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Full Length Research Paper

Modelling the spatial distribution of endemic Caesalpinioideae in Central Africa, a contribution to the evaluation of actual protected areas in the region

Joël Ndayishimiye[1,4]*, Michelle Greve[2], Piet Stoffelen[3], Marie J. Bigendako[1], Charles De Cannière[4], Jens- C. Svenning[2] and Jan Bogaert[5]

[1]Faculty of Sciences, University of Burundi, PO Box. 2700, Bujumbura, Burundi.
[2]Ecoinformatics and Biodiversity Group, Department of Bioscience, Aarhus University, Ny Munkegade 114, DK-8000 Aarhus C, Denmark.
[3]National Botanic Garden of Belgium, Domein van Bouchout, B-1860, Meise, Belgium.
[4]Landscape Ecology and Plant Production Systems Research Group, Free University of Brussels (ULB), 50 Avenue F.D. Roosevelt, CP 169, B-1050 Brussels, Belgium.
[5]Biodiversity and Landscape Unit, University of Liège, Gembloux Agro-Bio Tech. Passage des Déportés 2, B-5030 Gembloux, Belgium.

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Understanding why some regions have higher levels of diversity and which factors are driving the occurrence of species in a particular area is crucial for environmental management and for the development of species conservation strategies. In this study, we studied seven species of the Caesalpinioideae that are endemic in Central Africa (Democratic Republic of the Congo, Burundi and Rwanda). The objectives of this study were to identify the environmental factors that constrain their distribution, to determine the potential areas where each species could be present, to assess the current conservation status of each species and to evaluate how well the species are protected by the protected areas in the region. Distributions were analyzed and potential distributions predicted using the Maxent species distribution algorithm with climatic (precipitation and temperature) and non-climatic predictor variables (soil, elevation, and slope). Environmental variables and species occurrence data were obtained respectively from the WorldClim database and from herbarium specimens kept at the National Botanic Garden of Belgium and the Université Libre de Bruxelles. Our results suggest that the distribution of endemic species is influenced by a combination of climatic and non-climatic variables. Soil type, temperature annual range and precipitation of the driest month were the most important predictor variables. Overlaying the potential distributions of the seven selected species indicated three areas of concentration of endemic species which should be given particular conservation attention. Comparing the potential distributions to the current Central African protected areas showed that the endemic species are not well protected, as 97% of their potential habitat is localized outside protected areas. Hence, additional reserves should be created to improve the protection of these endemic plant species.

Key words: Caesalpinioideae, maxent, species distribution model, species response curve, protected area.

INTRODUCTION

Biodiversity conservation is one of the major concerns in biogeography and ecology. Species richness is distributed non-uniformly across the biosphere (Sechrest et al., 2002) and nature conservation is often based on the concept of biodiversity hotspots (Myers et al., 2000; Brooks et al., 2002; Roberts et al., 2002). Many studies have discussed the factors determining the spatial distribution of species. Their results also depend on the

*Corresponding author. E-mail: ndayishimiye_joel@yahoo.fr.

spatial scale of the study (Mackey and Lindenmayer, 2001; Quist et al., 2004; Trivedi et al., 2008; Blach-Overgaard et al., 2010; Soberón, 2010). Species distribution models (SDMs) that use environmental factors based on historical collections are increasingly being used to not only analyze species distributions, but also to predict the presence or absence of species or their habitats in unrecorded areas (Guisan and Hofer, 2003; Araújo et al., 2005; Wintle et al., 2005; Elith et al., 2006; Elith and Leathwick, 2009). Notably, SDMs have been used to predict potentially suitable areas for the preservation of endangered and rare species (Papes and Gaubert, 2007; Solano and Feria, 2007; Ko et al., 2009; Thorn et al., 2009; Gallagher et al., 2010; Rebelo and Jones, 2010), for the identification of potential sites for reintroduction or restoration (Klar et al., 2008; Kumar and Stohlgren, 2009) and for assessing potential effects of future climate change on species distributions as well as on local species diversity (Pearson and Dawson, 2003; Hole et al., 2009). To enable the analysis of the impacts of climate change on species, it is essential to quantify the relative importance of climate relative to other descriptors of the environment (Morueta-Holme et al., 2010; Newbold, 2010).

There are still large gaps in the knowledge of species distribution of the flora in some parts of Central Africa such as the Congo Basin, and many areas remain very poorly sampled (Küper et al., 2006). Therefore, the objectives of this study were to assess the current conservation status of the seven species of the Caesalpinioideae subfamily which are endemic to Central Africa (Democratic Republic of the Congo, Burundi and Rwanda), to determine their potential distributions in the region, to identify the environmental factors that constrain their distributions and to evaluate how well their distributions are covered by the actual protected areas in the region.

The study is focused on endemic species because they are of particular biogeographic and conservation interest (Lamoreux et al., 2006). An endemic species is confined to or characteristic of a restricted geographic area, and may have a small population size and an associated relatively high extinction risk (Rabinowitz, 1981; Anderson, 1994; Ceballos et al., 1998; Broennimann et al., 2005). Endemic species are also found sensitive to climate change (Malcolm et al., 2006; Ohlemüller et al., 2008; Morueta-Holme et al., 2010) and have in several studies been found to be concentrated in areas of long-term climate stability (Jansson, 2003; Svenning and Skov, 2007; Fløjgaard et al., 2010. It is therefore, important to understand the range determinants of endemic species in order to develop effective conservation strategies that take the impact of current and future drivers of biodiversity loss into account.

