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Original Article

Conservation of Nature

Climate Change Influencing the Potential Distribution of a Brazilian Savanna Indicator Species

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ABSTRACT

The objective of this study was to model the potential effect of future climate change on the distribution of a tree species indicator of Cerrado. For the modeling, we used 488 occurrence points of the species and also bioclimatic variables corresponding to 2050 and 2070, for the more optimistic and pessimistic scenarios. All generated models were classified as consistent, getting an area under curve higher than 0.90. The current modeling of *Connarus suberosus* showed that 88% of the area with a high probability of species occurrence is inside the Cerrado domain. Future projections suggest losses in the environmental suitability area around 40.8% and 44.8% in the optimistic scenario, 61.6% and 81.6% in the pessimistic scenario considering 2050 and 2070, respectively. Furthermore, we found a tendency of the *C. suberosus* to move in the Atlantic Forest direction. This modeling is an alert that the *C. suberosus* will suffer from future climate change.

Keywords: bioclimatic variable, *Connarus suberosus*, environmental suitability, Neotropical savanna, maximum entropy.

1. INTRODUCTION

Several scientists believe that extremes of hot temperatures will occur with higher frequency and duration. The increment on global warming is associated with the rising on the concentration of greenhouse gases caused by anthropic interventions (Stocker et al., 2013). Rapid changes in the climatic conditions can harm the migration of species to environments suitable for its adaptation. These effects become even more emphasized on tree species, which usually are much more adapted to specific microclimatic conditions (Buckeridge et al., 2007).

Understanding geographic patterns of species distribution is a fundamental key for the identification of areas with elevated conservation importance (Siqueira & Durigan, 2007). Also, it may help to recognize the susceptibility of areas to environmental and anthropic changes (Cupertino-Eisenlohr et al., 2017) on the potential risk of species extinction (Thomas et al., 2004; Malcolm et al., 2006; Ohlemüller et al., 2008) and how it can affect the economy of communities that depend on these resources to live (Nabout et al., 2011, 2016).

The potential species distribution modeling (SDM) using bioclimatic variables is an efficient way to study geographic distribution of species (e.g. Elith et al., 2006; Pearson et al., 2007; Werneck et al., 2012). Moreover, SDM can be applied as a tool to indicate how environmental changes can modify the characteristics of forests, including changes in spatial distribution (Williams et al., 2003). Approaches applying models can predict the geographic distribution of communities and tropical forests structure (Dubuis et al., 2011), including assessments about dynamics of phytogeographic patterns (Collevatti et al., 2012a). That includes the conversion of the Latin American savannas into different biomes (Moncrieff et al., 2016) and the savannization process of tropical forests in Brazil (Salazar et al., 2007).

The Cerrado domain, also known as the neotropical savanna, has suffered from continuous deforestation during the last decades, becoming one of the most endangered savannas in the world and one of the most threatened biomes in Brazil (Silva & Bates, 2002; Aguiar et al., 2016).

The *Connarus suberosus* Planch is a typical Cerrado vegetation species (Matheus et al., 2009) reported with high indicator value (Bueno et al., 2016). Many indicator species can be used to monitor trends in forest dynamics (Carignan & Villard, 2002) and to characterize the environmental preferences (Cáceres et al., 2010). Furthermore, species strongly associated with particular habitat features could also be useful as an indicator for conservation purposes, land management, landscape mapping or design of natural reserves (Dufrêne & Legendre, 1997; Carignan & Villard, 2002; Cáceres et al., 2010).

The objective of this study was to evaluate the effect of future climate change on the *C. suberosus* distribution. The modeling was performed for both the most optimistic and the most pessimistic IPCC scenarios in terms of temperature increment, projecting to 2050 and 2070.

2. MATERIAL AND METHODS

Covering around 2 million square kilometers, the Cerrado domain occupies approximately 22% of the Brazilian territory and works as a corridor between the Amazon and Atlantic Forest domains (Ribeiro & Walter, 2008). The typical Cerrado vegetation grows on acid and dystrophic soils (Oliveira-Filho & Ratter, 2002; Mendonça et al., 2008) and is considered the richest tropical savanna in the world in terms of biodiversity (Klink & Machado, 2005).

This biome has a high level of endemism for many groups of animals and plants (Machado et al., 2004). Studies have already listed more than 11,000 vascular plants species (Mendonça et al., 2008) where approximately 44% of the species is endemic (Klink & Machado, 2005). The elevated presence of endemic species and the constant process of habitat loss classifies the Cerrado domain as one of the global biodiversity hotspots (Myers et al., 2000).

