



Spatio-temporal dynamics of suitable habitats for *Detarium microcarpum* Guill. & Perr. (Caesalpinaceae), a priority food tree species in Benin (West Africa)

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Abstract

Detarium microcarpum (Caesalpinaceae) is a priority, multipurpose, and indigenous food tree species in West Africa. However, data related to its efficient conservation and sustainable use, through changing ecological environments, are still lacking. Thus, species occurrence records were combined with climatic and soil data in Maximum Entropy (Maxent), a species distribution modelling algorithm, to evaluate the impacts of future environmental conditions (under CNRM-CM5 and HadGEM2-ES) on the species' potential distribution in Benin. Results indicated that the species' present potential distribution range was mainly found in the Sudanian and Sudano-Guinean ecological regions. Some extensions and retractions of the present-day distribution (lowly, moderately and highly suitable habitats) were noted under future climates based on the two scenarios. Introduction of *D. microcarpum* in suitable habitats are required for its efficient conservation in West Africa.

Keywords Benin · Climate change · Sustainable management · *Detarium microcarpum* · Ecological niche modelling

Introduction

Plant genetic resources are important component of biodiversity, which is vital for food security and livelihoods improvement (Termote et al. 2010). Millions of Africans value plant non-timber forest products (NTFPs), to satisfy their daily needs for food, nutritional and health care products, domestic energy, and income generation (Cernansky

2015). These NTFPs are key component of any efficient forest management system (Goussanou et al. 2011; Akouèhou et al. 2014; Assogbadjo et al. 2017). Thus, integration of valuable NTFPs in productive agricultural spaces, has been recommended to sustain livelihoods of African's growing population and improve environmental quality (World Agroforestry Center 2008; Leakey 2010).

Detarium microcarpum Guill. & Perr. (Caesalpinaceae), is an indigenous food tree species, that provides locals in tropical Africa with food, medicinal, craft materials, etc. (Kouyaté and van Damme 2006; Adjahossou et al. 2016; Agbo et al. 2018). This species is found in various land use systems, where they are intensively exploited for livelihood improvement in Benin.

Overexploitation of timber and NTFPs is causing fragmentation and disturbance of tropical ecosystems. This pressure is increasing and is leading to isolation, decline, or even extinction of many valuable species' population (Adjahossou et al. 2016; Agbo et al. 2017). Moreover, climate changes are causing serious threat to biological resources (Ilmen and Benjelloun 2013). Increasing temperature and/or decreasing rainfall may modify extent and shape of species' suitable habitats; thus, inducing reduction of global species' diversity (IPCC 2007; Padonou et al. 2015). Projections indicate

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that 20–30% of plants and animal species will face great risks of extinction if global warming exceeds 1.5–2.5 °C in Africa (IPCC 2007; Busby et al. 2010). Therefore, diversity and global production of plant NTFPs are also expected to decline due to climate change manifestations (Idohou et al. 2017).

Ecological niche modelling (ENM), one of the most recent fields in geographic distribution assessment, has emerged as a powerful tool for understanding species' present-day distribution and anticipating future shifts in response to environmental changes (Peterson et al. 2011). In this field, maximum entropy modelling is the most used algorithm yielding excellent results in comparative tests (Pearson 2007; Elith et al. 2010). When dealing with climate research, the use of scenarios can help evaluate uncertainty about human contributions to climate change, adaptability of species and possible expansion or retraction of the suitable habitat (Peterson et al. 2011). Applying this algorithm in the case of *D. microcarpum* might give insight, regarding the design of appropriate conservation and development programmes.

Protected areas network have recently been recognized as one of the appropriate systems to sustainably conserve biological diversity (Marshall et al. 2012). However, as exploding demography causes increase in the needs of plant NTFPs, protected areas become vulnerable and their protection status is increasingly questionable (Castro et al. 2015). This calls for incorporation of species ecological niche modelling in spatial conservation plans to ensure effectiveness of protected areas for ensuring occurrence, survival and full accomplishment of plant species' life cycle.

This study aims at proposing sustainable management plan for *D. microcarpum* by answering the following three questions:

1. What is the geographical distribution of *D. microcarpum* in Benin?
2. Which environmental factors influence the species' geographical distribution under present-day and future climates?