The subfamily of the Caesalpinioideae was chosen as a model taxon for several reasons, as it is widely distributed in humid tropical Africa, and its species are often abundant or even dominant in forested ecosystems in the tropics (Polhill and Raven, 1981; Wieringa, 1999; Gross et al., 2000; Sprent, 2005). Most tropical species in this subfamily are large trees, shrubs or lianas and the subfamily is well known taxonomically (Bruneau et al., 2001; Lewis et al., 2005): about 171 genera and 2251 species are actually known worldwide. In Africa, there are 501 known species grouped in 84 genera (Lebrun and Stork, 2008). Across Central Africa, approximately 197 species and 57 genera are described (Wilczek et al., 1952). The subfamily contains 55 endemic species in the Democratic Republic of the Congo, Rwanda and Burundi (Ndjele, 1988). Some Caesalpinioideae species in the region have been thought to be associated with long-term stable forest areas (Sosef, 1994; Robbrecht, 1996; Leal, 2001, 2004; Tchouto et al., 2008).

The following analyses were carried out: (i) identification of the environmental factors that constrain the distribution of endemic Caesalpinioideae species in Central Africa, (ii) estimation of species' responses to these environmental variables, (iii) mapping the potential distribution of the study species, (iv) combining these potential distribution to create a single map of suitable areas for endemic Caesalpinioideae, and (v) assessment of how well current status protected areas in Central Africa cover the distribution of the Caesalpinioideae endemic species. The results will be compared and discussed in relation to White's (1979, 1983) phytogeographical classification of Central Africa. A better understanding of the geographical ecology of these species will improve our understanding of their current distribution and their vulnerability to deforestation and climate change.

MATERIALS AND METHODS

Study area

The study area comprises the Democratic Republic of the Congo, Burundi and Rwanda (Figure 1). The extent of the region is 2,399,572 sq.km: 2,345,000 for the Democratic Republic of the Congo (D.R. Congo), 27,834 for Burundi and 26,338 for Rwanda (Koffi, 2005). The dominant vegetation is forest, with the rainforest of the Congo Basin constituting the second largest rainforest area in the World (Mayaux et al., 2003), but other vegetation types also occur (woodlands, savannahs, secondary forest formations) (Roche, 1979; White, 1979, 1983). The Congolese rainforest is characterized by a high biodiversity: about 9750 species of plants are known, 3300 of which are endemic to this region (including Cameroon and Gabon; Mittermeier et al., 2003). Two types of climate characterize the study region: (i) An equatorial type is characterized by an annual average temperature of 25 to 27°C and annual rainfall of 2000 to 3000 mm with no dry season. (ii) A subequatorial type with alternating rainy and dry seasons and an annual average temperature of 18 to 21°C (Sys, 1960).

Data collection

Data were extracted from a database containing data from the herbaria of the National Botanical Garden of Belgium (BR) and the

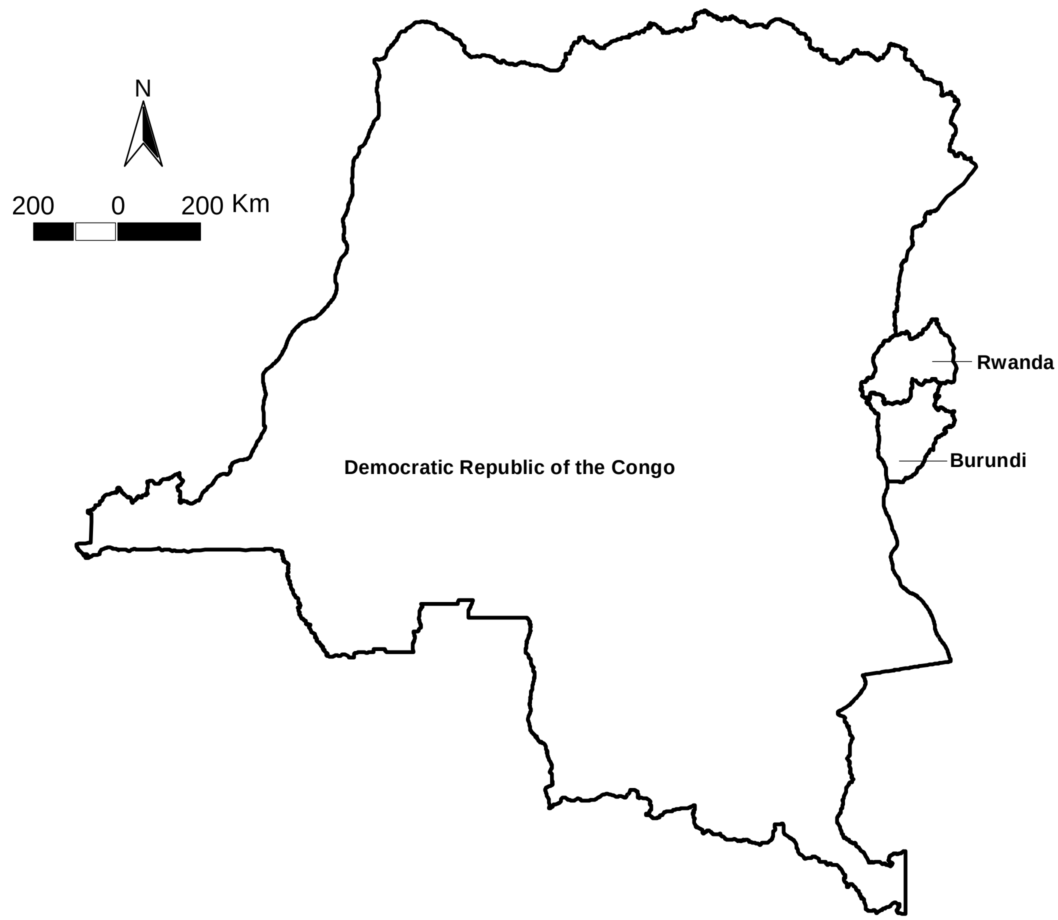

Figure 1. Map of study area.