An important Cerrado species is the *Connarus suberosus* Planch (Matheus et al., 2009). This species belongs to the Connaraceae botanic family and can reach 7 m in height. The flowering happens between August and October. The seeds have low germination and its fruits get mature between November and February (Lorenzi, 2002; Matheus et al., 2009). The species is listed between the top 10 species of the typical Cerrado vegetation (Bueno et al., 2016). Due to the large number of records within this biome this species can be considered an indicative of the Cerrado domain (Matheus et al., 2009).

We extracted 488 occurrence points from NeoTropTree (Oliveira-Filho, 2017) to be used during the modeling step (Figure 1). NeoTropTree database contains tree species checklist gathered from literature and prepared for sites distributed across the Neotropical region. It has been used as support for several researches, such as floristic and geographic patterns, phylogenetic diversity and conservation strategies (see details at Oliveira-Filho, 2017).

We used rasters files of 19 bioclimatic variables with resolution of 1 Km (Hijmans et al., 2005). To avoid collinearity, we excluded variables which correlation is above 90% based on ecological relevance. From the 19 bioclimatic variables we ended up with 10: annual mean temperature, mean diurnal range, isothermality, maximum temperature of warmest month, annual temperature range, annual precipitation, driest month precipitation, precipitation seasonality, precipitation of warmest quarter and precipitation of coldest quarter.

The modeling process was based on the principle of maximum entropy, considering only the observed data. The algorithm subscribes the known distribution by the estimated distribution, avoiding the insertion of unfounded constraints (Phillips et al., 2006; Pearson et al., 2007). The presence-only data are more appropriate for predicting potential distribution such as climate change impact applications (Miller, 2010) and this characteristic was used for the choice of the algorithm (Bueno et al., 2016). Besides, many studies have already demonstrated the effectiveness of the MaxEnt approach on ecological niche modeling. The algorithm is also considered robust and consistent (Elith et al., 2006; Pearson et al., 2007; Werneck et al., 2012; Aguiar et al., 2016; Bueno et al., 2016) and was implemented in the MaxEnt 3.4 software. We used replicated subsample, the minimum training presence threshold, and a maximum of 5000 iterations. The data were divided into 75% for training and 25%

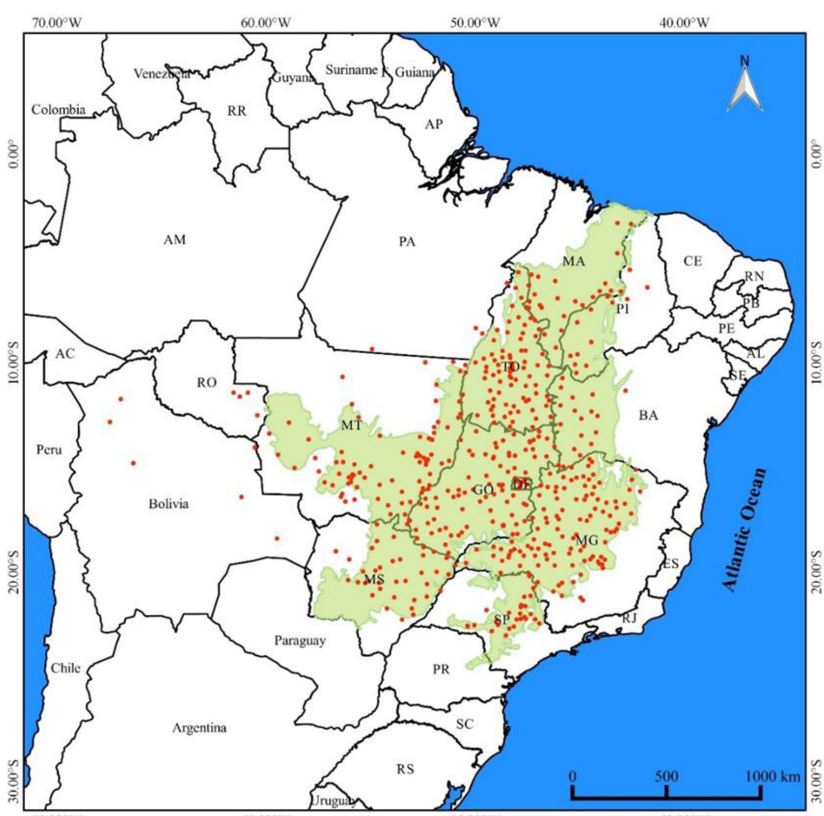

Figure 1. Geographic distribution of *Connarus suberosus* showing the 488 occurrence points. The shaded area and the red points indicate the Brazilian Cerrado domain and the species occurrence points, respectively.

for validation. So, we applied the maximum entropy algorithm on 366 occurrence points to estimate the species distribution and the remaining 122 points were used to validation. Twenty-five models were generated and the analysis was performed averaging the constructed models results.