3. How efficiently do protected areas network conserve the geographical distribution areas of *D. microcarpum*?

Methods

Study area

The study was conducted in the Republic of Benin (West Africa) which belongs to the so-called Dahomey gap ecological zone, where *D. microcarpum* naturally occurs (Agbo et al. 2018). The Dahomey gap is this abnormally drier and hotter ecological zone inside the Upper Guinean forest, where savannah ecosystems reach the seacoast, mostly on Benin and Togo (Nagel et al. 2003). Phytodistricts where the species occurs within the Sudanian and Guineo-Sudanian zones, were visited: Atacora chain, Mekrou-Pendjari, North Borgou, South Borgou, Bassila and Zou (Table 1). In the Sudanian zone, low rainfalls (< 1000 mm) and moderately high temperatures (24–31 °C) on a diversity of vulnerable soil types (hydromorphic, ferruginous, and lithosols) favor environmental degradation. This species also occurs in the sub-humid zone, with a bite higher rainfalls (1100–1300 mm) and lower temperatures (25–29 °C), on mostly ferruginous and ferrallitic soils (Adomou 2005). Both phytodistricts are suitable to a diversity of tropical savannahs, woodland, dry and gallery forests (Adomou 2005).

Sampling and data collection

Occurrence data

Field surveys were organized across the Sudanian and Sudano-Guinean phytodistricts, where the species' occurrence data were collected. A total of 189 occurrences were recorded, using a Global Positioning System (GPS). These occurrence data were supplemented by those downloaded from the Global Biodiversity Information Facility (GBIF: <http://www.gbif.org>). After checking the occurrences for

Table 1 Ecological characterization of the climatic zone of study area

Phytodistricts	Climatic zone	Rainfall regime	Rainfall (mm)	Major soil types	Dominant vegetation
Bassila	Guineo-Sudanian	Tendency to unimodal	Min: 1100	Ferrallitic soils with concretions and breastplates	Semi-deciduous forest, woodland, and riparian forest
Zou			Max: 1300		
South Borgou	Sudanian	Unimodal	Min: 1100	Ferruginous soils on crystalline rocks	Dry forest, woodland, and riparian forest
North Borgou			Max: 1200		
Atacora Chain			Min: 1100		
Mekrou-Pendjari	Max: 1200				
			Min: 900	Ferruginous soils with concretions on sedimentary rocks	Tree and Shrub savannahs, dry forest and riparian forest
			Max: 1000		

accuracy (Fig. 1), they were pre-processed in order to eliminate duplication within individual grid cells, using ENM-Tools (<http://www.ENMTools.com>; Warren et al. 2010).

Environmental data

In this study, we used bioclimatic data, from the WorldClim database (<http://www.worldclim.org>) at a spatial resolution of 30 arc sec (1 km²). These bioclimatic data are the 19 climatic variables generated (Table 2) from raw climate data (precipitation and temperature) that significantly influence geographical distribution of the plant species (Wembou et al. 2017). As soil provides environmental physical support to plant species and remains important factor for the geographic distribution in the tropics tree species (Linder et al. 2005), additional soil layers were imported from Harmonized World Soil Database, version 1.2 (FAO/IIASA/ISRIC/ISSCAS/JRC 2012). The layers used were cation exchange capacity (cec) at different horizons: 0–5 cm (cec1), 5–15 cm (cec2), 15–30 cm (cec3), 30–60 cm (cec4), 60–100 cm (cec5); clay content (clay) at different horizons: 0–5 cm (clay1), 5–15 cm (clay2), 15–30 cm (clay3), 30–60 cm

Table 2 The climatic variables used in the modelling. (<http://www.worldclim.org/bioclim>)

Code	Bioclimatic variables
BIO 1	Annual average temperature
BIO 2	Average daytime deviation (maximum temperature - minimum temperature, monthly average)
BIO 3	Isothermality (BIO1/BIO7) × 100
BIO 4	Temperature seasonality (coefficient of variation)
BIO 5	Maximum temperature of the hottest period
BIO 6	Minimum temperature of the coldest period
BIO 7	Annual temperature deviation (BIO5–BIO6)
BIO 8	Average temperature for the wettest quarter
BIO 9	Average driest quarter
BIO 10	Average temperature of the warmest quarter
BIO 11	Average temperature of the coldest quarter
BIO 12	Annual precipitation
BIO 13	Precipitation from the wettest period
BIO 14	Precipitation of the driest period
BIO 15	Seasonality of precipitation (coefficient of variation)
BIO 16	Wettest quarter precipitation
BIO 17	Precipitation of the driest quarter
BIO 18	Precipitation of the hottest quarter
BIO 19	Precipitation of the coldest quarter

