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Modeling the Distribution of Three Cactus Species of the Caatinga Biome in Future Climate Scenarios

ARNÓBIO DE MENDONÇA BARRETO CAVALCANTE (Corresponding author)

National Institute for Space Research, Northeast Regional Center, Eusébio, CE 61.760-000, Brazil
E-mail: arnobio.cavalcante@inpe.br; cavalcantearnobio@gmail.com

ARYBERG DE SOUZA DUARTE

National Institute for Space Research, Northeast Regional Center, Eusébio, CE 61.760-000, Brazil
E-mail: arybergduarte@gmail.com

ABSTRACT

The climate predictions for the Caatinga (shrubland) biome this century include increased air temperature and reduced rainfall, leading to aridization. Studies about the risks posed to the biome's flora are scarce. The present article reports a study to model the distribution of three epiphytic cactus species native to the Caatinga biome (*Rhipsalis floccosa* Salm-Dyck ex Pfeiff., *Rhipsalis lindbergiana* K. Schum and *Rhipsalis russellii* Britton & Rose) in future climate scenarios. For this purpose, we used nine environmental variables obtained from biodiversity databases and the MaxEnt algorithm, considering two future time intervals, 2041-2060 and 2061-2080, centered respectively in 2050 and 2070, with the 1961-1990 time slice as current reference. The greenhouse gas concentration scenarios were RCP 4.5 and 8.5. Five distribution models were generated for each target species. All the future models projected contraction of more than 87% in the areas with high occurrence potential of the species in relation to the present area. The areas of high potential are in the majority at elevations with specific characteristics. The drastic contraction effect of the potential areas is a warning of possible local extinctions of the target species in the Caatinga biome. Furthermore, it allows inferring local extinction for other epiphyte species with similar climate requirements. Therefore, it appears premature to make any prediction of a low impact of climate change on the Caatinga biome.

Key Words: Climate Change; Cactaceae; Rhipsalis; MaxEnt; Epiphytic Cactus; Impact

Modelando a distribuição de três espécies de cactos do bioma caatinga sob cenários climáticos futuros

RESUMO

As previsões climáticas para o bioma Caatinga neste século incluem aumento de temperatura do ar e redução das chuvas, levando-o à aridização. Estudos sobre os perigos que corre sua flora são escassos nesse contexto. O presente estudo tratou de modelar a distribuição de *Rhipsalis floccosa* Salm-Dyck ex Pfeiff., *Rhipsalis lindbergiana* K. Schum and *Rhipsalis russellii* Britton & Rose, cactos epífitos e nativos do bioma Caatinga em cenários climáticos futuros. Para tal, utilizou-se de bases de dados de biodiversidade, nove variáveis ambientais e o algoritmo MaxEnt. Considerou-se os intervalos de tempo futuros 2041-2060 e 2061-2080 centrados, respectivamente, em 2050 e 2070, e como referência corrente a fatia de tempo 1961-1990. Os cenários de gases de efeito estufa foram RCP4.5 e 8.5. Cinco modelos de distribuição foram gerados por espécie-alvo. Todos os modelos futuros projetaram para uma contração acima de 87% das áreas de alto potencial de ocorrência das espécies em relação à mesma área corrente. As áreas de alto potencial são, majoritariamente, elevações com características específicas. O drástico efeito contração das áreas potenciais é um alerta para possíveis extinções locais das espécies-alvo no bioma Caatinga. Ademais, permite inferir extinções locais também para outras espécies epífitas com exigências semelhantes. Portanto, parece prematuro afirmar qualquer predição de baixo impacto das mudanças climáticas para o bioma Caatinga.

Palavras-chave: mudança climática, cactaceae, rhipsalis, maxent.

INTRODUCTION

The theme of climate change due to global warming has gained scientific predominance due to its negative present and future impacts on human quality of life and biodiversity. The evidence supporting the occurrence of this phenomenon is plentiful, as reported in a huge number of academic works in recent years. The global reference about the subject is the Fifth Assessment Report on Climate Change (AR5), prepared by the Intergovernmental Panel on Climate Change, which confirms the occurrence of climate changes with impacts on all continents and oceans (IPCC 2014 a, b, c). It is also worth mentioning Bellard et al. (2012) and Pecl et al. (2017), who reviewed the impacts of climate change on present and future biodiversity.

In Brazil, the reference is the First National Assessment Report on Climate Change prepared by the Brazilian Panel on Climate Change, which predicts increased air temperature and greater frequency of extreme weather events throughout the country (PBMC 2014 a, b). With respect to the country's Northeast region, the works of Marengo (2008, 2014), Sales et al. (2015), Lacerda et al. (2016) and Marengo et al. (2017) stand out, all of which project pessimistic scenarios for the region, with a tendency for a higher number of months with water deficit (aridization).

For the Caatinga biome, mainly inserted in the Northeast region, the forecasts are for a tendency for average temperature increase of 4.5 ºC and 50% reduction of rainfall by the end of this century (Brasil 2016 a). With respect to the biological aspects of the biome, particularly the vegetation and flora, the prediction is for a shift from the present vegetation to species better suited to arid conditions, with predominance of cacti (Marengo 2007, 2008). In relation to flora, mention can be made of the reviews of Santos et al. (2014), according to which native species of the Caatinga biome exist that are physiologically well equipped to withstand extreme droughts, and Albuquerque et al. (2012), who stated that precipitation followed by temperature are the main physical elements responsible for promoting and hampering biological processes in the biome, together with those driving climate change. Both reviews indicate a large gap in knowledge of the effects of climate change on the flora.

The fact is that the climate changes under way will continue to affect the Caatinga biome and the available studies are insufficient for an adequate assessment of the present and future effects on the biome's assemblage of plant species, which according to Giullieti et al. (2006) contains more than 5,344 phanerogam species. This scarcity of knowledge is worrying, because according to the diagnosis of the Fifth National Report on Biodiversity (Brasil 2016 b), the Caatinga biome is classified as the fourth most devastated biome in the country, with only 53.4% of the native vegetation remaining. Besides this, the Caatinga biome was recently included on the list of global regions most ecologically sensitive to climate variability, along with the Arctic Tundra, parts of the Boreal Forest (Tiaga) and Tropical Forest biomes, among others (Seddon et al. 2016).

