

A relict species restricted to a quartzitic mountain in tropical America: an example of microrefugium?

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Received: August 29, 2014. Accepted: March 11, 2015

ABSTRACT

We examined the distribution of *Coccoloba cereifera*, a tropical endemic species that occurs in a small area in the *Espinhaço* mountain range, southeastern Brazil. It is hypothesized that its narrow distribution is strongly related to the spatially scattered distribution of sandfields. However, this soil type extends far beyond the small region where *C. cereifera* is currently found, indicating that other factors might be involved in the distribution of this species. *Coccoloba cereifera* also displays all traits of a relict population in a microrefugium. As a result, we were encouraged to explore other factors potentially related to the distribution of the species. In an attempt to aid in the understanding of the processes and mechanisms that lead *C. cereifera* to present the narrow actual distribution, we applied two distribution modelling approaches to investigate the potential distribution of the species beyond the small known distribution area. The distribution seems to be strongly associated with sandy patches/grasslands formed among rocky outcrops and is limited by some topoclimatic and/or topographic features. Some of them related to the existence of a microrefugium, a fact also suggested by the pattern of distribution of the species in the past. From the management point of view, the existence of a microrefugium in this area calls for changes in conservation efforts and priorities.

Keywords: *Coccoloba cereifera*, Espinhaço Mountains, maximum entropy, rupestrian grasslands, Serra do Cipó

Introduction

All over the world, mountain regions present a wide range of environments otherwise only seen over broad latitudinal distances (Spehn *et al.* 2010). Overall, plants occurring at high elevation have evolved from ancient plants found in lowland habitats, with subsequent enrichment through dispersal along these mountain environments (Arroyo *et al.* 2010). Furthermore, habitat isolation due to climatic and/or geological events is also responsible for a great β -diversity, mainly in the tropics (e.g., Janzen 1967; Tang 2012). The tropical Andes, for example, contain approximately one sixth of all known plant species in less than 1% of the world's terrestrial area (Mittermeier *et al.* 1997; Richter 2009). In Brazil, despite its world-renowned forests, some mountain regions also present high levels of species richness and endemism (e.g., Safford 1999; Martinelli 2007).

In southeastern Brazil, the vegetation of the *Espinhaço* mountains is mostly represented by a unique flora known as rupestrian grasslands ('*Campos Rupestres*') (Fernandes *et al.* 2014). This vegetation comprises one of the most speciose and highly endemic flora of the tropics, where some families may reach up to 80-90% endemism (Giulietti *et al.*

1987). In a broad scale, many factors would be responsible for this high biological diversity, such as the great latitudinal variation (Alves *et al.* 2014), the presence of a mosaic of phytophysiognomies (Rapini *et al.* 2008), the ancient age of these geological formations, and the great variety of microclimates (Barbosa 2012). In 2005, the southern portion of this mountain range (in the state of Minas Gerais) was recognized as a Biosphere Reserve by UNESCO. This region has strong climatic differences from the north portion, with higher humidity, lower average temperature and higher average elevations (e.g., Alves & Kolbek 2010). In addition, according to Echternacht *et al.* (2011), geological, climatic and biotic conditions are also very different between the northern, central and southern areas of this southern portion, which have many recognized areas of endemism. The largest continuous area of the southern *Espinhaço* mountain range comprises an endemism unit formed by the regions of *Diamantina Plateau* and *Serra do Cipó*. Inside these regions, many small areas present idiosyncratic microclimates, which host several micro-endemic plant species, in general due to the high geological heterogeneity and insularity. One of those species is the trioecious and highly sclerophyllous *Coccoloba cereifera* (Polygonaceae), which is currently only found in

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the region of *Serra do Cipó* (Ribeiro & Fernandes 1999; 2000; Silva *et al.* 2008). As far as we know, this species occurs in a small area of approximately 26 km² (Ribeiro & Fernandes 1999; Moreira *et al.* 2008; 2010). Ribeiro & Fernandes (2000) postulated that its restricted distribution was strongly related to the clonal growth and spatially scattered distribution of sandfields, a soil type for which the species appeared to show high frequency. However, sandfields extend far beyond this small region, a simple indication that other factors might be involved in the distribution of *C. cereifera*, which displays all traits of a relict population in a microrefugium (see Rull 2009; Mosblech *et al.* 2011; Hampe & Jump 2011; Keppel *et al.* 2011): it is restricted to a small area, shows low genetic diversity, has clonal growth, low dispersal and is also isolated (see Ribeiro & Fernandes 1999; Moreira *et al.* 2008; 2010).