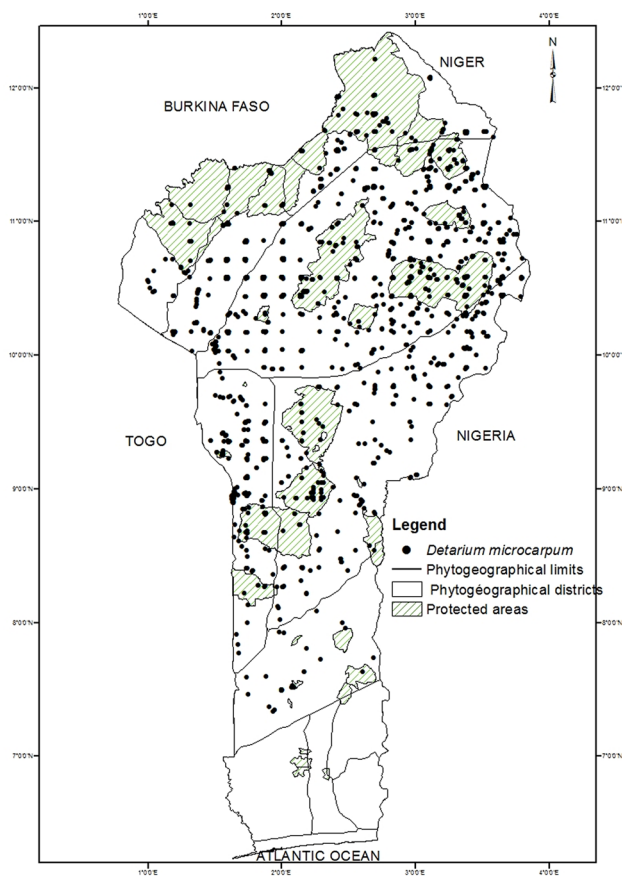


Fig. 1 Geographic distribution of *D. microcarpum* occurrence across Benin included in this study

(clay4), 60–100 cm (clay5); organic carbon content (oc) at different horizons: 0–5 cm (oc1), 5–15 cm (oc2), 15–30 cm (oc3), 30–60 cm (oc4), 60–100 cm (oc5); pH (ph) at different horizons: 0–5 cm (ph1), 5–15 cm (ph2), 15–30 cm (ph3), 30–60 cm (ph4), 60–100 cm (ph5); sand content (sand) at different horizons: 0–5 cm (sand1), 5–15 cm (sand2), 15–30 cm (sand3), 30–60 cm (sand4), 60–100 cm (sand5); and silt content (silt) at different horizons: 0–5 cm (silt1), 5–15 cm (silt2), 15–30 cm (silt3), 30–60 cm (silt4), 60–100 cm (silt5).

Data analysis

Modelling and validation of the model

Bioclimatic variables were used in a Jackknife test, using MaxEnt 3.3.3k (Phillips et al. 2006), in order to determine those contributing the most to the distribution modelling (Padonou et al. 2015). Fifty percent of the species' presence points were used to evaluate the model and 50% to validate it (Idohou et al. 2017). Each model was repeated five times to produce robust model performance estimates. The performance of the model was evaluated using Partial ROC procedure. In light of criticisms on the AUC metric, we used a recently proposed modification named Partial ROC (Peterson et al. 2008). ROC analysis is a method designed to evaluate the specificity (absence of commission error) and

sensitivity (absence of omission error) of a diagnostic test (Fielding and Bell 1997). Partial AUC values are presented as a ratio between the AUC (with modified x -axis, from traditional applications) and the null expectation of AUC. The replicate type with the highest AUC ratio was chosen for modelling the ecological niche of the species.

To assess potential impacts of climate changes on the species distributions, we transferred present-day model to two future climate models namely HadGEM2-ES and CNRM-CM5, recently used for West Africa (Idohou et al. 2017). These climate models with relatively drastic views of future conditions are based on the representative concentration pathway (RCP) 8.5 for the 2050-time horizon.

Mapping and spatial analysis

Outputs produced by the models were imported into ArcGis 10.3 software (ESRI 2014) to classify the different suitability levels for *D. microcarpum* from the logistic probability thresholds of presence ranging between 0 and 1. Three habitat suitability classes were defined across the geographical study zone: areas with probability below the threshold of 0.23 considered as of low suitability, those with probability between 0.23 and 0.45 that are of medium suitability, and those between 0.45 and 1, representing high suitability areas for *D. microcarpum* (Saupe et al. 2012). Using the ArcGis spatial analyst tool, the extent of each habitat suitability level, under both present-day and future conditions (time horizon 2050) was calculated.

