resolution: 90 m.
Declivity	Four declivity classes were obtained: (i) From 0 to 2.86º; (ii) From 2.86º to 16.7º; (iii) from 16.7º to 25.17º and (iv) Greater than 25.17º.	Base derived from SRTM (NASA) radar image available at: http://srtm.usgs.gov. Resolution: 90 m.
Geology	Encompassed all geological formations of the studied region	Base obtained from Geominas available at: www.geominas.mg.gov.br.
Land Cover	The properly classified satellite imagery evidenced the following land covers: (i) Rocky outcrop; (ii) Grassland; (iii) Non-grassland; (iv) Exposed land; and (v) Water.	Landsat 7 ETM+ georeferencied image taken from the Earth Science Data Interface Program of the University of Maryland Global Land Cover Facility, available at: http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp. Resolution: 30 m.
Rainfall	Average rainfall for January, from 1985 to 2001. The following classes were settled: (i) From 100 to 150 mm; (ii) From 150 to 200 mm and (iii) From 200 to 250 mm.	Base provided by INPE/CEPETEC. Resolution: 90 m.
Soil	Encompassed all soil types of the studied region	Base gathered from Geominas available at: www.geominas.mg.gov.br
Temperature	Annual average temperature from 1985 to 2001. Four classes were taken: (i) Lower than 19ºC; (ii) Between 19ºC and 21ºC; (iii) Between 21ºC and 22ºC and (iv) Between 22ºC and 24ºC.	Annual average temperature from 1985 to 2001. Four classes were taken: (i) Lower than 19ºC; (ii) Between 19ºC and 21ºC; (iii) Between 21ºC and 22ºC and (iv) Between 22ºC and 24ºC. Base provided by INPE/CEPETEC. Resolution: 90 m.

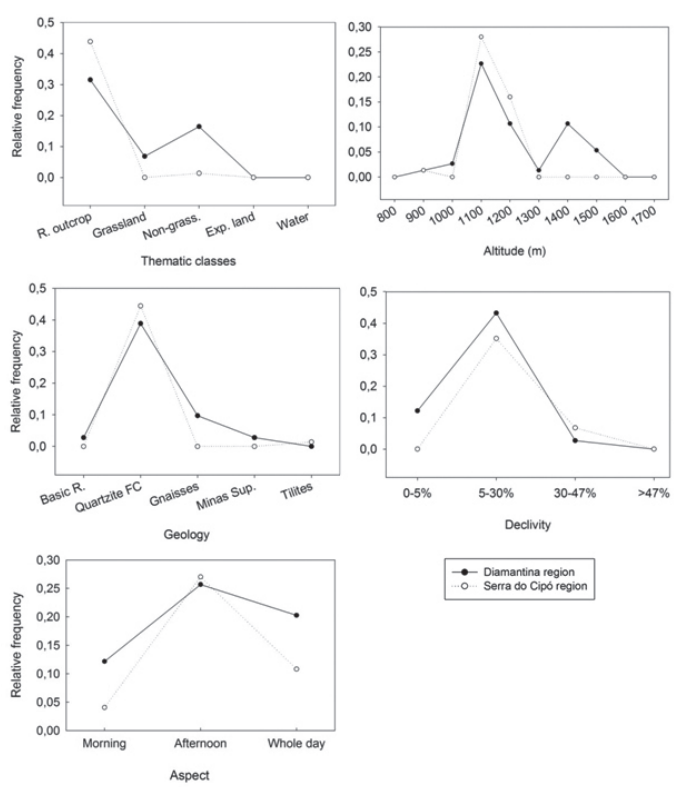

Figure 2. Relative frequency of occurrence points of *S. glaucescens* for thematic classes, altitude, geology, declivity and aspect. Showing similar patterns for Serra do Cipó and Diamantina.

the two regions studied (Figure 3). In Diamantina region (northern), occurrence was greater in litolic soils, under lower temperatures (between 19 and 21ºC), and average rainfall of 200 to 250 mm per month. On the other hand, in Serra do Cipó region (southern) the peaks of incidence were in Cambisoils, under higher temperatures (21 to 22ºC) and lower rainfall (between 150 and 200 mm per month).

When tested, the model presented a high predictive efficacy. Out of the 121 occurrence points plotted against the probability map, 87.63% overlapped areas of very high probability suggested by the model (Figure 4), while 100% of the 24 non-occurrence points matched areas of null probability.