In order to model the current *C. suberosus* distribution, we used climatic layers based on an average value from 1960 to 1990 Worldclim data. The climate change forecast was based on the climate projections of the Fifth Intergovernmental Panel on Climate Change ($IPCC_5$) from the Global Climate Models (GCMs) for four representative pathways of greenhouse gases concentration (RCP) (Worldclim, 2017). The possible effects of climate change were evaluated using the RCP 2.6 and 8.5 for both 2050 and 2070 (Community Climate System Model - CCSM 4.0; CESM, 2017). The RCP 2.6 is the most optimistic scenario and represents an increase in the global temperature varying from 0.3 to 1.7 °C until 2100. However, the RCP 8.5 shows a more pessimistic scenario with an increase in the global temperature ranging from 1.4 to 4.8 °C until 2100 (Stocker et al., 2013).

The model validation was performed analyzing the receiver operating characteristic curve (ROC). The ROC curve evaluates the absence of commission error (specificity) and the absence of omission error (sensitivity), providing the predictive performance of the model on all possible thresholds (area under the curve value – AUC). The AUC value varies between 0 and 1; for values below 0.5, the adjusted model is worse than a random model. For values closer to 1, the model used is more efficient than a random model (Elith et al., 2006; Phillips, 2017). Additionally, we calculated the loss of area reclassifying the maps according to the probability of occurrence greater than 0.5, which means a suitability varying from moderate to high.

3. RESULTS

According to the jackknife test, the four most important variables for modeling were: isothermality, temperature annual range, annual precipitation and precipitation seasonality. The models had a good adjustment and were classified as consistent, getting an AUC higher than 0.90 for all generated models (Current model, AUC = 0.908; RCP 2.6 model for year 2050, AUC = 0.908; RCP 8.5 model for year 2050, AUC = 0.902; RCP 2.6 model for year 2070, AUC = 0.905; and RCP 8.5 model for year 2070, AUC = 0.904).

Considering only the current predictive model, more than 99% of the total area with probability (probability of occurrence > 0.5) to finding *C. suberosus* is found in Brazil (Figure 2), being 88% included in the Cerrado domain. Small areas for species occurrence can also be found in the Atlantic Forest (7.7%), Amazon (3.2%), Caatinga and Pantanal domains (1% including both).

Comparing the current distribution model and RCP 2.6, distributions showed a reduction of 40.8% of the areas suitable for *C. suberosus* for 2050 (Figure 3a) and a reduction of 44.8% for 2070 (Figure 3b). The RCP 8.5 scenario indicates a reduction of 61.6% of suitable areas for 2050 (Figure 3c) and 81.6% for 2070 (Figure 3d).

All future scenarios show that the *C. suberosus* suitability will be restricted in the Atlantic Forest direction. The models generated for the RCP 8.5 scenario indicated some fragments with a probability of *C. suberosus* occurrence greater than 0.5 on the Eastern and Southern Cerrado domain.

The RCP 2.6 projected for 2070 and RCP 8.5 projected for 2070 showed *C. suberosus* occurring in the West of Bahia state and in large portions of Goiás and Minas Gerais states (Figure 4).

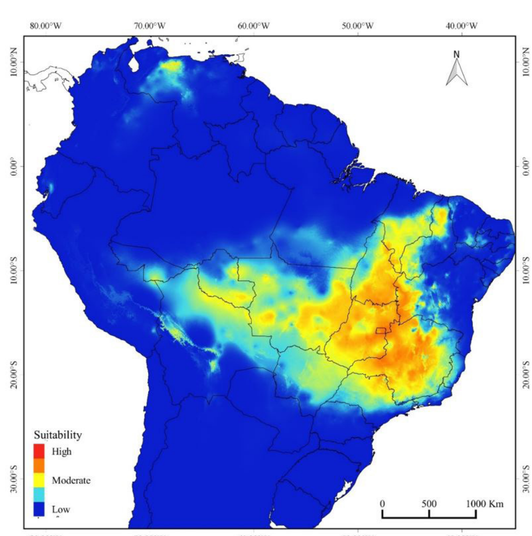

Figure 2. Current occurrence probability for the *Connarus suberosus* species on Neotropics.