The term 'microrefugia' was framed by Rull *et al.* (1988) in an attempt to explain the persistence in time of high-mountain species on the Venezuelan *tepui*s (table-top mountain ecosystems occurring in northern South America; also formed by quartzitic or arenitic sandfields). It is thought that during the Pleistocene dry phases in South America (e.g., Vuilleumier 1971), small favourable sites (which idiosyncratic microclimates) might have favoured the persistence of some species in mountain ecosystems, which are well suited to hold microrefugia (McLachlan *et al.* 2005; González-Astorga *et al.* 2005; Holderegger & Thiel-Egenter 2009; Previšić *et al.* 2009). With the arrival of more humid climates at the end of Pleistocene, many of these species were still present and could readily recolonize the adjacent areas (Rull 2009). However, Pleistocene glacial and interglacial periods may affect mountain species in different ways (Hewitt 2000). In some cases, rapid warming periods are suggested to have promptly reduced distribution ranges and depleted genetic diversity of organisms, thus being confined to microrefugia (Martínez-Freiría 2014). The complex topography of mountain environments creates a range of different microclimates (Geiger 1965) that are of critical importance for species distribution and diversity (Fernandes & Price 1991; Brown 1994) as well as for the existence of these refuges (Scherrer & Körner 2010; Dobrowsky 2011).

Microclimates are directly influenced by topographic factors such as elevation, slope or aspect, which have been widely used as predictor variables in distribution models. To generate environmental suitability maps, distribution models make use of environmental data associated with known distributions of the target species. These models have become increasingly important and have been used in many ecological applications (Araújo & Peterson 2012); e.g., to understand species' ecological requirements (Raxworthy *et al.* 2003; Elith *et al.* 2006), to understand species biogeography (Pearson 2006); as well as to identify historical refugia for biodiversity (Waltari *et al.* 2007; Carnaval & Moritz 2008; Vega *et al.* 2010).

In an attempt to improve in the understanding of the processes and mechanisms that lead *C. cereifera* to show

the actual narrow distribution we apply two distribution modelling approaches. First, we constructed a model to investigate the potential distribution of the species beyond the small known distribution area, and a second model to examine its distribution in the past; with the goal of finding a pattern for a microrefugium formation. Finally, we discuss some implications of the findings for the construction of distribution models for narrow endemic species in the speciose rupestrian grassland vegetation.

Material and methods

The species native range

The distribution range of *Coccoloba cereifera* Schw. is only located in *Serra do Cipó*, a region in the southern portion of the *Espinhaço* mountain range (Fig. 1). The *Espinhaço* Mountains are of quartzitic origin, running north-south (10°-20°S) ca. 1200 km with two distinct parts: *Chapada Diamantina* in the north and *Serra do Espinhaço* itself in the south (Rizzini 1979). The region of *Serra do Cipó* ranges 650-1670 m a.s.l. in altitude and is predominantly covered by grasslands, with few shrubs and small trees except near watercourses where small riparian forests are found (Giulietti *et al.* 1987). Above 900m soils are shallow, acidic, and nutrient-poor, with excessively drained sands that are highly erodible (Marques *et al.* 2002; Medina & Fernandes 2007; Negreiros *et al.* 2012). Quartzitic outcrops are common and in their crevices a more humid soil can be found. The regions above 900m in *Serra do Cipó* and across most of the *Espinhaço* mountain range support highly xerophytic vegetation with high plant species diversity (Rizzini 1979; Giulietti *et al.* 1987), with many congeneric sympatric species (e.g., Madeira & Fernandes 1999; Lüttge *et al.* 2007). Substantial overlapping of distribution is present, characterizing this region as an endemism area (Müller 1973; Morrone 1994; 2001; Echternacht *et al.* 2011). Its climate is characterized by dry winters and rainy summers with an annual mean rainfall of 1500 mm and an annual mean temperature of 17.4 to 19.8°C (Madeira & Fernandes 1999).

Modelling approaches

To understand which variables are involved in the potential distribution of the species beyond the small known distribution area we carried out a distribution model for *C. cereifera* for its native distribution area and surroundings, with a fine resolution of ~ 0.000278° (~30m) (Model A). To explore the distribution of this species in the past, we surveyed a model for *C. cereifera* for its native distribution area, with a coarse resolution of ~0.0082° (~1km), and projected this model to three scenarios: ~120.000 years B.P. (last interglacial maximum), ~21.000 years B.P. (last glacial maximum), and ~6.000 years B.P. (Mid-Holocene) (Model B).