In summary, based on the combination of climate changes under way, in particular the tendency for aridization, along with alterations in the composition and structure of vegetation, anthropogenic destruction and vulnerability, the worst-case outlook for the Caatinga biome is one of total collapse, unless effective preventive actions are taken. In light of this apocalyptic vision of the future, there is an urgent need for more studies to shed light on the possible effects of climate change on the plant species in the Caatinga biome. In this context and considering only the structure of the vegetation, what spatial alterations (contraction, expansion, stabilization or disappearance) of the Caatinga biome can be expected in this century, regarding areas suitable for native plant species in face of climate change?

In this sense, a numerical tool to provide ecological insights and predict the distribution of species in climate change conditions is species distribution modeling, also called bioclimatic or ecological niche modeling (Pearson and Dawson 2003, Guisan and Thuiller 2005, Elith and Leathwick 2009). Such models are generated by a technique that associates records of the occurrence of the species with a set of environmental variables, to estimate habitats that are suitable to maintain a viable population (Guisan and Zimmermann 2000), as long as that niche is preserved in space and time (Pearman et al. 2008).

This approach has been successfully applied to predict the potential occurrence of native species (Téllez-Valdés and Dávila-Aranda 2003, Butler et al. 2012, Yang et al. 2013) and invasive species (Peterson et al. 2003, Giovanelli et al. 2008, Beaumont et al. 2009, Stohlgren et al. 2010), as well as to assess the future effects of climate change on the geographic redistribution of species of different taxonomic groups (Araújo et al. 2006, Ogawa-Onishi et al. 2010, Cortes et al. 2014).

Despite the use of inappropriate terminology related to ecological niche modeling (Peterson and Soberón 2012), as well as the existence of errors in the models and the complexity of the natural systems in question, which imposes confidence limits on the predictions, species distribution modeling is the most common tool used in studies to forecast biodiversity (Bellard et al. 2012), providing an initial approximation regarding the potentially dramatic impacts of climate change on the distribution of species (Pearson and Dawson 2003).

In this context, the objective of this study was to model the geographic distribution of three true epiphytic cactus species in the Caatinga biome, considering two possible future climate scenarios, to shed light on their spatio-temporal responses and thus to identify vulnerabilities that require conservation measures.

MATERIAL AND METHODS

Description of the Area Studied

The area for which the model was projected is the Caatinga biome, nearly all of which is located in the Northeast region of Brazil (Figure 1), with area of 844,453 km^2 or 10% of the country's territory (MMA 2018). Because it is totally situated between the Equator and Tropic of Capricorn (3° to 18° South latitude), the entire biome receives abundant sunlight throughout the year. The temperatures are high, with little variability: yearly average being between 25 and 30 °C and little difference between the coldest and hottest months (Sampaio 2003). The water availability, unlike the temperature, is extremely variable in space and time, with erratic rain, concentrated in only a few months, and irregular alternation of dry and wet years (Sampaio 2010). The annual average rainfall fluctuates between slightly under 300 mm to just above 1,000 mm (Reddy 1983). The terrain in the region is also highly variable, with large depressions, sedimentary plateaus and residual massifs. The areas that rise above 1,000 meters block cold fronts, making them wet and windy, while the leeward areas are semiarid (Cavalcante 2005).

The Caatinga biome is essentially covered by vegetation submitted to a semiarid climate, where the flora presents adaptations to water deficiency and significant endemism (Rodal and Sampaio 2002). However, there are small enclaves of other vegetation types, such as mountain forests, savannas and rocky fields (Giullieti et al. 2006).

This plurality of vegetation consists of some 200 botanical families, of which the Cactaceae is among the most important. Besides its richness, with 23 native endemic and non-endemic genera and 91 species (Flora do Brasil 2017), this family also plays important economic, social and environmental roles (Taylor and Zappi 2004, Cavalcante et al. 2013, Cavalcante and Vasconcelos 2016), making it emblematic of the biome and the entire Northeast region of Brazil.

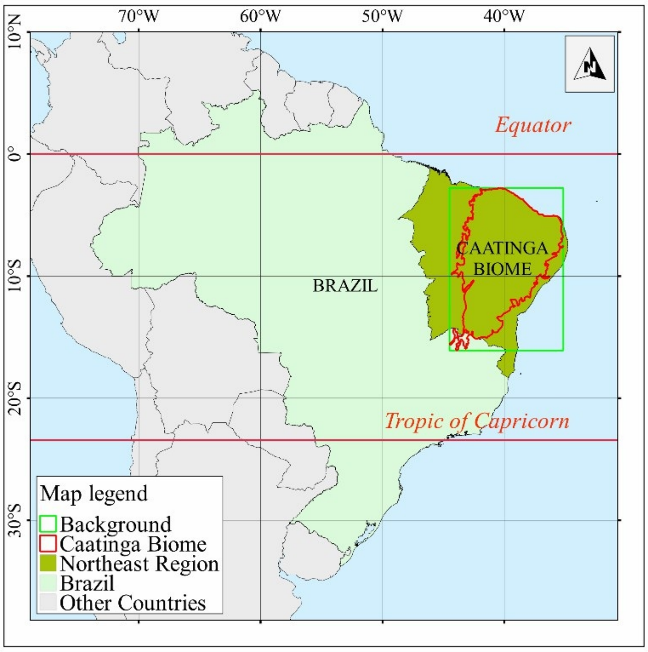

Figure 1. Location of the Caatinga biome.

Species Selected

Of the 91 native cactus species present in the Caatinga biome, seven are true epiphytic cacti (Flora do Brasil 2017). Among them, we selected *Rhipsalis floccosa* Salm-Dyck ex Pfeiff., *Rhipsalis lindbergiana* K. Schum and *Rhipsalis russellii* Britton & Rose (correct and accepted names). These not endemic species occur in the biome on plants and rocks, from near sea level to an elevation of 1,200 meters, and are most commonly present in the wettest parts of the biome (Taylor and Zappi 2004). These three species are not considered endangered in Brazil (Martinelli and Moraes 2013). We chose them for having satisfactory biological and ecological knowledge available, especially quantitative and qualitative data, as necessary for the algorithm.

Modeling and Simulation

The records of the presence and location of *R. floccosa*, *R. lindbergiana* and *R. russellii* according to decimal geographic coordinates were obtained from two online databases, the Global Biodiversity Information Facility (www.gbif.org) and SpeciesLink (www.splink.cria.org.br). We did not use records of the absence of the species. Therefore, a total of 45 (*R. floccosa*), 26 (*R. lindbergiana*) and 15 (*R. russellii*) georeferenced presence points were observed in the Caatinga biome and retrieved. All the retrieved points were checked one at a time in sequence, for removal of points with incorrect geographic coordinates, records before 2000 and duplicate records from the same locale, as described by Dalapicolla (2016). The remaining dataset contained 37, 20 and 14 records of the presence of *R. floccosa*, *R. lindbergiana* and *R. russellii*, respectively. These points were plotted on an altitude map of the terrain in the Caatinga biome (Figure 2).