In order to assess effectiveness of protected areas in the conservation of the species under current and future conditions, a gap analysis was carried out by superimposing the national protected areas network of Benin to the distribution maps obtained and suitable areas present in protected areas were calculated.

Results

Contribution of environmental variables and validation of the model

A total of seven climatic and soil layers mostly contributed to the model: average daytime deviation (BIO2), isothermality (BIO3), minimum temperature of the coldest period (BIO6), annual precipitation (BIO12), wettest quarter precipitation (BIO16), precipitation of the driest quarter (BIO17) and cation exchange capacity at 5–15 cm horizon (Cec2) (Table 3). The Jackknife test showed that the environmental variables that significantly increased the gain of information explaining the distribution of *D. microcarpum* when used in isolation were BIO16, followed by Cec2

Table 3 Contribution of seven (07) selected environmental variables

Variable	Contribution (%)
Wettest quarter precipitation	37.2
Cation exchange capacity (5–15 cm horizon)	23.8
Precipitation of the driest quarter	15.5
Minimum temperature of the coldest period	10.6
Annual precipitation	6.7
Average daytime deviation	3.8
Isothermality (BIO1/BIO7) \times 100	2.6

(Fig. 2). Then, soil and precipitations remain the variables that hold more information not contained in the others.

The AUC ratio frequency from the distribution of null values according to the Partial ROC procedure among the five (05) replicates, clearly showed that the AUC ratio is above 1 which implies that the model has excellent performance (Fig. 3).

Present-day and future suitable areas for the conservation of *D. microcarpum* in Benin

The model showed that current suitable habitats for *D. microcarpum* were mainly located in the Sudanian and Sudano-Guinean climate regions, precisely in Atacora Chain, Bassila, North Borgou, South Borgou, and Zou phytodistricts. Low suitable areas were located within the Mekrou-Pendjari phytodistrict and those in the southern part of Benin (Plain, Oueme valley, Pobe and Coastal phytodistrict) belonging to the Guineo-Congolese climate regions (Fig. 4). For future projections by 2050, the CNRM-CM5 and HadGEM2-ES models showed slight variations in habitat suitability levels. In general, there is an expansion of very highly suitable habitats for the species and consequently, a decrease of habitats that are of medium suitability and of low suitability. Nonetheless, the trend remains broadly the same.

Assessment of the change in suitable habitat for *D. microcarpum* revealed that approximately 22,371.08 km² (19.86%) of Benin's national territory, distributed from north to south (not included) the islands on the Niger River: 11.262 km² were currently very suitable to *D. microcarpum* (Table 4). Medium suitability and low suitability areas occupied respectively 58,507.15 km² (51.95%) and 31,743.77 km² (28.19%) of Benin territory. With the future bioclimatic projections by 2050, the CNRM-CM and HadGEM2-ES models project a slight increase of 5.6% and 8.8% respectively of the currently very suitable areas but predicted a slight decrease in medium and low suitability ecological niche of the species.