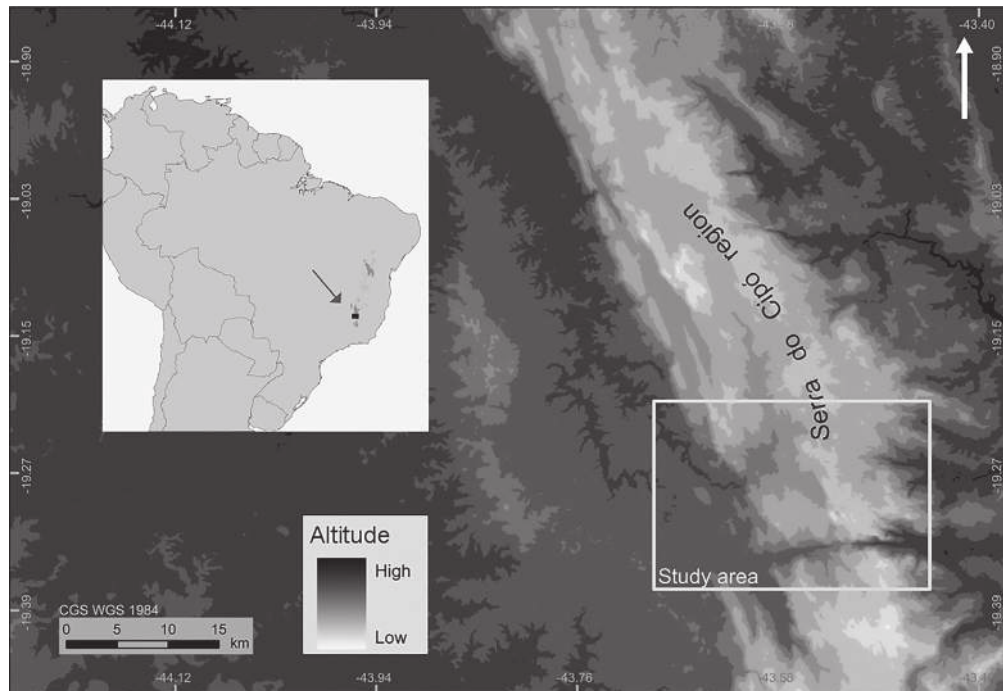


Figure 1. Location of the study area within the *Espinhaço* range in Brazil.

Occurrence points used in both models

To construct both distribution models we acquired all known occurrence points from the native distributions of *C. cereifera*. More than two hundred points were obtained for the occurrence of the species; they were within the small known area of approximately 26 km² where the species was argued to be solely distributed (Ribeiro & Fernandes 1999). Many points were ruled out due to overcrowding in the same pixel; hence reducing the effects of spatial autocorrelation (see Hernandez *et al.* 2006; Phillips *et al.* 2006; Pearson *et al.* 2007; Thorn *et al.* 2009). Hence, 162 points of occurrence for the species were used for model A (with a fine resolution), and 28 points were used for the model B (with a coarse resolution).

Model A

Our dataset for model A (all variables were clipped to the study area as shown in Figure 1) was composed of an ASTER GDEM (Global Digital Elevation Model, property of METI and NASA) obtained at the Earth Remote Sensing Data Analysis Center (ERSDAC, <http://www.gdem.aster.ersdac.or.jp>) with a spatial resolution of ~ 0.000278° (~ 30 m) and its derivations: slope and aspect, created with the Surface Analysis toolbox in ArcView® (ESRI, Redlands, CA), and a wetness index created with the raster calculator in ArcView® (ESRI, Redlands, CA), following Beven & Kirkby (1978); as shown in Equation 1.

$$\text{WETNESS INDEX} = \text{LN} (\text{AS}/\text{TANB}) \text{ (EQUATION 1)}$$

Additionally, we used a solar radiation layer for the winter (in the southern hemisphere some south-face regions receive less radiation in the winter) (resolution of ~ 0.000278°) created with the Solar Analyst toolbox in ArcView® (ESRI, Redlands, CA), percent bare cover (Hansen *et al.* 2003) acquired from the Global Land Cover Facility of University of Maryland (<http://glcf.umd.edu/data/vcf>), originally with a spatial resolution of ~ 0.0045° (~ 500 m), resampled to ~ 0.000278° (~ 30 m) for analysis, NDVI (normalized difference vegetation index) layers for the dry season and wet season, and the annual NDVI range, all provided by the Geochronos database (MODIS 16-Day L3 Global 250m SIN Grid, <http://www.geochronos.org>), originally with a spatial resolution of ~ 0.00225° (~ 250 m), resampled to ~ 0.000278° (~ 30 m) for analysis, and a potential cold air pooling algorithm (CAP), created following Lundquist *et al.* (2008).

We performed a test for multicollinearity examining correlation among all variables (Pearson correlation test, $r > 0.85$) (e.g., Kumar & Stohlgren 2009) based on 1000 random points for the calibration area; the variables did not show high correlation structure in the study area.

We used the maximum entropy approach for model development, which has been found to have the best performance among many modelling methods (Elith *et al.* 2006; 2011; Hernandez *et al.* 2006). MaxEnt software version 3.3.3 (Computer Sciences Department – Princeton University, 2004) was utilized to generate a statistically significant logistic model of potential occurrence (environmental suitability) for *C. cereifera*. As MaxEnt generates a probability

distribution output between 0 and 100%, we selected the lowest presence decision threshold (LPT), which enables the validation and interpretation of the model (Liu *et al.* 2005; Pearson *et al.* 2007). The LPT is a binary approach which defines the smallest possible range of suitable habitat that also includes all the presence data points used in model (Pearson *et al.* 2007). The model was validated by the area under the receiver operating characteristic curve (AUC), which is considered an effective indicator of model performance, independent of the threshold probability (Manel *et al.* 2001). Additionally, we conducted excursions to the predicted areas (using the LPT binary output map) as an attempt to observe the presence or absence of the species in these areas. These data together with some occurrences from the literature (Ribeiro & Fernandes 1999) and herbaria (Missouri Botanical Garden and Herbarium of The New York Botanical Garden, accessed through GBIF Data Portal, data.gbif.org, 2010-09-15, *two occurrence points are out-to-date, from 70') were used to construct a confusion matrix describing at which frequency the presences and absences are predicted correctly or incorrectly (Fielding & Bell 1997). To understand the importance of each variable, we also selected the jackknife approach in MaxEnt.