With respect to the dimension of the set of variables used in the modeling, we initially selected variables revealing dominant control and that were associated with the particularities of the target species and the study area. In this respect, we considered the effectiveness of the environmental variable in starting and ending physiological events, as well as in influencing the spatial arrangement of the plants in the Caatinga biome. These choices were based on the specialized literature (Ab'Sáber 2003, Taylor and Zappi 2004, Cavalcante 2005, Sampaio 2010, Albuquerque et al. 2012, Santos et al. 2014), which pointed to climate variables, and indirectly to topographic variables. Other variables, such as land use, soil type and biotic interaction, were not considered in this study.

The data for the three topographic variables, elevation, declivity and direction of the terrain, were obtained from http://eros.usgs.gov, while the climate variables related to temperature (11) and precipitation (8) were downloaded from the database available at http://worldclim.org (v. 1.4), with spatial resolution of 30 seconds (~ 1 km). We reduced this initial set of 22 environmental variables to 9 by applying principal component analysis (PCA), considering a maximum correlation between the environmental variables of 0.7 (Warren et al. 2014, Dalapicolla 2016). The resulting environmental variables with their respective codes were: Bio2 – mean diurnal temperature range; Bio3 – isothermality; Bio5 - maximum temperature of the warmest month; Bio12 - annual precipitation; Bio14 - precipitation of the driest month; Bio18 - precipitation of

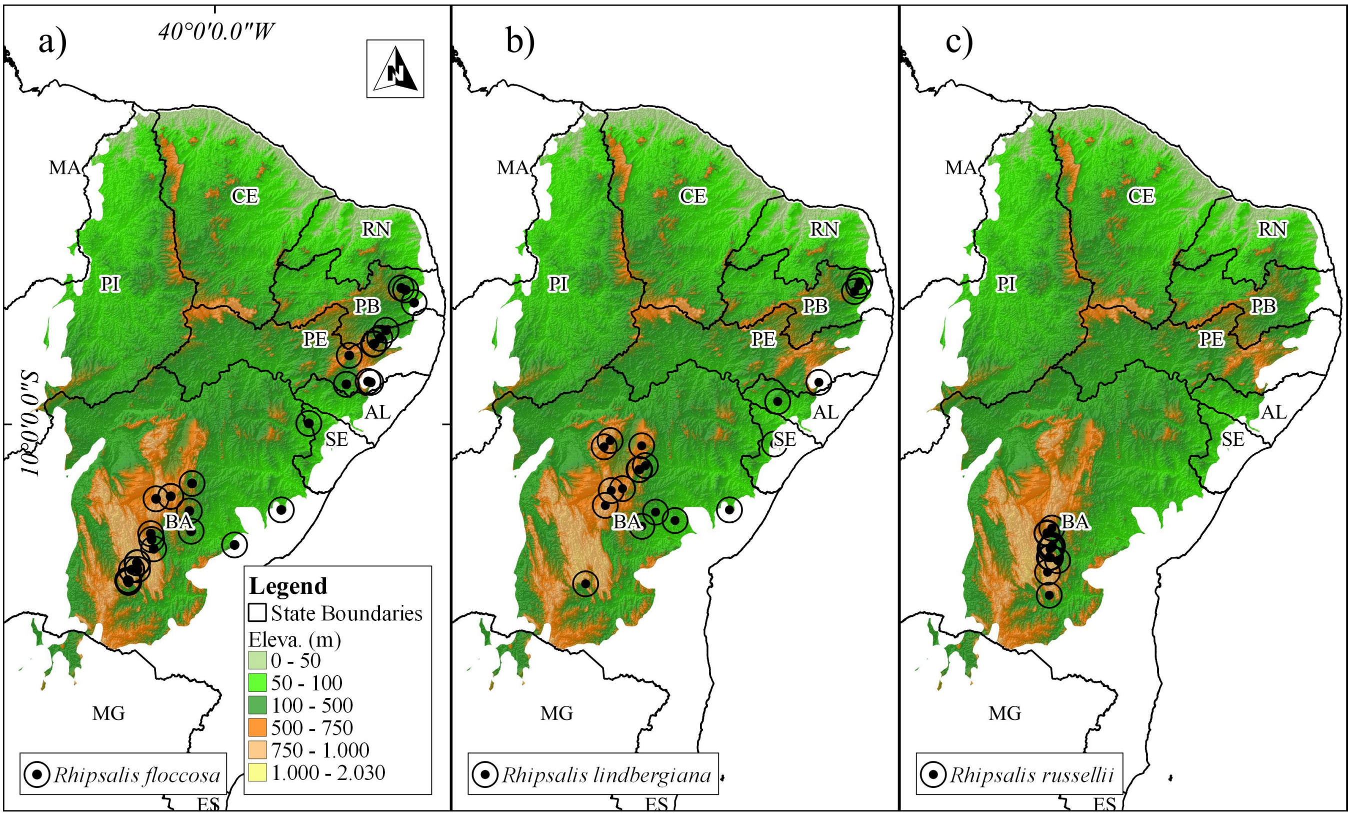

Figure 2. Current records of *R. floccosa* (a), *R. lindbergiana* (b) and *R. russellii* (c) regarding altitude in the Caatinga biome.

the warmest quarter; ELE - elevation; DEC – declivity; and DIR – direction.

For future climate conditions, we used data from the HadGEM2-ES model (Hadley Global Environment Model 2 - Earth System), considering the time slices 2041-2060 and 2061-2080, centered respectively in 2050 and 2070 (Hijmans et al. 2005), and the RCP4.5 and 8.5 scenarios (Van Vuuren et al. 2011). For current climate conditions, we used data covering the 1960-1990 period (Hijmans et al. 2005).

The programs applied in this work were MaxEnt 3.4.1 (http://biodiversityinformatics.amnh.org/open_source/maxent/) and QGIS 2.18 (http://www.qgis.org). The area under the curve (AUC) statistical test was used to validate or evaluate the quality of the final models generated (Phillips 2006, Beaumont et al. 2009), considering the following classification: $AUC < 0.80$ is a poor or null model; $0.81 < AUC\ 0.90$ is adequate; $0.91 < AUC \leq 0.95$ is good; and $0.95 < AUC \leq 1.00$ is excellent (Thuiller et al. 2006). Finally, we calculated the extent of the areas originally occupied by the target species along with the expanded or contracted future areas projected, using a GIS, from the present in accordance with changing climate.