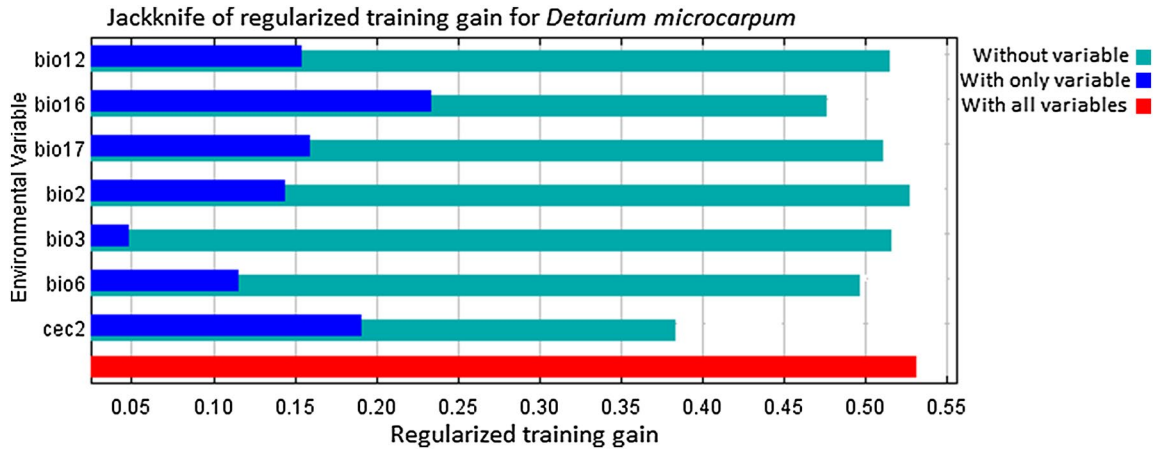


Fig. 2 Jackknife test result on contribution of models

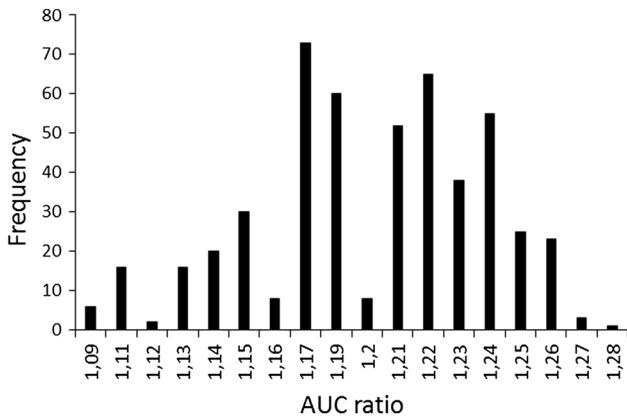


Fig. 3 Diagram showing the variation of the AUC ratio according to the Partial ROC procedure for *D. microcarpum*

Dynamics of suitable habitats of *D. microcarpum* present in protected areas of Benin

The Table 5 showed the distribution of populations of *D. microcarpum* in relation to protected areas in Benin. Assessment of the protected areas network to conserve the suitable areas for the species revealed that 25.25% of protected areas (approximately 5972.63 km²) is currently very suitable for the conservation of suitable areas for *D. microcarpum* (Table 6; Figs. 5, 6). Protected areas of the North Borgou, South Borgou and Bassila phytodistricts have a higher level of suitability for the conservation of *D. microcarpum* compared to those of the other three phytodistricts.

Effectiveness under future projections indicated a slight increase in habitats currently highly suitable for the conservation of *D. microcarpum* in protected areas network in Benin. On the other hand, these models project a decrease in habitats that are moderately suitable for the conservation of *D. microcarpum* in protected area.

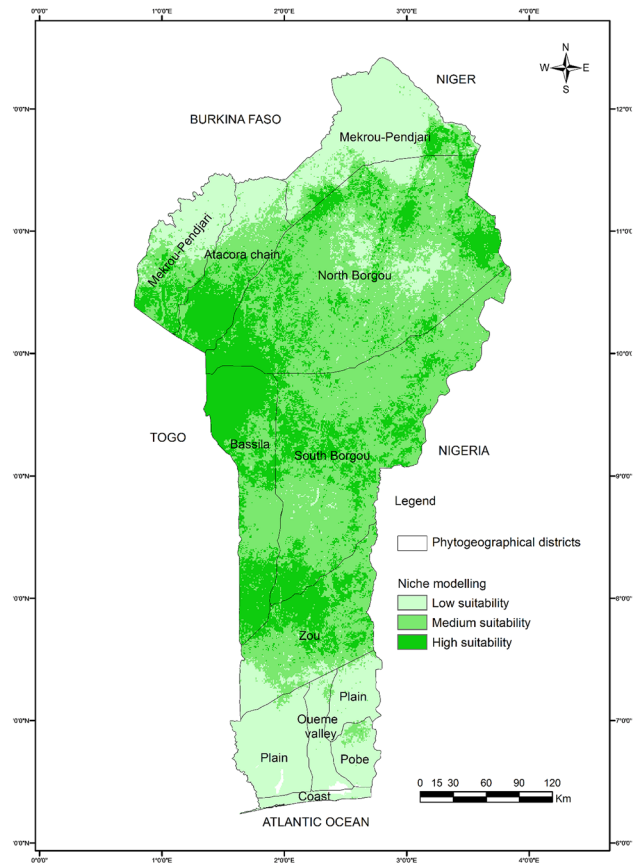


Fig. 4 Map showing the present-day suitable habitats of *D. microcarpum* in Benin

This decrease varies from -4.04% (for the CNRM-CM5 model) to -10.28% (for the HadGEM2-ES). The models project an increase in habitats that are poorly suitable for the conservation of *D. microcarpum* at the level of protected area networks according to the two models

Table 4 Dynamic of suitable areas for *D. microcarpum* for the present and the two future models in Benin