Université Libre de Bruxelles (BRLU). The selected 6670 specimens of the Caesalpinioideae (197 species) were collected between 1899 and 2007. Spatial references, when absent on specimen labels, were reconstructed using Bamps' gazetteer (1982). Species were considered endemic when their distribution was limited to only one single phytogeographical region of White (1979, 1983). Endemic species were determined based on literature data (Wilczek et al., 1952; Ndjele, 1988; Lock, 1989; Léonard, 1993; Breteler and Nguema Miyono, 2008; Lebrun and Stork, 2008; Breteler, 2010). Only endemic species with more than ten locality records were retained for modelling. Table 1 lists the seven endemic species used in this study, their phytogeographical region following the classification of White (1979, 1983), their life form and habitats.

Environmental variables used to build the model are based on former habitat modelling studies (Skov and Borchsenius, 1997; Kumar et al., 2009; Murienne et al., 2009; Stabach et al., 2009; Blach-Overgaard et al., 2010) and are known to be relevant for vegetation distribution. These predictors (Table 2) include climatic variables (precipitation and temperature) as well as non-climatic variables (soil, elevation, and slope). Climatic variables obtained from the WorldClim dataset (Hijmans et al., 2005), while soil type information came from the Harmonised World Soil Database (Fischer et al., 2008); topographic variables (elevation and slope) were extracted from a digital elevation model (DEM) obtained from Shuttle Radar Topographic Mission (SRTM). All environmental variables were rescaled to a $2.5 \times 2.5'$spatial resolution.

Data analysis

It has been shown that the choice of environmental variables has a significant effect on model accuracy (Parolo et al., 2008; Peterson and Nakazawa, 2008). Models developed with environmental variables that have a direct effect on species distribution are considered more accurate, biologically informative and generalizable than models developed with variables having only an indirect effect (Austin et al., 2006; Newbold, 2010). Furthermore, SDM results are difficult to interpret when predictor variables are correlated (Kivinen et al., 2008). In the case of our study, only uncorrelated or partially correlated variables ($|r| < 0.80$) were used for modelling (Giovanelli et al., 2010). The threshold was used to reduce collinearity between variables.

We used the Maximum Entropy SDM algorithm "Maxent" version 3.2.1 (Phillips et al., 2004, 2006). This algorithm was chosen because it is applicable to presence-only data (Phillips et al., 2004, 2006), it has been shown to perform well when compared other methods (Deblauwe et al., 2008; Wisz et al., 2008) and since it has been reported to be relatively robust to small sample sizes (Hernandez et al., 2006; Gibson et al., 2007; Pearson et al., 2007). Default values for the convergence threshold (10^{-5}), the maximum number of iterations (500) and the logistic output format were used (Phillips and Dukík, 2008; Morueta-Holme et al., 2010). Seventy five percent of the records were used for model training and twenty percent for testing. To evaluate model performance, the Area Under the receiver operating characteristic Curve (AUC) was used (Elith et

Table 1. Endemic species of the Caesalpinioideae subfamily collected between 1899 and 2007. The phytogeographical regions occupied by each species are provided (Distr.), and is based on White's phytogeographical model (1979, 1983). Species were considered endemic when their distribution was limited to only one single phytogeographical region of White (1979, 1983). GC: Guineo-Congolian regional centre of endemism; Z: Zambezian regional centre of endemism. *N* is the number of samples.

Species	N	Distr.	Life form and associated habitat
Anthonotha gilletii (De Wild.) J.Léonard	31	GC	Tree; forest on firm-ground forests; sometimes grows in swampy forests and in gallery forest.
Crudia harmsiana De Wild.	45	GC	Tree; forest (riverine formations periodically flooded; swampy forest generally grows along rivers)
Crudia laurentii De Wild.	33	GC	Tree; forest (riverine formations periodically flooded).
Cryptosepalum katangense(De Wild.) J.Léonard	14	Z	Suffrutex; grows in woodland or open forest
Dialium pentandrum Steyaert	16	GC	Tree; forest (terra firm forest)
Leonardoxa romii (De Wild.) Aubrév.	71	GC	Tree or shrub; forests on firm ground; sometimes in gallery forest
Pseudomacrolobium mengei (De Wild.) Hauman	15	GC	Tree, forest (rain forest on plateau; secondary or riparian forests)

al., 2006; Pearson et al., 2007; Phillips et al., 2009; Hu and Jiang, 2010). Thuiller et al. (2003) have established a scale to enable interpretation of AUC values and for model validation: 0.90-1.00 = excellent; 0.80 to 0.90 = good; 0.70 to 0.80 = average; 0.60 to 0.70 = poor; 0.50 to 0.60 = insufficient. For an appropriate model, areas of high probability will cover the majority of presence records and areas with low probability will be characterized by low presences of records (Yost et al., 2008). Variables that produce the highest training gains are considered to be the most important predictor variables (Kouam et al., 2010).