RESULTS

Based on the set of the nine most independent environmental variables with the greatest power to contribute to the distribution of the target species, the PCA indicated that elevation (ELE), precipitation of the driest month (Bio14) and maximum temperature of the warmest month (Bio5), in that order, had the strongest contribution to the distribution model of *R. floccosa*, with a sum of contributions near 80%. For *R. lindbergiana*, the environmental variables with greatest contribution were precipitation of the driest month (Bio14), maximum temperature of the warmest month (Bio5) and elevation (ELE), which together had a contribution of just over 80%. Finally, the environmental variables with highest contribution to *R. russellii* were precipitation of the warmest quarter (Bio18), precipitation of the driest month (Bio14) and elevation (ELE), together representing nearly 90% of the contributions. Among these variables (ELE, Bio18, Bio14 and Bio5), ELE and Bio14 were common to the three target species. In turn, the environmental variable with the smallest contribution to the distribution model was annual precipitation (Bio12), which was below 0.20%.

For each target species we produced five final distribution models based on MaxEnt: one current distribution model (1961-1990); two future RCP4.5 distribution models, centered in 2050 (2041-2060) and 2070 (2061-2080); and two future RCP8.5 distribution models, centered in the same two years. Therefore, a total of 15 distribution models were produced. These final models had "excellent" precision for *R. floccosa* and *R. russellii*, with AUC values greater than or equal to 0.95, while the precision was "adequate" for *R. lindbergiana*, with $0.81 < AUC < 0.90$ (Table 1).

Table 1. AUC (area under the ROC curve) values of the final models.

Climate	Time Slices	AUC *R. floccosa*	 *R. lindbergiana*	 *R. russellii*
Current	1961-1990	0.95	0.87	0.99
RCP4.5	2041-2060	0.95	0.86	0.99
	2061-2080	0.95	0.86	0.99
RCP8.5	2041-2060	0.95	0.87	0.99
	2061-2080	0.95	0.86	0.99

The current distribution models produced for each target species, presented here repeating the scenarios RCP4.5 and RCP8.5 (Figures 3a, 4a, 5a, 6a, 7a, 8a), showed a probability gradient of occurrence of the target species ranging from zero (absence) to 1.00 (presence) in the Caatinga biome. This provided information not only of the areas with current records, but also other areas that currently have adequate environmental conditions for the presence of the target species. These other areas were located both contiguous to and isolated from the current areas with records of the species. The areas with highest occurrence potential (chance of presence > 0.75) covered about 6,000, 47,000 and 8,000 km^2, corresponding to 0.7%, 5.6% and 0.9% of the biome's total area (844,453 km^2), respectively, for *R. floccosa*, *R. lindbergiana* and *R. russellii* (Table 2).

For the future scenarios centered in 2050 and 2070, the distribution models produced (Figures 3bc, 4bc, 5bc, 6bc, 7bc and 8bc) showed different areas with high potential when comparing the current and future models for each species and between species. Despite the spatial differences, all the distribution models for 2050 (RCP4.5 and 8.5) and 2070 (RCP4.5 and 8.5) indicated the same effect, namely a contraction of the areas with high potential for presence of the target species in the future. This contraction varied from 87% to 100% in relation to the area with the current climate (Table 2).

The bioclimatic modeling with the climate changes included allowed identification of two possible future scenarios for distribution of the target species in relation

Table 2. Absolute and relative values for the areas with high potential presence (chance of occurrence > 0.75) of the target species in relation to the climate state in the Caatinga biome.

Species		Climate Condition Current	RCP4.5		RCP8.5	
	Interval (year)	1961-1990	2041-2060 (2050)	2061-2080 (2070)	2041-2060 (2050)	2061-2080 (2070)
R. floccosa	Area (km^2)	6,050.88	463.50	39.32	129.81	10.76
	Contraction (%)	----	92.34	99.35	97.85	99.82
R. lindbergiana	Area (km^2)	46,822.24	5,856.00	682.80	987.00	525.00
	Contraction (%)	----	87.49	98.54	97.89	98.88
R. russellii	Area (km^2)	7,643.57	769.00	1.72	0.58	0.00
	Contraction (%)	----	89.94	99.98	99.99	100.00