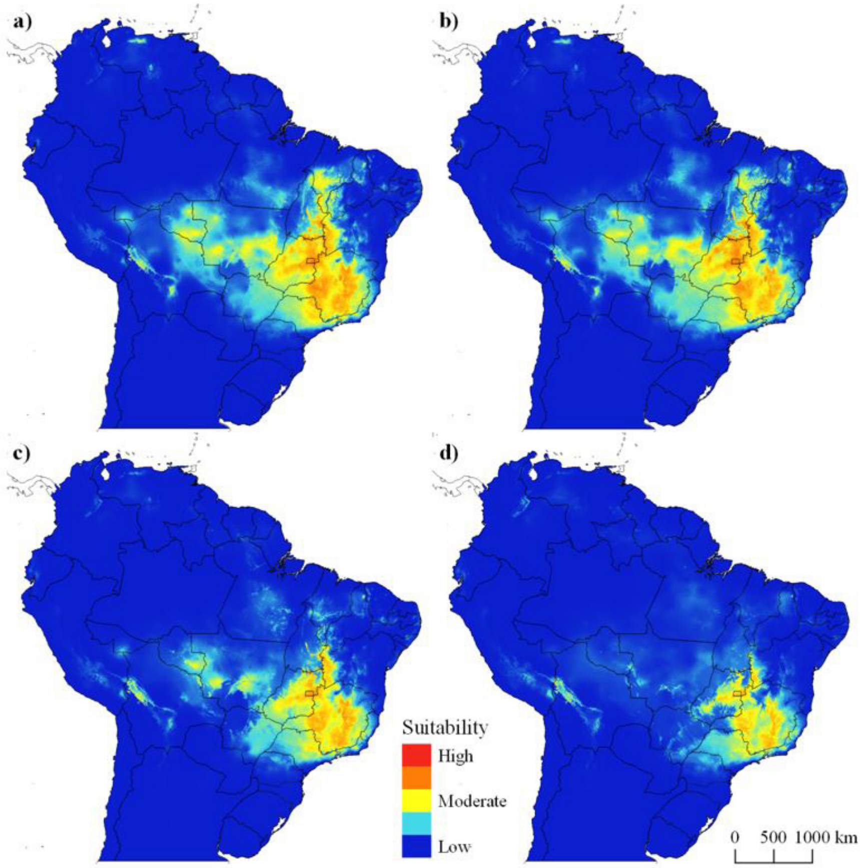

Figure 3. Potential distribution of *Connarus suberosus* on four representative pathways of greenhouse gases concentration scenarios: a) increase in the global temperature varying from 0.3 to 1.7 °C for 2050; b) increase in the global temperature varying from 0.3 to 1.7 °C for 2070; c) increase in the global temperature ranging from 1.4 to 4.8 °C for 2050; and d) increase in the global temperature ranging from 1.4 to 4.8 °C for 2070.

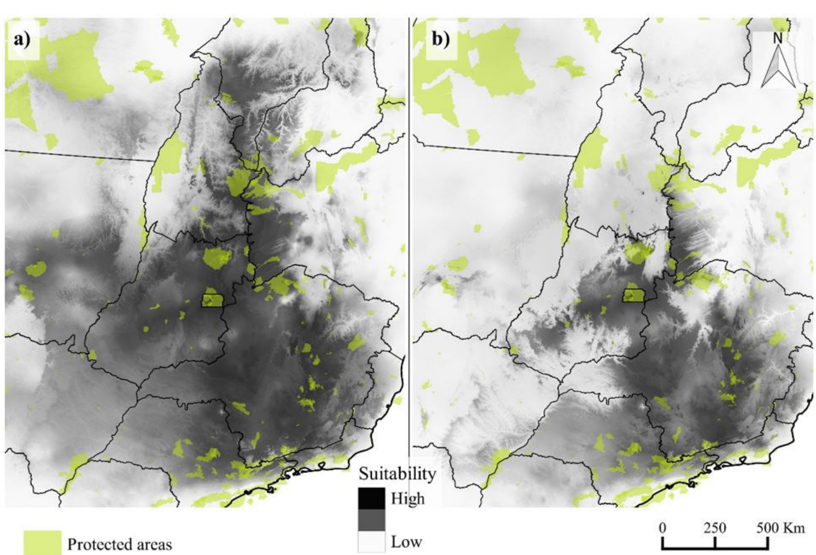

Figure 4. Potential distribution of *Connarus suberosus* and protected areas location. a) *C. suberosus* suitability projected for RCP 2.6 in 2050; and b) *C. suberosus* suitability projected for RCP 8.5 in 2070.