Model B

Bioclimatic variables are good predictors of the impacts of climate change on biodiversity (Pearson & Dawson 2003; Werneck *et al.* 2010). It is expected that these variables may satisfactorily determine the distribution of *C. cereifera* in a historical context, given that they represent strong climate associations with biotic environment (Schrage *et al.* 2008).

The bioclimatic variables for the present day (1950-2001) and for the last interglacial maximum (~120.000 years B.P.; Otto-Bliesner *et al.* 2008) were downloaded from the project Worldclim at a spatial resolution of 0.0083° (~1km) (Hijmans *et al.* 2005). The climate data used for the last glacial maximum and middle Holocene follow the general circulation model ECHAM3 (DKRZ, 1992), available on the webpage of the Intercomparison Project paleoclimate modeling (PMIP, <http://pmip.lscce.ipsl.fr>) and was kindly provided by Werneck, F.. The heterogeneity of paleoclimate in South America makes the most general circulation models simulate past climates with a very low definition (Werneck *et al.* 2010). Although models based on regional patterns probably have a higher performance in simulating the paleoclimate, regional climate reconstructions are not yet available for the South American continent. Thus, the ECHAM3 general circulation model was chosen for this study because it has, among all models used for this purpose, the best resolution and performance (e.g., Werneck *et al.* 2010). The variable elevation, used in conjunction with all other variable groups, was downloaded from the Worldclim project in a spatial resolution of 0.0083° (~1km) (Hijmans *et al.* 2005).

All bioclimatic variables were cut to cover the Brazilian territory, encompassing all known distribution of rupestrian grasslands. We performed a Pearson's correlation test to avoid the presence of multicollinearity among the variables. Those highly correlated ($r > 0.85$) were kept in the model in a qualitative way, based only on their biological relevance. Following this protocol, from 19 bioclimatic variables initially selected, only nine were retained in the final model (in conjunction with the variable "elevation").

The construction of the distribution model was also performed by the maximum entropy approach (MaxEnt), which was used for the generation of a statistically significant logistic model for the actual distribution of *C. cereifera*, that has been projected to past scenarios. We also used the lowest presence decision threshold (LPT) to construct binary maps.

Results

Model A

The model A successfully predicted the potential distribution of *C. cereifera* with good performance, as evidenced by the AUC of 0.96 (Figs. 2-3). Generally, values >0.9 are considered an indicative of high accuracy models (Swets 1988). Field surveys were then undertaken and aided in the identification of new occurrence points, indicating that the distribution area for *C. cereifera* was larger than the area previously known. The species currently has a distribution area of approximately 35 km². For a LPT threshold the success rate (accuracy) derived from the confusion matrix was ca. 74% and the sensibility, which is the probability of a true occurrence pixel be classified correctly, as ca. 92%.

According to the jackknife test of variable importance, the variable with highest gain when used in isolation was the dry season NDVI, which therefore appears to have the most useful information by itself. For example, the model predicts that the environmental suitability for *C. cereifera* decreases with an increase in the dry season NDVI, indicating a tendentious distribution of the species across areas that present dry/low productivity in the dry season. The environmental variable that most decreased the gain when omitted was altitude, which therefore appears to have the most information that is not present in the other variables. Altitude is an important variable probably because many other factors are related to it, e.g., temperature, humidity, and pressure (Fernandes & Price 1991 and references there in).

The jackknife procedure demonstrates the most important variables as leaving it out does not decrease model fit or test statistics. On the other hand, the "percent contribution" (calculated as the model is being generated) estimated which variables were mostly used, or rather, which ones most contributed to the gain of the model. The variable with the greatest relative contribution to the model was dry season NDVI (26.8%), followed by percent bare soil (18.9%),