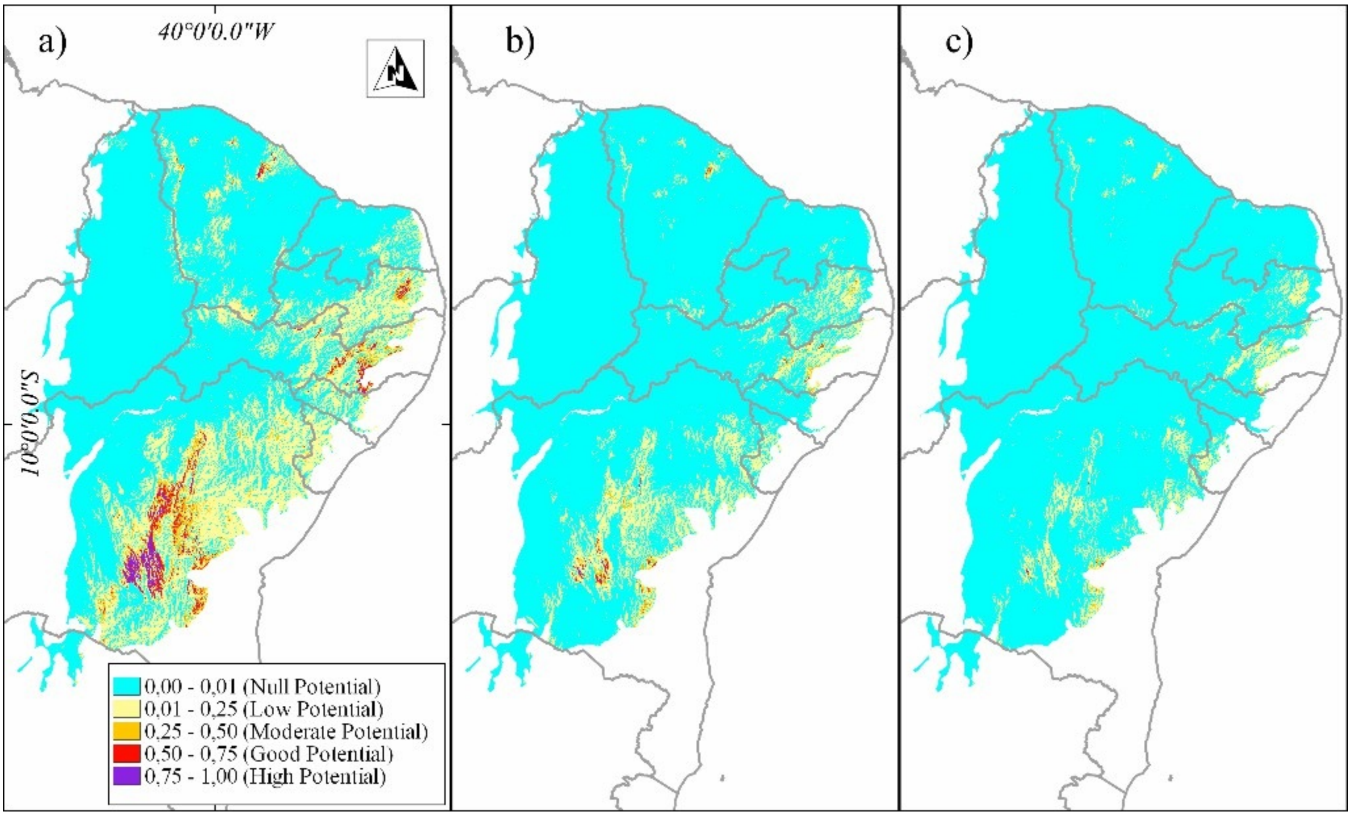

Figure 3. Simulation of the current spatial distribution (a) and those projected for 2050 (b) and 2070 (c) in the RCP4.5 scenario for *R. floccosa* in the Caatinga biome.

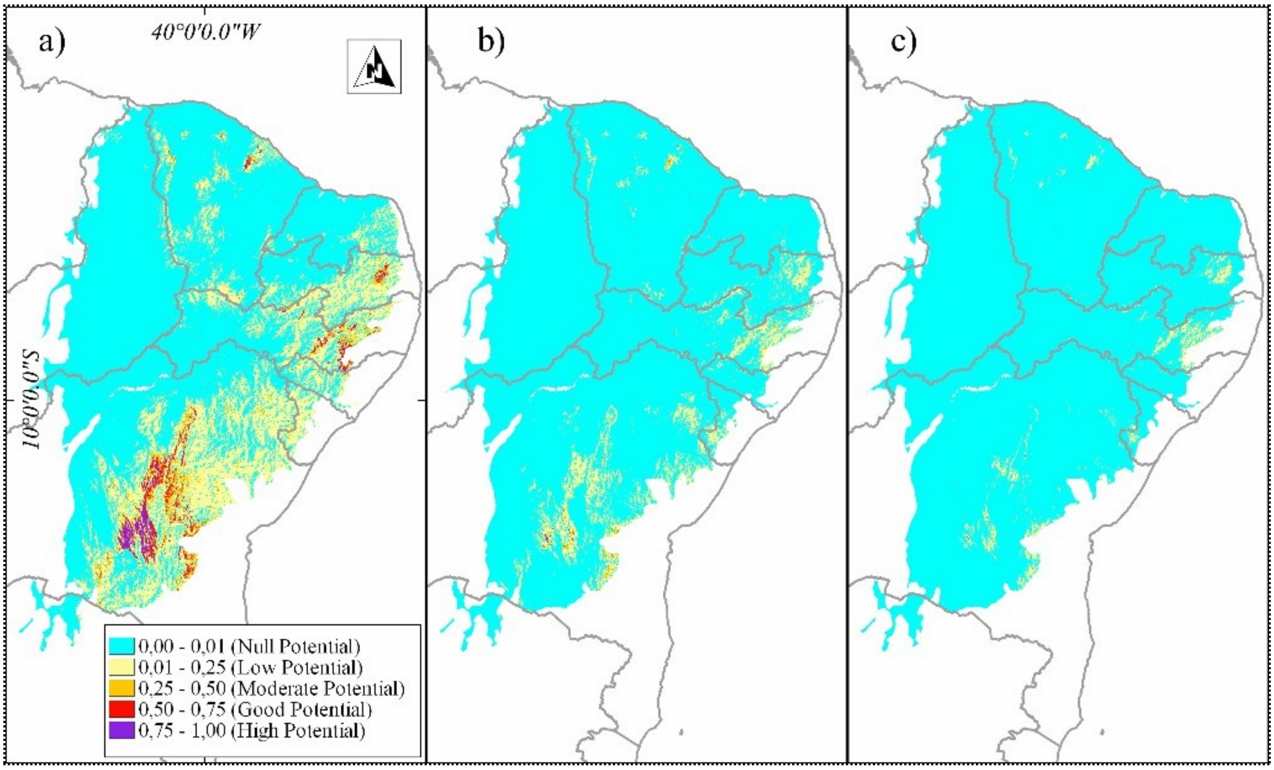

Figure 4. Simulation of the current spatial distribution (a) and those projected for 2050 (b) and 2070 (c) in the RCP8.5 scenario for *R. floccosa* in the Caatinga biome.