ArcView 3.3 was used for creation and handling of maps. A combined map of potential distributions of the seven endemic species was created by overlay the locality records of all endemic species with the environmental layers used in this study. The degree to which current protected areas cover the distribution of Caesalpinioideae endemic species was analyzed by superimposing the combined Caesalpinoideae map of each species and the Central African protected areas map published by Laghmouch and Hardy (2008). The comparison of these two measures permitted an assessment of the degree of conservation protection of these Central African endemic species.

RESULTS

The current and potential species distribution

The seven species considered here and their suitable areas as estimated by Maxent are distributed across different regions of Central Africa (Figure 2). The predictive map for *Anthonotha gilletii* shows a high suitability in the central part, while suitable areas for *D. pentadrum* are distributed in Eastern parts of the region. The predictive map of *Crudia harmsiana,Crudia laurentii* and *Pseudomacrolobium mengei* showed high habitat suitability in western parts of D.R. Congo with moderate suitability in its central parts. *Leonardoxa romii* has high habitat suitability in central parts of the D.R. Congo, while *Cryptosepalum katangense* finds high habitat suitability in south parts, especially in the Katanga province.

Models for all species had reasonable discriminatory power, as AUC values ranged 0.73 to 0.98 (Table 3), indicating average to excellent models. The best models were obtained for *C. harmsiana*, *C. Laurentii* and *C. katangense*.

Factors determining species distribution

Different environmental factors influence the distribution of the seven endemic species, with soil type, temperature annual range, and precipitation of the driest month emerging as the best predictors (Table 4). The precipitation of coldest quarter is also an important predictor for six species out of seven.

Considering species response curves (Figure 3) it is noteworthy that many species are associated with specific soil types as well as water bodies, for example, A. *gilletii* and *D. pentadrum* mostly by nitosols and gleysols, and *C. laurentii* and *C. harmsiana* by water bodies. Concerning climatic response curves, *C. katangense* is negatively related to annual precipitation, while *L. romii* and *P. mengei* are positively related to precipitation of the driest month (Figure 3).

Potential areas of the occurrence and overlap with protected areas in Central Africa

A combined map of potential distributions of the seven endemic species indicated that suitable areas for the endemic species are clustered in three main zones (Figure 4). Suitable areas for the endemic species were very poorly covered by the existing protected areas in Central Africa (Figure 4 and Table 5). Currently, 44 national parks are known in D.R. Congo, covering an area of 299,373 km^2 representing 12.4% of the study area. The class with the highest predicted probability (0.75 to 1.00) for the considered endemic species corresponds to an area of about 30,841 km^2, of which 3.3% (1,027 km^2) are situated inside the protected zones (Figure 3 and Table 5). The three parks that shelter the potentially favorable zones to the endemic species are

Table 2. Environmental predictor variables used to model the potential distribution of the seven Caesalpinioideae species endemic to Central Africa (*A. gilletii*, *C. harmsiana*, *C. laurentii*, *C. katangense*, *D. pentandrum*, *L. romii, P. mengei*).

Code	Description	Data type	Unit
BIO7	Temperature annual range*	Continuous	°C
BIO10	Mean temperature of the warmest quarter	Continuous	°C
BIO12	Annual precipitation	Continuous	mm
BIO14	Precipitation of the driest month	Continuous	mm
BIO18	Precipitation of the warmest quarter	Continuous	mm
BIO19	Precipitation of the coldest quarter	Continuous	mm
EL	Elevation	Continuous	m
SL	Slope	Continuous	°
ST	Soil type	Categorical	31 categories

*The difference between the maximum temperature of warmest month and the minimum temperature of coldest month.

the Upemba National Park (2.2%; 9°3'S, 26°38'E; Southern Katanga province; 672942 km^2), the Ngiri Reserve (0.7%; 0°40'N, 18°9'E; Western Equateur Province; 226862 km^2) and the Maiko National Park (0.4%; 0°25'S, 27°42'E; Maniema, North Kivu and Oriental Provinces; 127569 km^2). The Maiko National Park and the Ngiri Reserve are localized in the Guineo-Congolian regional centre of endemism. The Upemba National Park occupies the Zambezian regional centre of endemism in the Southern Katanga Province. The proportion of the number of samples found inside the protected area does not exceed 14% of the total number of samples collected for the endemic species. This result confirms that large areas inside protected areas remain insufficiently sampled.

DISCUSSION

We showed how SDMs can be used to predict potentialspecies distribution in areas for which very few biodiversity data are available. The models provide good discriminatory ability, at the level of average to excellent following the Thuiller et al. (2003) scales. AUC values are all above 0.70 for the seven species used in this study. However, the quality of the obtained models depends on the species considered (Table 3). The maps of the potential distributions (Figure 2) suggest that their distributions may range somewhat beyond the localities where the species were collected. Among the seven endemic species considered in this study, six had the highest probability of occurrence in the Guineo-Congolian regional centre of endemism and the Afromontane Archipelago-like regional centre of endemism, including the Lake Victoria regional mosaic in Eastern D.R. Congo (*A. gilletii*, *C. harmsiana*, *C. laurentii*, *D. pentadrum*, *L. romii* and *P. mengei*) and only one (*C. katangense*) was strictly confined to the Zambezian regional centre of endemism according to White's classification (1979, 1983). Nevertheless, *A. gilletii*, *D. pentadrum* and *L. romii* were more widely distributed in the Guineo-Congolian regional centre of endemism than *C. harmsiana*, *C. laurentii* and *P. mengei*, which have a preference for areas closer to the Congo River (Figure 2b, c, g). These findings agree with the previous observations that these three Caesalpinioideae tree species grow exclusively along streams or rivers (White and Abernethy, 1997; Wieringa, 1999). These riverine areas correspond to zones that have been proposed as tropical African forest refugia in D.R. Congo (Maley, 1991).