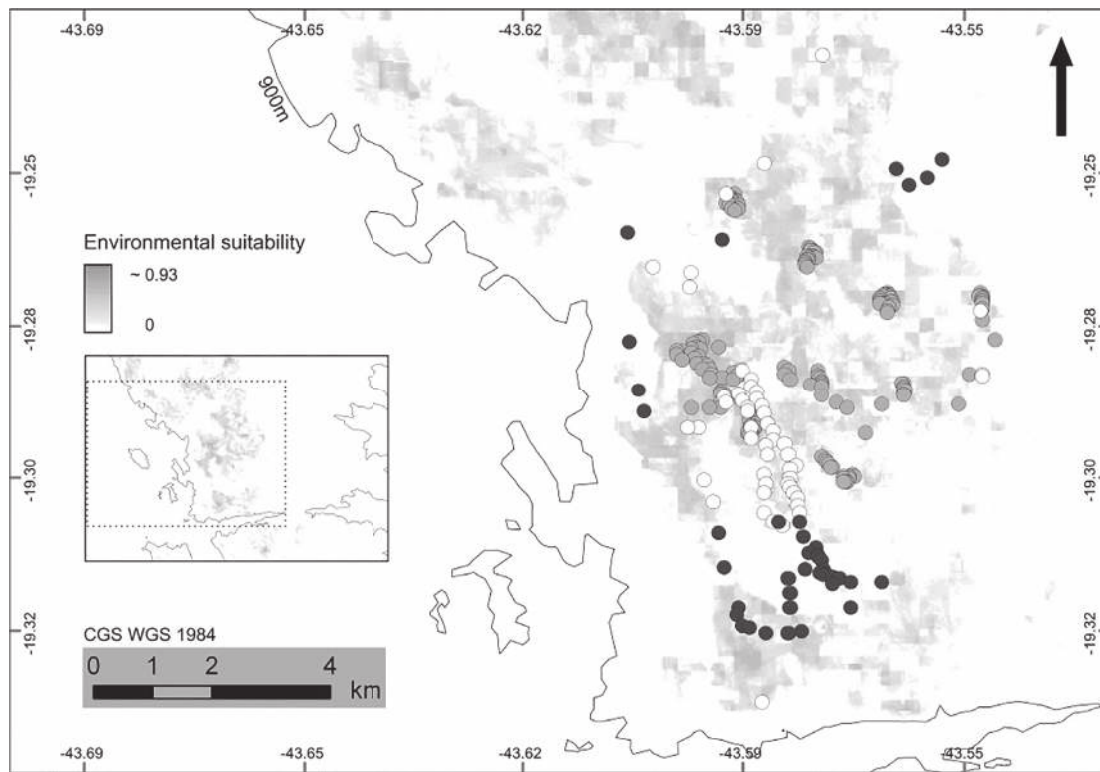


Figure 2. Environmental suitability for *Cocoloba cereifera* Schw. (Polygonaceae) within the study area. Gray circles are the occurrence points for the species used to construct the model; white circles are the new occurrence points; and black circles are absences.

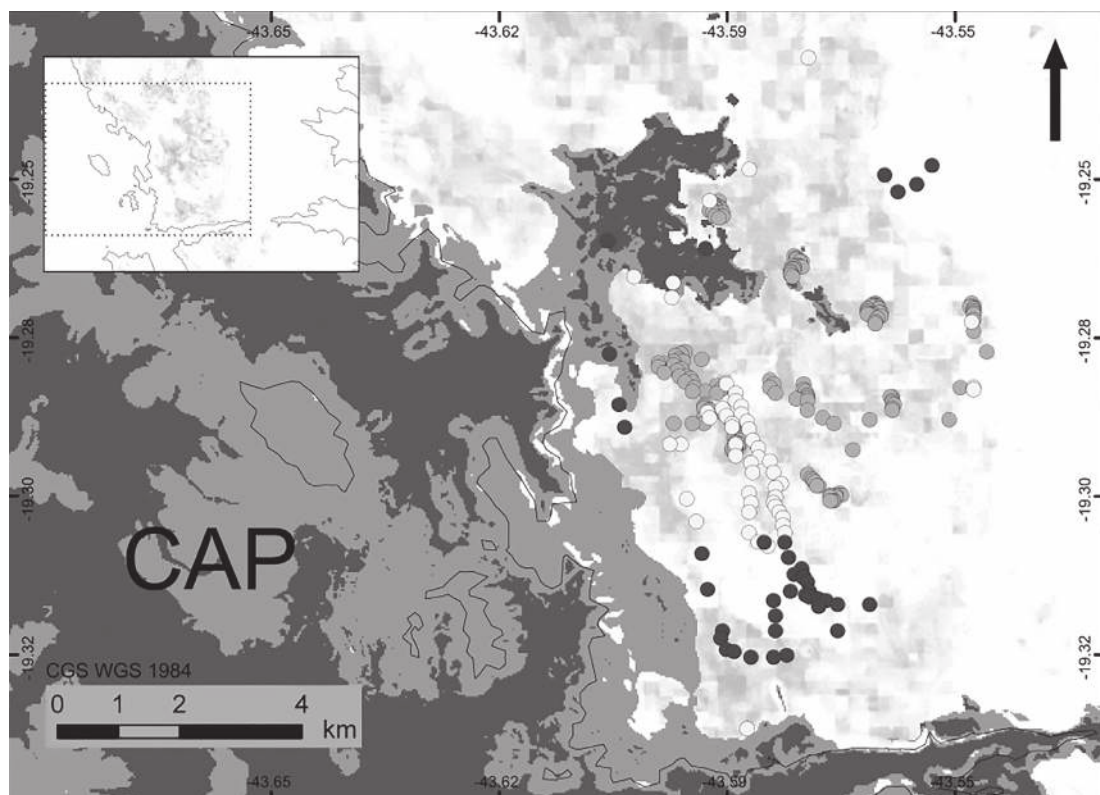


Figure 3. Potential cold air pooling (CAP) areas surrounding areas with high environmental suitability for *Cocoloba cereifera* Schw. (Polygonaceae) within the study area.

altitude (18.7%), CAP (12.7%), NDVI range (11.6%), wet season NDVI (4.4%), aspect (3.7%), and slope (2.9%). Wet index and winter solar radiation contributed with less than 1% each.