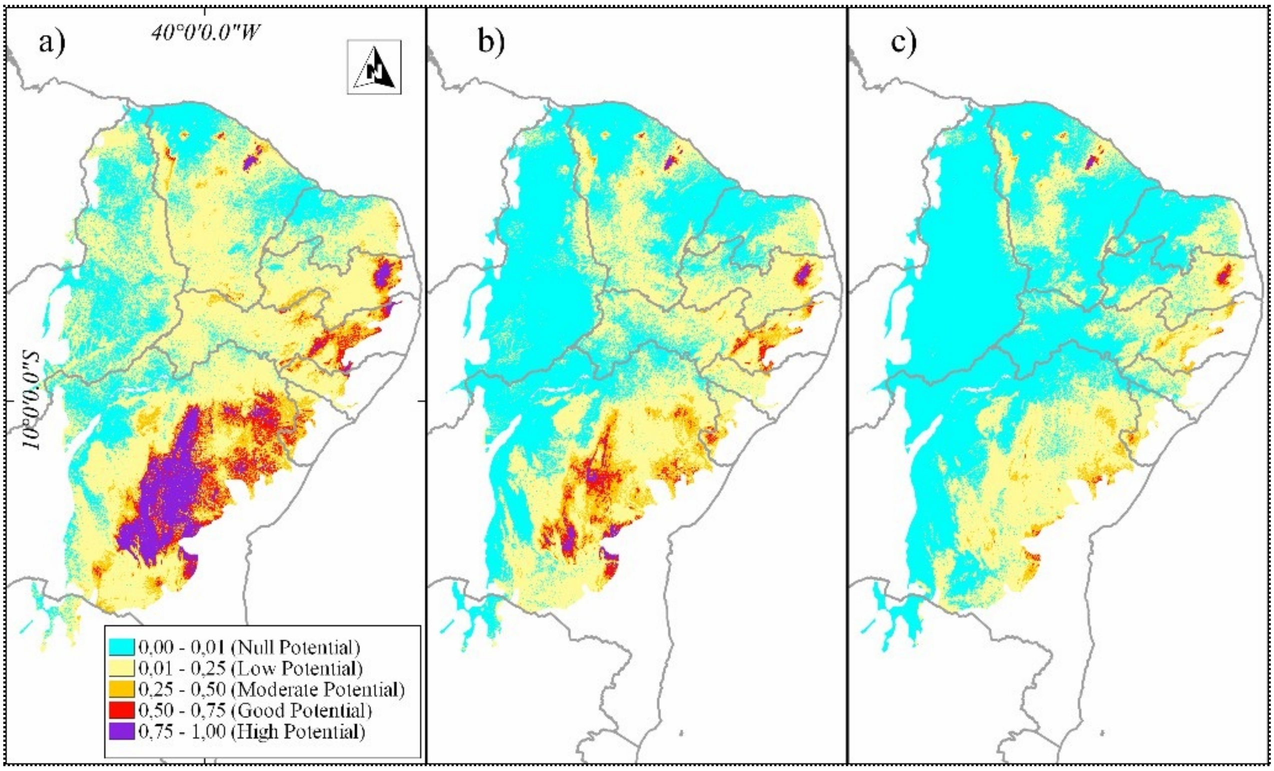

Figure 5. Simulation of the current spatial distribution (a) and those projected for 2050 (b) and 2070 (c) in the RCP4.5 scenario for *R. lindbergiana* in the Caatinga biome.

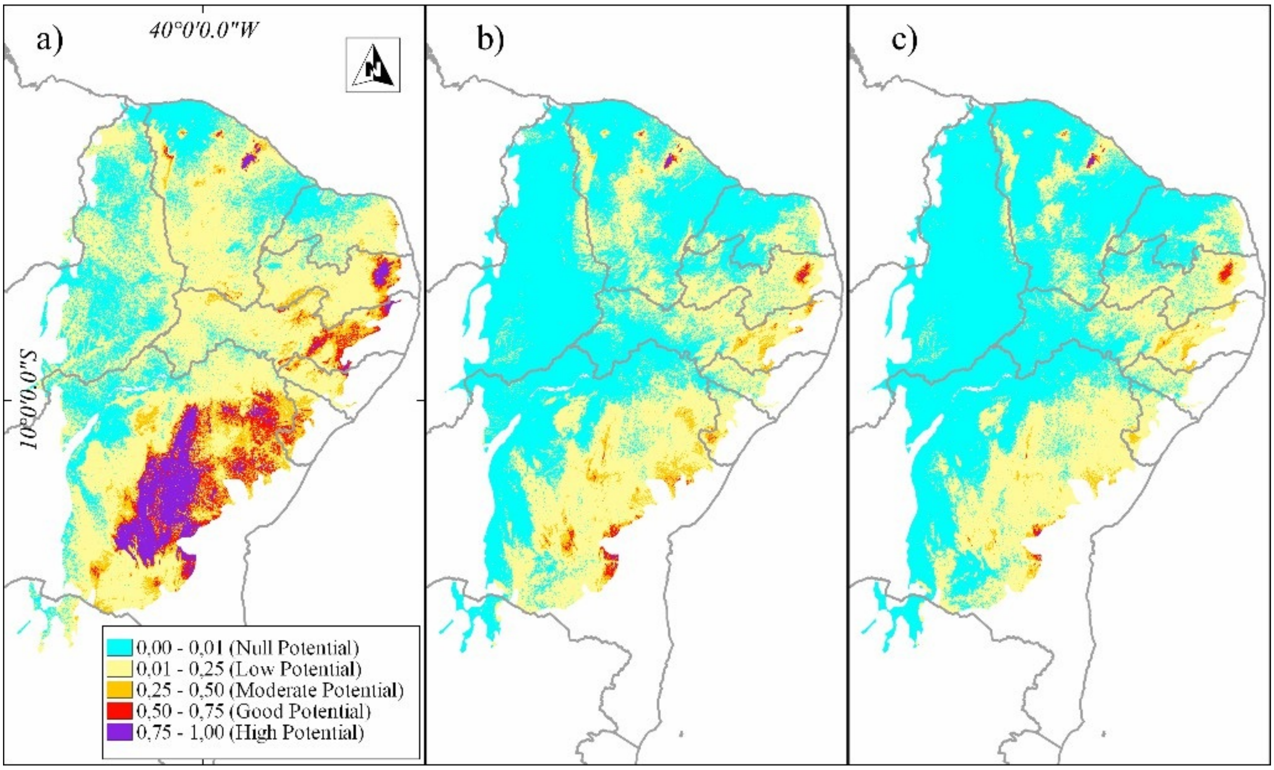

Figure 6. Simulation of the current spatial distribution (a) and those projected for 2050 (b) and 2070 (c) in the RCP8.5 scenario for *R. lindbergiana* in the Caatinga biome