	Low suitability		Medium suitability		High suitability	
	Area (km ²)	Trends (%)	Area (km ²)	Trends (%)	Area (km ²)	Trends (%)
Present	31,743.77	28.19	58,507.15	51.95	22,371.08	19.86
CNRM-CM5	29,912.58	26.56 (− 1.63) ^a	54,035.16	47.98 (− 3.97) ^a	28,674.26	25.46 (+ 5.6) ^a
HadGEM2-ES	28,724.07	25.50 (− 2.69) ^a	51,623	45.84 (− 6.11) ^a	32,274.93	28.66 (+ 8.8) ^a

^aPercentage of change in future suitable habitat relative to suitable habitat present

Table 5 Distribution of populations of *D. microcarpum* in relation to protected areas in Benin

Protected areas	Coordinates		Phytogeographic districts	Ecological regions
	Lat. N	Long. E		
Monts Kouffés Forest	8°36.667'	1°40.691'	Bassila	Sudano-Guinean
Penessoulou Forest	9°16.214'	1°33.418'		
Bassila Forest	8°57.805'	1°39.095'		
Sérou Forest	9°40.445'	1°41.673'		
Dassa Forest	7°48.352'	2°10.954'	Zou	
Atchérigbé Forest	7°31.037'	2°05.459'		
Ouémé-Boukou Forest	7°57.564'	2°28.336'		
N'Dali Forest	9°44.518'	2°41.821'	South Borgou	
Ouémé supérieur Forest	9°45.362'	2°24.629'		
Parakou Camp Forest	9°20.206'	2°36.925'		
Three Rivers Forest	10°30.464'	3°33.173'	North Borgou	Sudanian
Kandi Forest	11°05.820'	2°59.740'		
Sota Forest	11°03.179'	3°03.811'		
Mékrou Forest	10°16.668'	1°48.376'		
Ouénou-Bénou Forest	10°12.824'	2°39.574'		
W National Park	11°30.346'	3°06.257'	Mekrou-Pendjari	
Goun-Goun Forest	11°39.939'	3°11.739'		
Guéné Forest	11°41.211'	3°12.363'		
Birni Forest	10°01.023'	1°30.005'	Atacora Chain	
Pendjari National Park	11°25.301'	1°30.115'		

Table 6 Dynamic of suitable areas for *D. microcarpum* in protected area for the present and the two future models in Benin

	Low suitability		Medium suitability		High suitability	
	Area (km ²)	Trends (%)	Area (km ²)	Trends (%)	Area (km ²)	Trends (%)
Present	6290.41	26.60	11,387.56	48.15	5972.63	25.25
CNRM-CM5	7864.04	33.25 (+ 6.59) ^a	8955.90	37.87 (− 10.28) ^a	6830.66	28.88 (+ 3.63) ^a
HadGEM2-ES	7598.57	32.13 (+ 5.53) ^a	10,433.83	44.12 (− 4.04) ^a	5618.22	23.75 (− 1.5) ^a

^aPercentage of change in future suitable habitat relative to suitable habitat present

(Table 2; Figs. 3, 4). Main protected areas are the W and Pendjari national parks located in the phytodistricts Atacora Chain and Mekrou-Pendjari in Benin.

Discussion

Contribution of environmental variables and performance of the model

Results of this study showed that the seven ecological variables used for the prediction of *D. microcarpum* ecological niche are climatic and edaphic variables. This implies that the distribution of *D. microcarpum* is influenced by