Model B

The model B also showed a satisfactory performance, as illustrated in the AUC of 0.99 (Fig. 4). The variable presenting the highest gain when used alone was altitude, i.e., the variable that shows the most useful information by itself. The variable inducing the lowest gain when omitted was the precipitation of wettest quarter, which seems to have much information not present in other variables.

The variable with the largest relative contribution to the model was altitude (38.3%), followed by precipitation of wettest quarter (33.2%), temperature seasonality (17.5%), precipitation of driest quarter (7.7%), mean temperature of coldest quarter (1.6%), and isothermality (1.2%). The variables precipitation of driest month, precipitation seasonality, temperature annual range and

mean temperature of warmest quarter contributed less than 1% each.

The distribution area predicted to the last interglacial maximum seems very unrealistic, with some sparse regions which have been predicted far from the core distribution area achieved from the last glacial maximum to current days (Fig. 4A). However, this absence of environmental suitability for the species in central Brazil would be an evidence of strong climatic oscillations similar to those that were responsible to shape the actual distribution of *C. cereifera* in the Holocene (e.g., Miller *et al.* 2013). Our results showed a predicted suitability area of ca. 645,000 km² for *C. cereifera* in the last glacial maximum (~21.000 years B.P.) (Fig. 4B), followed by a substantial reduction of ca. 86% of this area in the years centered in the middle Holocene (~6.000 years B.P.) (Fig. 4C). Moreover, the current environmental suitability area predicted for the species is more than 99% smaller than the distribution in the last glacial maximum, comprising ca. 3,172 km² (Fig. 4D). These values were calculated through the LPT threshold with an equal area projection (Albers Conic).

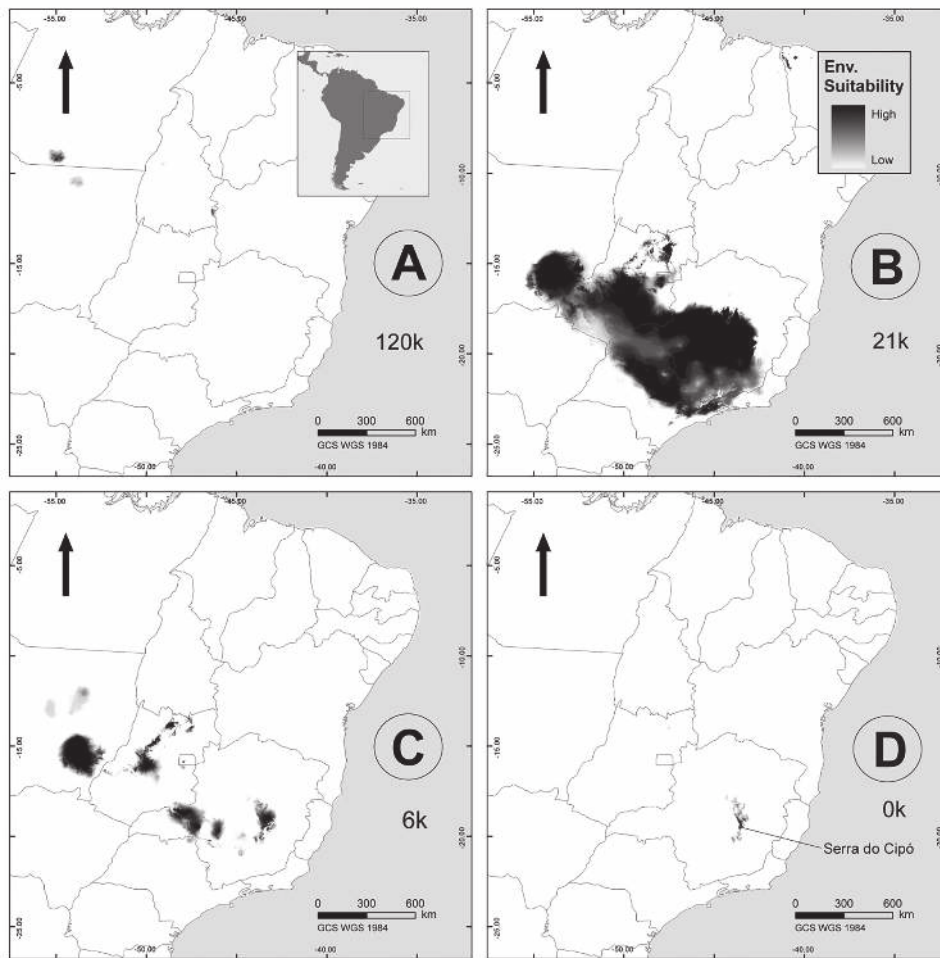


Figure 4. Environmental suitability for *Coccoloba cereifera* Schw. (Polygonaceae) in southeastern Brazil for the last interglacial maximum (A), last glacial maximum (B), mid-Holocene (C), and for a current scenario (D).