Environmental variables associated with the distribution of the seven endemic species suggest that their ecological requirements differ. It is shown that a mix of climatic and non-climatic variables are needed to explain endemic species distributions in Central Africa, with temperature annual range, precipitation of driest month, and soil type (including water bodies) being the most important predictor variables.

The zones showing high probability of presence for *A. gilletii*, *C. harmsiana*, *C. laurentii*, *D. pentadrum*, *L. romii* and *P. mengei* (Figure 2) overlapping in the areas identified on Figure 4. These areas can be characterized as follows: (1) several sites included in a large area in the Guineo-Congolian regional centre of endemism, (2) a zone situated in the eastern part of the D.R. Congo located in the Afromontane Archipelago-like regional centre of endemism, including the Lake Victoria regional mosaic. These results are coherent with the forest habitat types of *A. gilletii*, *C. harmsiana*, *C. laurentii*, *D. pentadrum*, *L. romii* and *P. mengei* as described in Table 1. The third zone (3) situated in the Southern part of the Katanga province of D.R. Congo included in the Zambezian regional centre of endemism is the other potential area of the species *C. katangense*. This species is commonly observed in the understory of the woodlands ("forêt claire") in Katanga, which is consistent with the

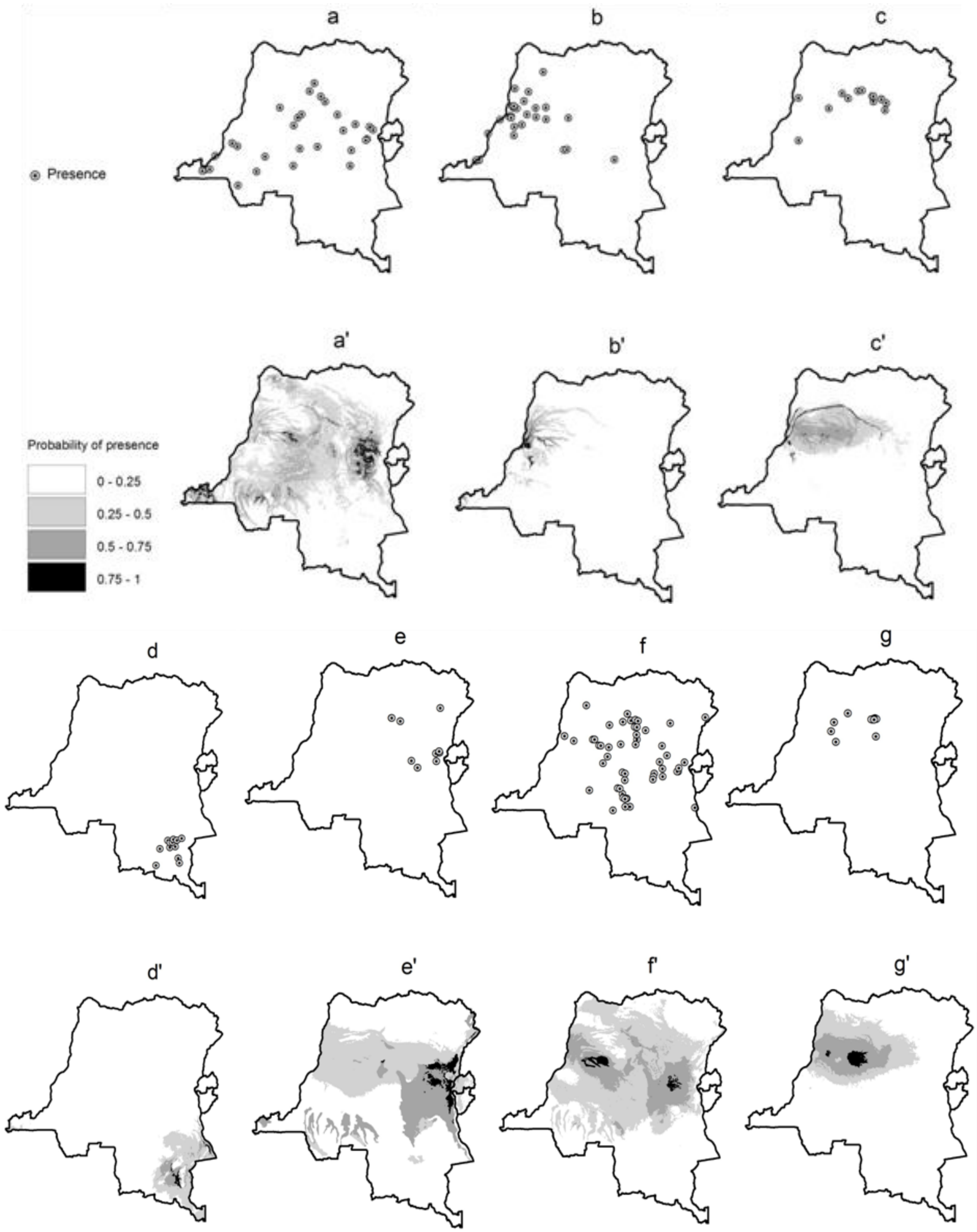

Figure 2. Current (a-g) and potential geographic distributions (a'-g') of the seven endemic Caesalpinioideae species in Central Africa. Points indicate the presence of field records. Probability of presence indicates habitat suitability and is based on the logistic output of the Maxent model. (a) *Anthonotha gilletii* (*N*=31); (b) *Crudia harmsiana* (*N*=45); (c) *Crudia laurentii* (*N*=33); (d) *Cryptosepalum katangense* (*N*=14); (e) *Dialium pentandrum* (*N*=16); (f) *Leonardoxa romii* (*N*=71); (g) *Pseudomacrolobium mengei* (*N*=15). *N* is the number of samples.