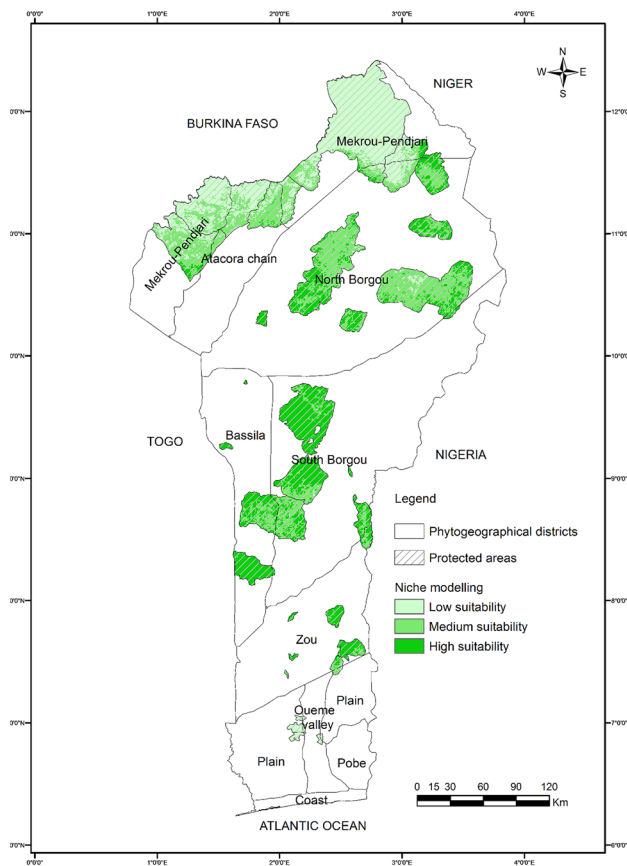


Fig. 5 Map showing the present-day suitable habitats of *D. microcarpum* present in protected areas in Benin

both climatic and edaphic factors. This result is corroborated by the work of several other authors who have shown that climate and soil constitute main factors shaping the distribution of forest species globally (do-Régo 2017; Idohou et al. 2017; Bourou 2012). Indeed, the edaphic variables have a physiological effect on the development of plants and orient the distribution of the latter according to their ecological requirements. Thus, the integration of these soil-related variables in modelling makes these models more functional and more accurate. However, in spite of the impact of soil variables on the determination of species-friendly zones and their importance to forest composition, these variables are sometimes not integrated in some models (Coudun et al. 2006).

Overall, the model performed well in predicting suitable conditions for each species. For the species, the distribution of AUC ratios was well above 1.0. As such, the model was judged as statistically significantly better than random.

Suitability of the habitats for the species conservation

Climate projections for future periods as determined by the CNRM-CM5 and HadGEM2-ES scenarios indicated that the areas suitable to the development of *D. microcarpum* would increase in 2050. This increase in the distribution area of *D. microcarpum* in Benin to the 2050 horizon could be explained mainly by the projected increase in rainfall. These results are consistent with those obtained by Gouwakinnou (2013) on *Sclerocarya birrea* (Anacardiaceae), Fandohan et al. (2013) on *Tamarindus indica* (Caesalpiniaceae) and Sodé (2013) on *Dialium guineense* (Caesalpiniaceae) but are contrary to those of Ayihouénu et al. (2016) on *Parkia biglobosa* (Mimosaceae). Therefore, the idea that climate change could change the range of plant species as suggested by several studies (van Zonneveld et al. 2009; Gouwakinnou 2013; Bourou 2012; Fandohan et al. 2013) seems to be confirmed.

Protected areas are reserves that still favor the conservation of biodiversity (Houinato et al. 2001). It is often reported that a species present in a protected area has a high probability of survival without further intervention and management measures once the protected area is adequately managed (Heywood 2008; Agbo et al. 2017). Assessment of the relationship of *D. microcarpum* distribution to protected areas showed good potential of current protected areas to conserve populations of each species. In addition, our future projections revealed some increase in the protected areas suitability. This confirms the effectiveness of the protected area system in conserving this species, as demonstrated by the work of Adjahossou et al. (2016) who affirmed that sacred and classified forests play a major role in the conservation of forest tree species. According to these authors, *D. microcarpum* is one of the valuable species in Benin whose conservation of suitable habitats is ensured in part by protected areas, in particular in the Sudanian and Sudano-Guinean zones.

Implication of the study for the in situ conservation of *D. microcarpum*

The study of the distribution of forest species like *D. microcarpum* is of major importance for the knowledge of their habitats requirements to plan adequate management strategies for the species countrywide. The distribution map of *D. microcarpum* showed that the species is widely distributed in Benin. This finding suggests that *D. microcarpum* is a species adapted to different soil types in dry forests, shrub and wooded savannas. As a matter of fact, the species could be used for restoration or reforestation programs using native species. However, only the Sudanian and Sudano-Guinean climatic regions remain