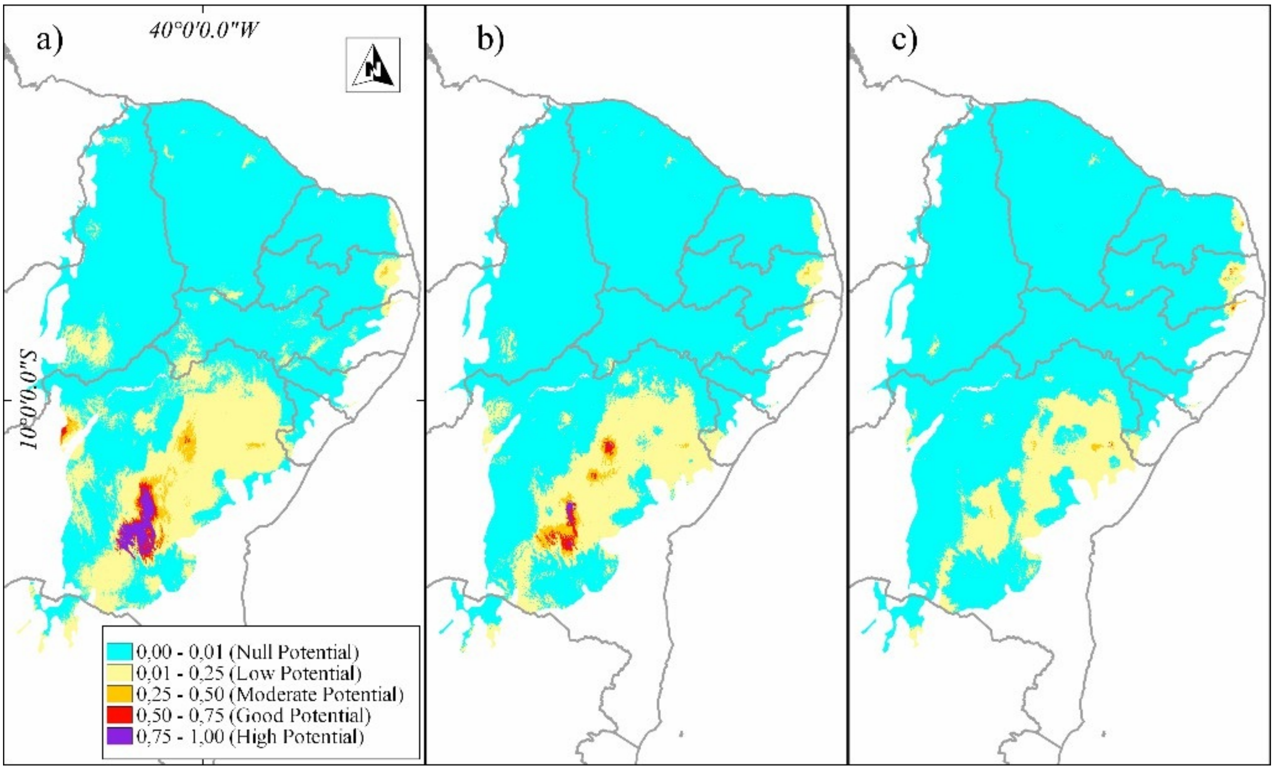

Figure 7. Simulation of the current spatial distribution (a) and those projected for 2050 (b) and 2070 (c) in the RCP4.5 scenario for *R. russellii* in the Caatinga biome.

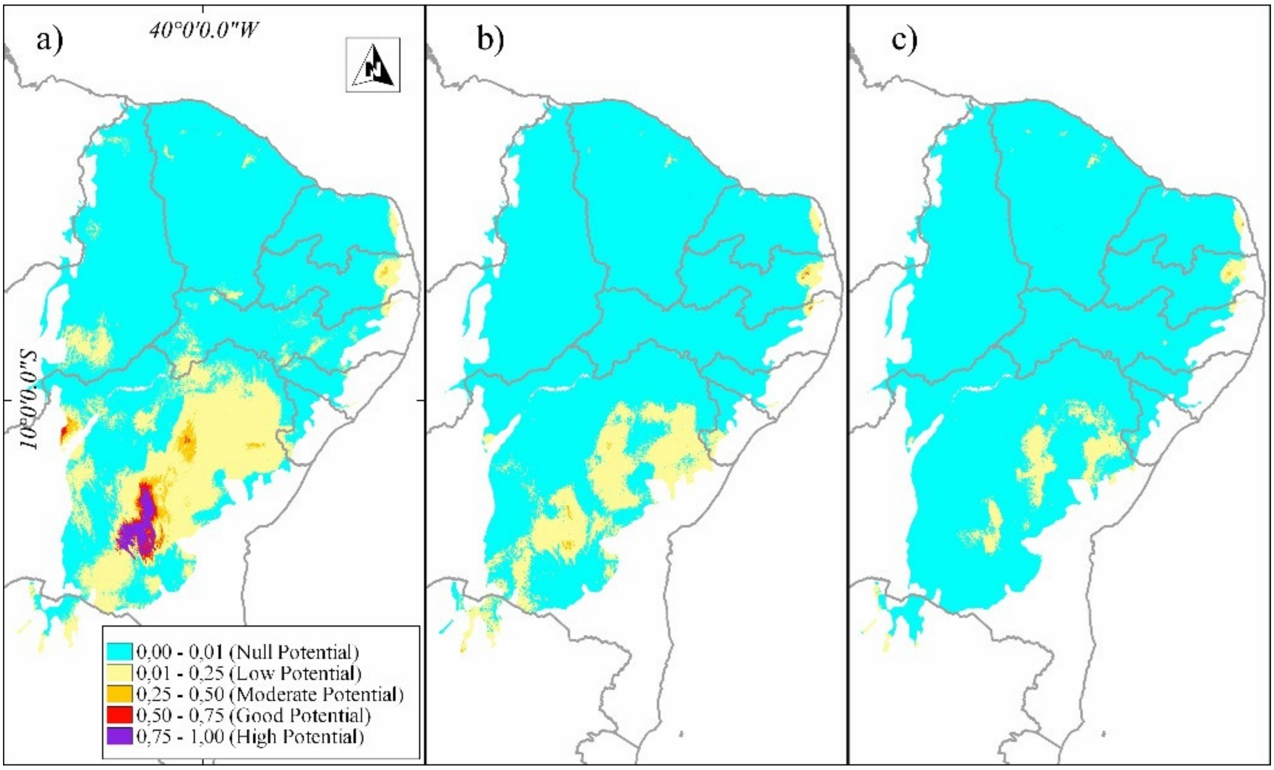

Figure 8. Simulation of the current spatial distribution (a) and those projected for 2050 (b) and 2070 (c) in the RCP8.5 scenario for *R. russellii* in the Caatinga biome.

to the present situation. In the first scenario, with lesser impact from higher temperature and lower precipitation in the biome, corresponding to RCP4.5/2050 (Figures 3b, 5b and 7b), there was substantial contraction of areas with high potential, but 10% of the original area still remained. The area losses were 92%, 88% and 90%, respectively, for *R. floccosa*, *R. lindbergiana* and *R. russellii*. In the second scenario, corresponding to any of the conditions RCP4.5/2070 (Figures 3c, 5c and 7c), RCP8.5/2050 (Figures 4b, 6b and 8b) and RCP8.5/2070 (Figures 4c, 6c and 8c), the loss of suitable area for the target species would be catastrophic, with drastic contraction of all the areas of possible occurrence, especially areas with high potential, where losses were up to 100% (Table 2).