Table 3. Area under the curve (AUC) statistics obtained from the Maxent model of seven Caesalpinioideae species endemic to only one single phytogeographical region, as defined by White (1979, 1983). 75% of the records were used as training data, and 25% as testing data. AUC values are all average to excellent.

Species	Training data	Testing data
Anthonotha gilletii (De Wild.) J.Léonard	0.90	0.73
Crudia harmsiana De Wild.	0.98	0.88
Crudia laurentii De Wild.	0.96	0.82
Cryptosepalum katangense (De Wild.) J.Léonard	0.96	0.92
Dialium pentandrum Steyaert	0.86	0.80
Leonardoxa romii (De Wild.) Aubrév.	0.84	0.81
Pseudomacrolobium mengei (De Wild.) Hauman	0.94	0.96

Table 4. Contribution (%) of the environmental predictor variables to the Maxent distribution model for the seven endemic Caesalpinioideae species in Central Africa. The missing data symbol (–) indicates that the variable does not have any effect on the species distribution. BIO7 = Temperature annual range; BIO10 = Mean temperature of warmest quarter; BIO12 = Annual precipitation; BIO14 = Precipitation of driest month; BIO18 = Precipitation of warmest quarter; BIO19 = Precipitation of coldest quarter. ANTGIL= *Anthonotha gilletii*, CRUHAR= *Crudia harmsiana,* CRULAU= *Crudia laurentii,* CRYKAT= *Cryptosepalum katangense,* DIAPEN= *Dialium pentandrum,* LEOROM= *Leonardoxa romii,* PSEMEN= *Pseudomacrolobium mengei*.

Variables	ANTGIL	CRUHAR	CRULAU	CRYKAT	DIAPEN	LEOROM	PSEMEN
BIO7	3.9	26.3	5.9	3.6	5.1	1.6	0.5
BIO10	0.4	–	–	–	4.0	2.3	1.0
BIO12	0.6	0.1	–	47.2	–	1.1	–
BIO14	6.0	2.5	58.3	1.0	11.3	47.9	78.0
BIO18	20.2	–	1.3	1.5	–	0.9	–
BIO19	1.4	0.3	6.5	37.4	–	21.8	5.3
Elevation	16.8	23.4	2.7	–	–	4.6	15.1
Soil	44.3	45.9	24.4	6.6	79.6	19.4	0.1
Slope	10.8	1.6	0.9	2.7	–	0.4	–

sites where the species was sampled (Lebrun and Stork, 2008). Notably, these three endemic-rich areas have also previously been identified as areas with a high degree of endemism (White, 1983; Cincotta et al., 2000; Olson et al., 2001; Mutke and Barthlott, 2005).

By modelling the potential distribution of a species, its biogeographical limits, beyond those directly documented by collections, can be estimated. When comparing collection localities to the potential distribution maps (Figure 2), one notices that the potential distributions partially extend beyond the vicinity of the historical collections. Notably, potential distributions of *A. gilletii*, *D. pentandrum* and *L. romii* cover large areas of the Guineo-Congolian regional centre of endemism and may reach the limits of the Afromontane Archipelago-like regional centre of endemism, including the Lake Victoria regional mosaic. However, the potential distributions of *C. harmsiana*, *C. laurentii*, *C. katangense* and *P. mengei* indicate that these species are confined to a small geographical area in the Guineo-Congolian regional centre of endemism and the Zambezian regional centre of endemism. The model development in this study presents also some limitations. Species occurrence data are often affected by sampling intensity and records are often higher in easily accessible areas (Koffi et al., 2008; Phillips and Elith, 2010) and along rivers (Wilting et al., 2010). Based on our results, areas predicted to be characterized by a high probability of presence are also areas where most collections have been made. The environmental variables used to model the Caesalpinioideae endemic species are not the only factors to influence species distribution. Other factors such as dispersal and biotic interactions may also determine species distributions (Roura-Pascual and Suarez, 2008; Kearney and Porter, 2009; Blach-Overgaard et al., 2010; Morueta-Holme et al., 2010).

The results of this study have implications for the conservation of species restricted to in only one single phytogeographical region. Indeed, endemic species are by definition confined to small geographical areas, but