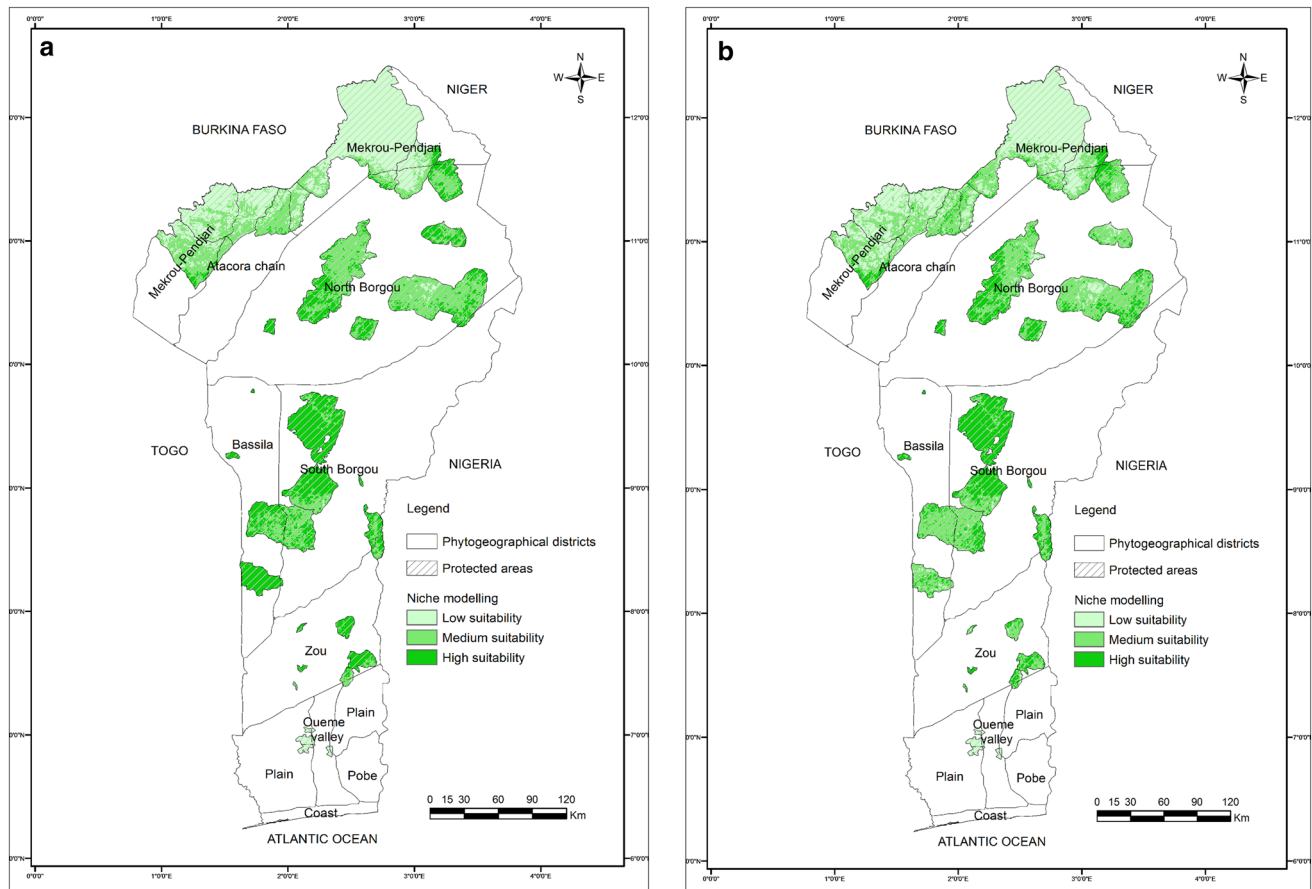


Fig. 6 Map showing suitable future habitats (Horizon 2050) of *D. microcarpum* occurring in protected areas of Benin under **a** CNRM-CM5 and **b** HadGEM2-ES

overall present-day and future suitability habitats to the development of *D. microcarpum* and can serve as a sustainable conservation zone for this species in Benin. We note that there is a distribution according to the climatic region since the species is not present in the southern part of the country (Guineo-Congolese region). This could be explained by the difference in climatic conditions from one biogeographical region to another; the Sudanian and Sudano-Guinean region with relatively high average temperatures with low precipitation compared to the Guineo-Congolese region (Bowe 2007; Fandohan et al. 2010; Bowe and Haq 2010). *D. microcarpum* is a species of dry zone (Cavin 2007; Kouyaté and Lamien 2011).

Any action to protect and safeguard a plant genetic resource requires the implementation of rational and participatory management policies by local communities and the in-situ conservation of this plant species in the suitable habitats to its culture and development (Luque and Vainikainen 2008; Norris et al. 2010). Thus, this study, which allowed to know the suitable areas for conservation of *D. microcarpum* thanks to a powerful tool of modelling is very important for the conservation of this species in Benin. Moreover, the

occurrences collected on *D. microcarpum* constitute a crucial base for subsequent studies.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests in this manuscript.

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