DISCUSSION

As mentioned, the variables ELE (elevation) and Bio14 (precipitation of the driest month) stood out in the distribution models of the target species. In the case of ELE, although stable for the time scale considered here (about 80 years), this variable will play an important role in the Caatinga biome, with a strong influence on temperature and rainfall, and thus on the distribution of areas with suitable climates for the presence of the target species. For some elevations higher than 600 m in the biome, the temperatures are more moderate and the rainfall is greater and better distributed in the year in comparison with areas with lower elevation. This conjugation of relief, temperature and rainfall regime favors the existence of humid areas covered by forest formations. This impairs the lower plant cover, which is predominantly xerophilic. These areas of elevated humid forest formations interspersed in the Caatinga biome are known as exception landscapes or *ilhas de umidade*, and exist throughout the biome, such as Serra de Baturité in the state of Ceará and Chapada Diamantina in Bahia (Ab'Sáber 2003, Cavalcante 2005).

The target species are true epiphytic cacti, whose stem stores little water, so they only use water when rain or dew is present. Therefore, besides requiring a robust supporting plant, preferably a tree, they also need a regular supply of water. Since some elevated areas in the Caatinga biome have these conditions, it is possible to assume these areas are potential niches of the target species. Furthermore, these species are common in humid areas of Brazil's Northeast (Taylor and Zappi 2004), the region containing nearly all the biome. Hence, it is likely that a fraction of these humid areas in the Northeast are also elevated areas of the Caatinga biome.

With respect to the other variable, Bio14, it also contributes to the presence of these humid forest formations in the Caatinga biome. Although in the driest month or throughout the dry season the rainfall levels are low in the biome, in these upland enclaves the rainfall is more abundant than at lower altitudes in the same month or season (Zanella and Sales 2011). In this respect, a minimally regular supply of water is necessary to maintain the forest, and hence the target species, which are sustained by the forest. Obviously the accumulation of rainfall during the year is important (B12 - annual precipitation), but regular distribution of rain or greater supply of water in the driest month appears to be more decisive for the presence of the target species. In the Caatinga biome, water availability is the dominant factor determining the presence of plants, through the timing of their biological processes, followed by temperature, photoperiod and soil conditions (Albuquerque et al. 2012).

Comparison of the current distribution models produced for the target species (Figures 3a-4a, 5a-6a, 7a-8a) with the current records of these species' presence plotted over altitude in the Caatinga biome (Figure 2), indicated a strong preference of the target species for upland areas. For example, the areas with high potential of occurrence (chance of occurrence >0.75) are concentrated in the Chapada Diamantina complex in Bahia, where the predominant altitude is about 500 m, but can reach up to 2,000 m (Juncá 2005). This provides further evidence that upland humid areas provide the best conditions for the presence of the target species in the Caatinga biome.

Current distribution models indicate the areas that have environmental conditions suitable for the occurrence of a particular species. But climate change in future years can alter the spatial distribution of these areas. All the future distribution models generated here, considering the climate scenarios centered in 2050 and 2070 (Figures 3bc, 4bc, 5bc, 6bc, 7bc and 8bc), projected contraction of the areas with high potential for the presence of the target species.

This contraction of potential areas for determined species is not an uncommon projection. Various authors have reported similar results for other plant species, including other cacti. Téllez-Valdés and Dávila-Aranda (2003), Dávila et al. (2013), in modeling the potential distribution in the rest of this century of several cactus species in the Tehuacán-Cuicatlán biosphere (Mexico) in response to climate change, found that in the worst scenario, all the species would face contraction of their adequate areas. However, other simulations of the response to climate change of cactus species have shown effects other than just contraction, with the possibility of expansion (Butler et al. 2012) or contraction, expansion or stability (Cortes et al. 2014). Each cactus species has its own particularities and can respond differently to simulated climate changes. These differences are even greater when comparing cacti that grow in the soil and true epiphytic cacti. Therefore, to obtain a clearer picture of the probable distribution of cactus species in the future in response to climate changes, it is prudent to study each one separately.

We constructed two possible future scenarios for areas with high potential for the target species: a scenario of strong contraction and another of total disappearance. Both scenarios are grave for the persistence of the target species in the Caatinga biome. Even if the less severe scenario is confirmed, the remaining adequate areas would be small, isolated and widely dispersed in the biome. Hence, these future scenarios serve as a warning, because they not only indicate the possibility of local extinctions of the target species in the Caatinga biome, they also allow inferring the same destiny for other true epiphytes, both cacti and other families of plants, such as orchids and bromeliads, which have similar environmental requirements. This alert for elevated ecosystems has already been sounded. According to Randin et al. (2009), these ecosystems will likely be strongly affected by global warming during the twenty-first century, with substantial loss of biodiversity.

In this context, mention should be made of the role of scale in constructing scenarios. When the Caatinga biome was projected for the future with continental scale, its humid forest enclaves disappeared completely (Zanin et al. 2016), while on a regional scale, as used here, some of these enclaves persisted, depending on the climate scenario and time slice considered. This calls attention to the need to carefully model the distribution of species, seeking the greatest biological realism. Randin et al. (2009) showed that models with regional or local scale can forecast the persistence of adequate habitats, while models having larger scale can indicate total loss, suggesting that projections with regional or local scale better reflect the possible future distribution patterns of species.

The impacts of climate change on biodiversity cannot be predicted precisely because many uncertainties exist (Bellard et al. 2012), but modeling the distribution of a species can provide an initial approximation of these impacts (Pearson and Dawson 2003). Therefore, based on the distribution models reported here, which project a sharp contraction of areas with high potential for occurrence of the target species for the end of this century, and considering the existence of humid forest enclaves in the Caatinga biome, it is reasonable to recommend conservation actions for the target species and their habitats, in light of the possibility of a strong negative impact of climate change. Therefore, for the first half of this century, we recommend preventive adaptation actions to reduce the vulnerability of the target species and their habitats, through programs to raise awareness in local communities, by informing their members about the interplay of biodiversity, their means of subsistence and climate change (http://www.adaptationlearning.net/).

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