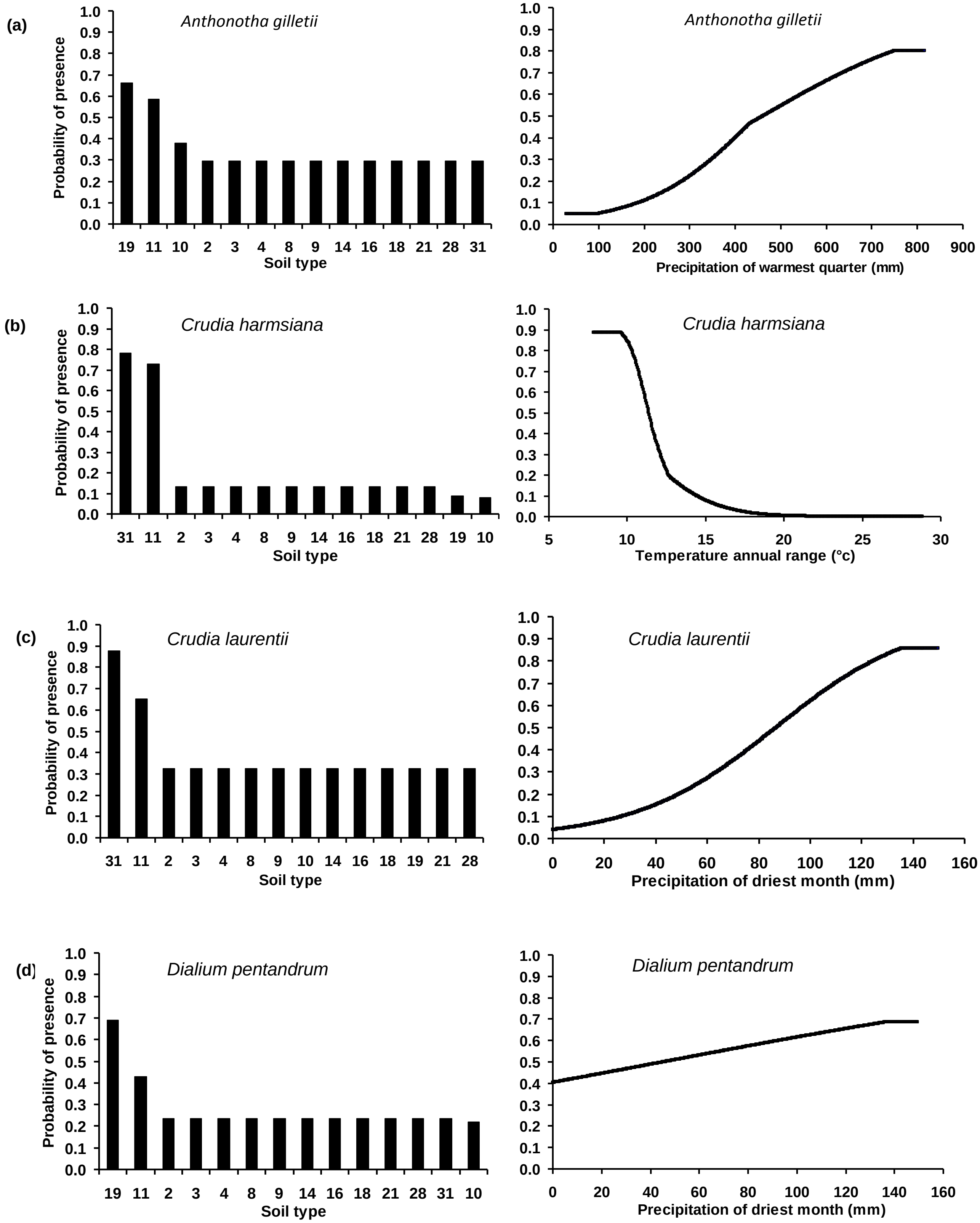

Figure 3. Response curves of the two most important environmental determinants of the distribution of each of seven Caesalpinioideae endemic species in Central Africa. a: *Anthonotha gilletii*, b: *Crudia harmsiana*, c: *Crudia laurentii*, d: *Dialium pentandrum*, e: *Cryptosepalum katangense*, f: *Leonardoxa romii*, g: *Pseudomacrolobium mengei*. Soil types are coded by numbers (2: Alisols; 3: Andosols; 4: Arenosols; 8: Cambisols; 9: Fluvisols; 10: Ferralsols; 11: Gleysols; 14: Histosols; 16: Leptosols; 18: Lixisols; 19: Nitisols; 21: Phaeozems; 28: Vertisols; 31: Water Bodies).