Discussion

The distribution of *S. glaucescens* was strongly associated to quartzite rocky outcrops. Even when the species appeared in non-grassland formations,

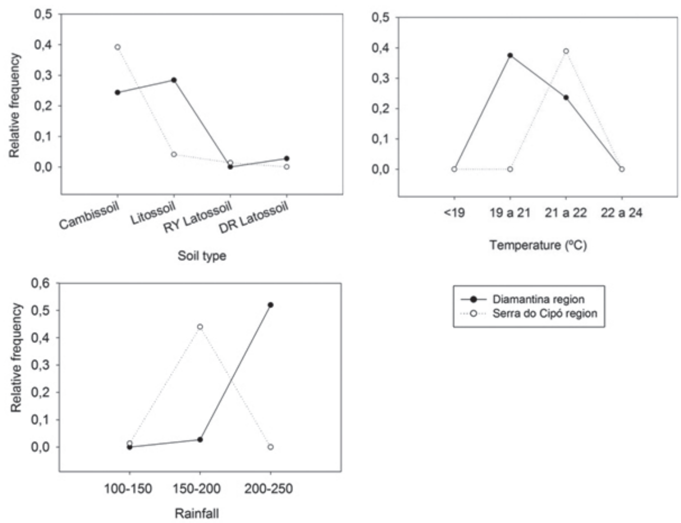

Figure 3. Relative frequency of *Syagrus glaucescens*' occurrence points for soil type (RY = red yellow; DR = dark red), temperature and rainfall. Showing differences between Serra do Cipó and Diamantina.

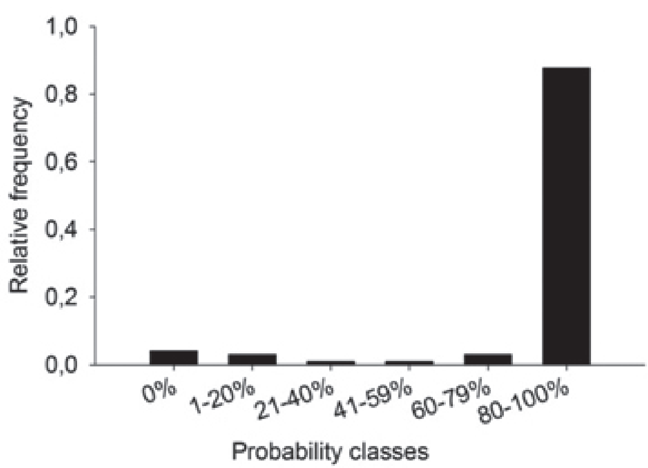

Figure 4. Relative frequency of occurrence points by classes of occurrence probability of the model.

outcrops were always found in adjacent areas. Although, the differences observed in the pattern of occurrence between individuals from Serra do Cipó and Diamantina reinforces the dichotomy between the populations from the two regions. These results corroborate the conclusion by Glassman (1987) that there would be two very close species of *Syagrus* Mart. differing in their distribution. The *S. glaucescens* would be endemic from Espinhaço Range in Minas Gerais, occurring from Serra do Cipó to Biribiri (near Diamantina), in altitudes ranging from 700 to 1200 meters, in grasslands, shrub-savannah (Campo Sujo) and woody-savannah (Cerrado). On the other hand, *S. duartei*, would be endemic from grasslands of Serra do Cipó, occurring on quartzite rocks at 1300 m of altitude. The union of the two species into the single taxon *S. glaucescens*, as proposed by Marcato and Pirani (2001), was not based on any genetic analyses. Therefore, it is fairly possible that the two populations indeed represent very similar species or varieties within the genus *Syagrus*.

However, several other hypotheses could be raised to explain such dissimilarities between populations, including the influence of biotic factors, not considered here (e.g., pollinators, seed dispersers and parasites). Therefore, solving this taxonomic problem would require a more in-depth survey, such as molecular and ecophysiologic analysis of individuals from both regions. For the distribution model obtained here, though, we keep considering *S. glaucescens* as a single species, bearing in mind the differences between regions.

Apart from region dissimilarities, altitude and declivity, associated to rocky outcrops, can be considered key factors for this species occurrence. For Amazonian palms, Vormisto *et al*. (2004) observed that the topographic variation remarkably influences the taxa distribution. In such case, topography alone would not be exerting a direct influence on the plant's biology, but would be acting in association to other environmental variables, creating suitable micro-habits for the species establishment. Even though there are no studies about it, it is thought that it should apply to *S. glaucescens* in the Espinhaço Range. It is possible that the occurrence of this species in so specific micro-habits, such as rocky outcrops, is conditioned by an association between quartzite outcrops, altitude, declivity, soil nutritional status and biotic variables, as the presence of seed dispersers. The most likely fruit disperser of *Syagrus,* is a rodent, probably belonging to the genus *Trichomys,* that has been seen into the breaches of rocky outcrops, where fruits of *S. glaucescens* (or rests) are frequently found (Fernades GW, personal observation, 2009). While no experiments have been carried-out to verify *S. glaucescens*' seed dispersion method and efficiency, it is likely that the rodents, by transporting the fruits to be consumed and/or stored in their nests, end-up spreading the species, allowing some fruits to accidentally germinate (Van der Pijl, 1982).