4. DISCUSSION

The model performance was better than a random model, exhibiting suitable predictive power. Although the *C. suberosus* occurrence extends to Pantanal domain, it is a species that represents a Cerrado typical (*lato sensu*) vegetation (IPJBRJ, 2018). SDM have been used to show how Cerrado is responding to the climate and precipitation changes (Collevatti et al., 2012b, 2015; Bueno et al., 2016; Buzatti et al., 2017; Lima et al., 2017). Studies are reporting that the Cerrado domain will lose a considerable amount of area due to climate change. The area loss in the Cerrado domain and movement towards the Atlantic Forest biome are consistent with the results presented by Lima et al. (2017), analyzing another indicator species *Tabebuia aurea*.

Comparing the current model against the future models obtained for the *C. suberosus* we can visualize the proportion of area loss due to the climate change. Thomas et al. (2004) pointed an extinction risk ranging between 48% and 56% for Cerrado species, and Siqueira & Peterson (2003) are suggesting 90% of area loss in aggressive scenarios. Predictive models for bats, birds, and trees have shown similar patterns, showing suitable areas for those species concentrating in Goiás, Minas Gerais and São Paulo states, moving to other biome limits (Siqueira & Peterson, 2003; Marini et al., 2009; Aguiar et al., 2016). Forecasts based on climatic scenarios for 2070 have shown not only a reduction for the actual savannas domains (Moncrieff et al., 2016) but also an increase of the savannization process of tropical forests as a consequence of climate changes (Salazar et al., 2007). According to Moncrieff et al. (2016), 57% of savannas domain in South America may be transformed into other biomes by 2070.

The Cerrado domain is one of the Brazilian's most devastated biomes, caused mainly by anthropogenic deforestation to land use changing (Thomas et al., 2004; Malcolm et al., 2006; Sano et al., 2008; Fernandes et al., 2016). Negative impacts on biological diversity and ecosystem stability should be expected, in addition to landscape modification due to local and regional climatic conditions (Parry et al., 2007). The enormous importance of the Brazilian Cerrado for agribusiness threats the biome conservation (Aguiar et al., 2016; Fernandes et al., 2016). The Cerrado biodiversity depends not only on the climatic conditions but also of the species ability to resist habitat loss and fragmentation (Thomas et al., 2004; Malcolm et al., 2006).

The *C. suberosus* species has economic potential and has been reported as an important species for multiple uses (Aquino et al., 2007; Matheus et al., 2009; Silva et al., 2015). Beyond the effect of climate change, we still need to investigate the influence of its economic exploitation. Future climate change scenarios for the Cerrado domain have shown the possibility of area loss and geographic distribution reduction considering the economic use of some species (e.g. *Hacornia speciosa* Gomez and *Lychnophora ericoides* Less.) (Simon et al., 2013; Nabout et al., 2016). The distribution displacement of the species of economic interest can affect not only the biodiversity, but also local economies (Nabout et al., 2011, 2016).

Avoid the biodiversity losses associated with climate change is a goal that must be pursued. The protected areas map in the results section showed that there are many places with high suitability of C. suberosus occurrence out of those areas. The creation of new protected areas and improving conservative practices should be urgently considered. Investing on projects for biodiversity conservation and maintenance of the structure and ecosystems function are important strategies for the achievement of these goals (Parry et al., 2007). Therefore, a landscape approach is essential to implement successful strategies for habitats restoration, ecological corridors implementation and conservation areas creation (Thuiller et al., 2008). Fragments of natural habitats that show an environmental suitability for Cerrado species occurrence should be maintained as conservation areas even if they are located in the agricultural areas (Aguiar et al., 2016). Minas Gerais state holds the most suitable areas for *C. suberosus* for both RCP scenarios, mainly in the regions close to Serra da Canastra, Serra do Espinhaço and Serra da Mantiqueira. Those areas have already protected areas most likely to the species occurrence (Figure 4).

Our models evidence possible competition between the *C. suberosus* and the Atlantic Forest species in the future, corroborating other studies findings (Scarano & Ceotto, 2015; Lima et al., 2017).

5. CONCLUSIONS

It is reasonable to expect a concretization of the movement detected by both scenarios (optimistic and pessimistic). Keep monitoring the *Connarus suberosus* occurrence to validate this study's finding is crucial to determine the velocity in which the area loss and distribution reduction is happening. Actions aiming the creation of protected areas and improvement of conservancy practices are essential to ensure not only the species survival but also the biome biodiversity preservation. Ecological corridors should be urgently implemented to support the species migration to suitability areas.

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