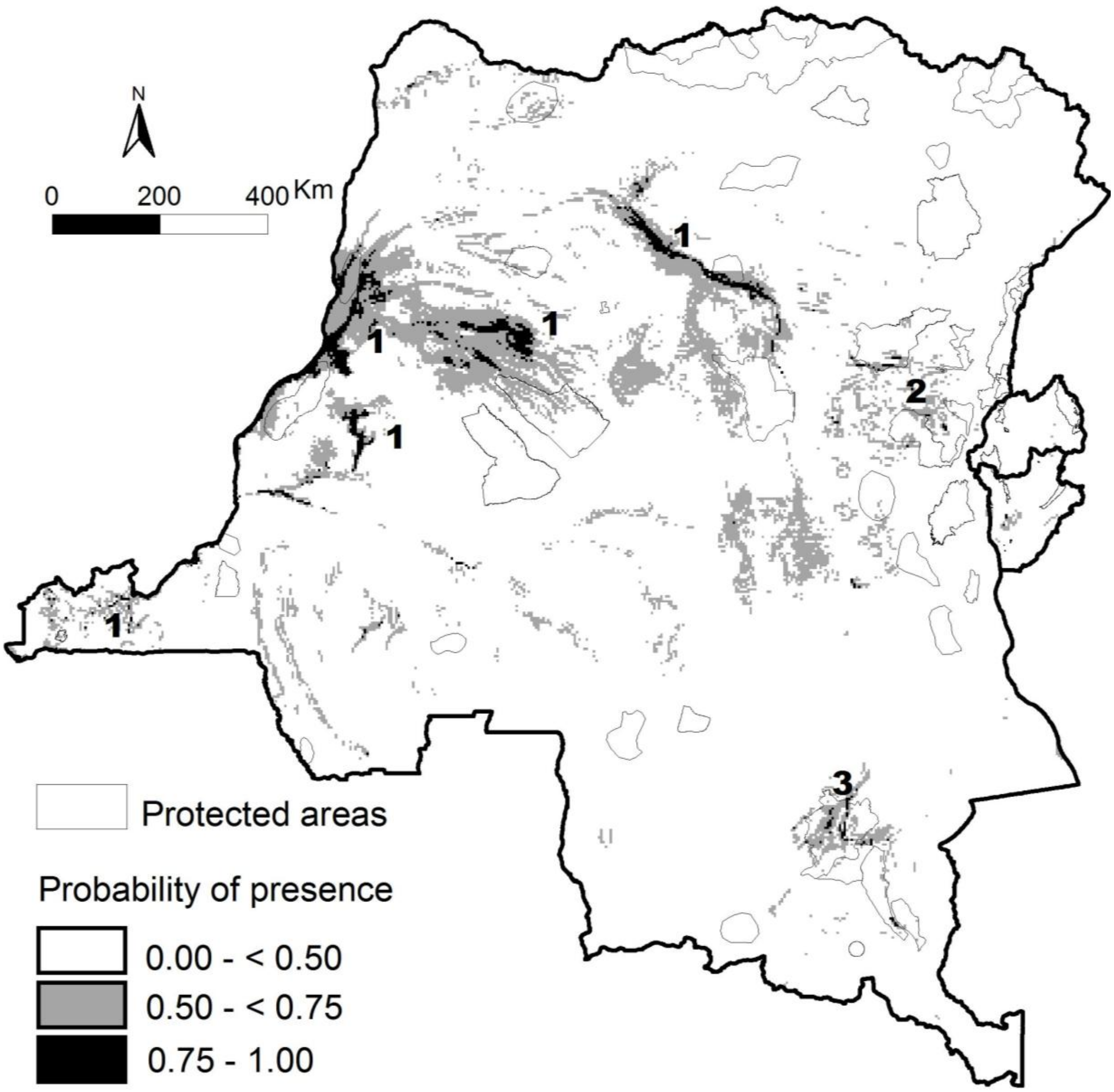

Figure 4. Overlay map of potential habitat for the seven Caesalpinioideae endemic species in Central Africa based on the Maxent model with nine predictor variables. Areas with a probability range between 0.75 to 1.00 can be interpreted as areas with high favorable habitat for the species (Freedman et al., 2008; Redon and Luque, 2010). (1: large area in the Guineo-Congolian regional centre of endemism; 2: eastern part of D.R. Congo in the Afromontane archipelago-like regional centre of endemism, including the Lake Victoria regional mosaic; 3: a zone in the southern part of the Katanga province located in the Zambezian regional centre of endemism). Potential areas where the endemic species occurred showed poor correspondence with the Central African protected areas.

may additionally be associated to particular habitats, have small population sizes, and/or low dispersal potential (Rabinowitz, 1981; Ceballos et al., 1998). Endemic species may also threatened by the destruction of their habitats and by climate change (Brooks et al., 2002; Morueta-Holme et al., 2010). Areas that potentially could contain a large number of endemic species in Central Africa are located in forested landscapes, which are mostly not covered by the current protected areas (Figure 4). Importantly, only a few small protected areas correspond to a high probability of presence of the endemic species considered here. On the scale of our study, deforestation and fragmentation are thus two major potential determinants of biodiversity loss and change of landscape structure (Bogaert et al., 2008; Bamba et al., 2010), including the studied endemic species. Preserving the areas with a high concentration of endemic species should decrease the risk of losing this part of Central African biodiversity. We note that special conservation efforts may be needed for *C. harmsiana*, *C.*

Table 5. Representation of zones with high probability of endemic Caesalpinioideae species in currently existing Central African protected areas. Probability of presence classes are indicated by letter (A: Probability of presence range between 0.75 and 1.00; Probability of presence range between 0.50 and <0.75; C: Probability of presence range between 0.00 and <0.50).

Variable	Probability of present classes		
	A	B	C
Total predicted surface of endemic species (km²)	30,841	236,047	2, 132, 684
Proportion of predicted surface of endemic species inside protected areas (%)	3.3	1.7	0.1
Proportion of predicted surface of endemic species outside protected areas (%)	96.7	98.3	99.9

laurentii, *C. katangense* and *P. mengei* as their potential distributions are limited to a small region (Figure 2).

Conclusions

Species Distribution Models were applied to analyze a specific group of species with a restricted distribution (Caesalpinioideae endemics) to in only one single phytogeographical region in Central Africa. The results of this study indicate that Species Distribution Models offer important new insights on the geographical ecology of these species. Firstly, at the scale of this study, the distribution of the considered Caesalpinioideae endemic species was found to be determined by a combination of climatic and non-climatic variables. Of the nine predictor variables used to build our model, soil type, temperature annual range and precipitation of driest month emerged as the strongest range predictors. A combined map of the potential distribution of the seven Caesalpinioideae endemics indicated three high-endemism areas, hereby confirming previous suggestions in the literature (White, 1983; Cincotta et al., 2000; Olson et al., 2001; Mutke and Barthlott, 2005). Importantly, we found that the potential ranges of the Caesalpinioideae endemics are poorly covered by the existing Central African protected areas. Hence, our results suggest that the establishment of additional major protected areas in the region is needed in order to safeguard the endemic biodiversity of Central Africa against deforestation and other negative factors.

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