Discussion

The presence of *C. cereifera* is strongly associated with sandy patches/grasslands (which show significantly low NDVI in dry season) formed among rocky outcrops (probably responsible for the high percentage of bare soil in predicted areas) by the deposition of locally formed sand (see Ribeiro & Fernandes 1999; 2000). The importance of NDVI range and wet season NDVI were clearly highlighted in our study.

In southern, eastern and western sides of the core distribution area of *C. cereifera* (see Fig. 2), topographic features also seem responsible to constrain the species distribution. Specifically, the southern portion is limited by a physical barrier imposed by a deep canyon (the *Travessão* canyon). In *Vellozia gigantea* (Velloziaceae) this physical barrier limits gene flow leading to different population genetic structures on each side of this canyon (Lousada *et al.* 2011). To the west and east portions, high slopes are probably acting as barriers to the dispersion of *C. cereifera*, since the species may have some difficulty to disperse, in view of its clonal distribution and unknown pollinator system (Ribeiro & Fernandes 2000; Silva *et al.* 2008). Though the species sets fruit during rainy season, little is known about the existence of dispersal for these fruits (Belo *et al.* 2013).

All areas predicted outside the occurrence core area (as we can see in model 2) should be understood as part of the fundamental niche of *C. cereifera*, which does not match the presence of the species (Pearson *et al.* 2007; Thorn *et al.* 2009). One small southern region, for instance, shows high environmental suitability, but the only record of *C. cereifera* there comes from the 1970's (Herbarium of The New York Botanical Garden, accessed through GBIF Data Portal, data.gbif.org, 2010-09-15). However, the region is now densely populated with a high degree of land disturbance, which might explain the current absence of the species.

Although we can observe that the species is distributed across early morning wet soils, the wet index was not important in the distribution model of the species. One explanation for the high humidity in the morning is the fog arising from clouds in surrounding CAP areas. The discussion of the effects of fog on plants is well developed. Scott (1890) already questioned its effects on plants. Fog may constitute a significant fraction of the total hydrologic input in an ecosystem during particular periods, such as the growing season, when plant demand for water is high (Breazeale *et al.* 1950; Dawson 1998). Fog or cloud water could help to diminish the stress effects in these extremely xeric areas by reducing plant transpiration or evaporation from the habitat and by improving plant water status by direct absorption through the foliage (e.g., Huntley *et al.* 1997; Dawson 1998; Teixeira & Valladares 2014). An interesting point is the fact that CAP areas seem responsible for shrinking the distribution of *C. cereifera*, as shown in Figure 3. In fact, some surrounding regions are constantly

covered by low clouds (NPUB, GWF, personal observation). This phenomenon occurs frequently in basins, valleys and sinks of mountain regions and can have a substantial impact on much species phenology, diversity and distribution (Rodrigo 2000; Chung *et al.* 2006; Daly *et al.* 2009), including *C. cereifera* (Fernandes *et al.* 2011). However, in the case of *C. cereifera*, the potential CAP area restricts the distribution of the species and may be related to the susceptibility of this species (and the majority of rupestrian grasslands species, e.g., Kolbek & Alves 2008) to multiple frosts, more common in these valley areas (Clements *et al.* 2003). Potential cold air pooling areas are an important variable that shape many microrefugia areas along the Pleistocene climatic fluctuations (Dobrowsky 2011), as may have a strong influence on this species distribution.

Indeed, climate fluctuations that occurred in South America during the Pleistocene period are not yet fully known. Data for the Pleistocene and Holocene in mountain regions of *Espinhaço* are often conflicting. However, a consensus exists that at least the southern part of this mountain chain was cooler and drier during the last glacial maxima than in present time (Vuilleumier 1971; Ledru 1993; Stute *et al.* 1995; Behling 1998; 2002; Ab'Saber 2000; Behling & Hooghiemstra 2001). In addition, the low atmospheric CO₂ levels of this period probably enhanced plant water loss (Mayle *et al.* 2004), maximizing the dryness. This scenario would also have contributed to a decrease in CAP intensity in these areas, which in turn may have been important to the spread of *C. cereifera* and/or its congeners to broad areas as we can see in model 2 (Fig. 4). During this period the vegetation zones in tropical South America may have lowered their distribution to ca. 1km (Rind & Peteet 1985; Clapperton 1990; Stute *et al.* 1995); thus implying that the rupestrian grassland vegetation of the *Espinhaço* mountain chain may have been able to spread into areas much lower in elevation than those currently found (e.g., Vuilleumier 1971), such as those that today are covered by *cerrado* (savannah) vegetation. Temperatures in the highlands may have reached below -5°C according to Behling & Lichte (1997). Furthermore, it is hypothesized that many thermophilous species (shrubs and trees) may have become locally extinct in these summits, which were covered solely by the cold adapted grassland vegetation, similar to the steppes (see Behling 2002).