Although the variables such as rainfall and temperature may not be actively interfering with the distribution, they might be related to the species abundance in the occurrence areas. Unfortunately, there are no studies on the biology and ecology of *S. glaucescens*, what makes it difficult to relate abundance and occurrence patterns to ecophysiologic traits.

Using satellite imagery and radar data to detect occurrence areas

For species of restrict and peculiar habitats, such as *S. glaucescens*, the detection of potential occurrence areas can be performed directly by classifying satellite imagery and detecting spectral signature (Turner *et al*., 2003). Laurent *et al*. (2005), using rather simple ranking methods and Landsat 7 ETM+ images, obtained good results studding the distribution of three North American bird species. Such birds are associated to a very specific vegetation type, which can be spectrally recognized during the plant reproduction period. This kind of analysis, although quick and simple, can accurately detected habitats potentially inhabited for such species, especially when combined to field data (Kerr and Ostrovsky, 2003).

Some troubles, however, can be noticed regarding satellite data quality and, as a result, the quality of the potential distribution map produced. The first, and more important, is about spatial resolution. The Landsat has an average spatial resolution of 30 m (multispectral mode), what makes impossible to detect the small rocky outcrops spread in the grassy matrix. Thus, this methodology becomes unsuitable for small and micro scale surveys. An alternative would be the use of data with higher spatial resolution, such as the ones provided by the satellites Ikonos (1m resolution on panchromatic mode and 4m on multispectral) and Quickbird (0.6 - 0.8 on panchromatic mode and 2.4 – 2.8 m on multispectral). The main trouble, however, in acquiring those images, are the costs, inaccessible for many research centers.

A cheaper option are the images from the satellite Aster (Advanced Spacebone Thermal Emission and Reflection Radiometer) which has 15m resolution images and, although not hyperspectrals, presents more bands. That allows for more compositions and more detailed classification compared to other images with higher spatial and spectral resolutions.

Otherwise, Landsat images are quite appropriate for larger scale surveys, such as for conservation planning, which, usually, require the assessment of large areas to identify possible alternatives for management and conservation (Wu and Smeins, 2000). The great advantage of Landsat is that, besides having a short repetition rate (16 days), it has a long archive, with images from the last 37 years. That allows for studying, for instance, the vegetal succession of a certain area or to detect and predict the expansion of exotic species.

Altitude and relief can dramatically alter the habitat and, as a result, the spatial distribution of individuals. However, satellite imagery shows the world in two dimensions. Thus, supplementary data of topography are needed in niche modeling (Laurent et al., 2005). The altitude data from SRTM (Shuttle Radar Topography Mission - NASA), in association with Landsat 7 images gives good results for studying habitat traits and species distribution (Turner et al., 2003). In fact, it seems that such combination was fundamental for the high success, achieved here, in predicting the spatial distribution of *S. glaucescens*.

Implications for conservation and future perspectives

Distribution models based on habitat traits get more reliable when including the species' natural history, such as reproduction strategies, dispersers and pollinators abundance, parasites and predators, conditions for germination, establishment, growth, susceptibility to environmental disturbs, and so on. Thus, additional studies on taxonomy, ecology and biology of *S. glaucescens* are necessary to create a more accurate and efficient distribution model. Nevertheless, for most of the endemic and threatened species, as for *S. glaucescens*, the details of natural history is still unknown, and there might not be enough time for studying them before drawing conservation strategies. In such cases, simple and quick models, as the one built here, can be of great help.

The probability map generated here has proved to be efficient in detecting occurrence areas of *S. glaucescens*. It can be used to plan actions to preserve this species as well as rocky outcrop communities from rupestrian fields of Espinhaço Range, in Minas Gerais. The maps produced by this sort of model can be used in association with other variables of interest (land use, fire regime, degree of threat, etc.) and, this way, help to locate rare endangered species and to design areas and routes for its conservation. For rare species, with distribution restricted to patches of a few meters (e.g., *Coccoloba cereifera*: Polygonaceae – Ribeiro and Fernandes, 2000), it might be necessary to perform more detailed surveys, in finer scales (Wu and Smeins, 2000). But, even in such cases, this model can still guide the field researches and support the development of more accurate maps of potential distribution.

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