Microrefugia are believed to be found in terrain positions that promote the consistent decoupling of the boundary layer from the free-atmosphere and can support once prevalent regional climates that have been lost due to climate shifts (Dobrowsky 2011). It seems that the actual distribution area of *C. cereifera* works as an interglacial microrefugium for the species, whose ancestral species may have had a much wider distribution due to a higher environmental suitability and also less environmental restrictions, e.g., CAP areas (Fig. 4). The germinative behaviour of *Miconia*

corallina (Melastomataceae) in this small area, for example, provides support for local adaptation of the inhabiting species, as in this core area individuals present dormant seeds, while outside of it seeds are non-dormant (Silveira *et al.* 2011). Among-population variation in seed dormancy and germination is strongly related to climatic conditions. Several other relict species are also found only in the *Coccoloba* microrefugium, such as the shrub *Chamaecrista semaphora* (Fabaceae), and the treelet *Collaea cipoensis* (Fabaceae) (Madeira & Fernandes 1999; Negreiros *et al.* 2008), among many others.

The existence of a microrefugium could have played a key role in the local processes that derived in the narrow distribution of *C. cereifera*. These are not necessarily present-day processes, and are probably partially due to reliction and extinction, following range contraction of formerly more widespread species as a result of climatic changes (e.g., Harley & Simmons 1986). The presence of plants in microrefugia is likely to be a phenomenon more common than previously expected. Most endemism and species richness intrinsic to the rupestrian grasslands could have been shaped in this way, such as the case of *Croton arlinae*, a plant restricted in a small area smaller than 1km² at São José Mountains (Medeiros *et al.* 2002).

The adaptation of species in microrefugia has many implications on the rates of genetic divergence under climate change (Hewitt 2000; Stewart *et al.* 2004) and also great implications to distribution modelling. Dobrowsky *et al.* (2006) constructed distribution models for the mountain species *Abies magnifica* in Sierra Nevada, USA, using data with and without cold-air pooling effects (related to microrefugia). Under a 4°C warming scenario the results varied greatly. The first model, without cold-air pooling effects, predicts that there is no environmental suitability within the study region in this hypothetical warm future, whereas the second model identifies potential microrefugia in valley bottoms.

The great challenge for the projection of *C. cereifera* distribution in the future is the scarcity of climatic data. Critically important is the creation of physiographically informed climate data to the modelling of this and other restrict and endemic species of mountain regions (Clements *et al.* 2003; Lundquist *et al.* 2008). The existence of a network of weather stations is essential for the development of more realistic modelling of present and future distribution of these species. Otherwise, mountains represent the most likely global regions where we may record the first footprints of climate change (IPCC 1996). In the tropics, these regions are inhabited by diverse flora and fauna, with high degree of endemism, and are where species struggle with the harsh environment and ever growing human induced disturbances (see Fernandes *et al.* 2014).

From a management point of view, the existence of a microrefugium in this area calls for changes in conservation tactics. Although the traits of the species suggest that it may be capable of surviving tem-

porally in small isolated areas, even under climatic changes, the recent and recurrent introductions of non-native invasive species, grazing, tourism, and frequent fires represent strong threats to the existence of *C. cereifera* and other sympatric species (see Viana *et al.* 2005; Barbosa *et al.* 2010; Moreira *et al.* 2010; Fernandes *et al.* 2011; 2014; Carvalho *et al.* 2012). This scenario is more worrying due to the fact that the distribution area of *C. cereifera* is not within the strictly protected area of *Parque Nacional da Serra do Cipó*, albeit the species is found in an area of some protection status (*APA Morro da Pedreira*). Overall, these conditions make this microrefugium species and area worth of further detailed studies and conservation efforts.

Acknowledgements

We are grateful to Moreira R.G. and Cornelissen T.G. for their help in providing data for occurrence points and Loreto P.Y., Alberto L. Teixeira and Hesketh M. for suggestions on the text. We thank the grants and logistic support of the Conselho Nacional de Pesquisa (CNPq: 140655/2008-5, 55 8250/2009-2, 474292/2010-0, 30 3352/2010-8, 151431/2014-0), CAPES (PGCI 02/2009, BEX 3236/10-2), Fundação de Amparo à Pesquisa do Estado de Minas Gerais, Natural Reserve Vellozia, and the Department of Earth Sciences of the University of Alberta for the work space. We also thank the MaxEnt discussion group for all appointments. This study was in partial fulfillment of the Ph.D. requirements of Barbosa N.P.U..

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