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Density and spatial pattern of *Parkia biglobosa* under climate change: the case of Benin

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Abstract: Parkia biglobosa (locust bean) is an indigenous species which, traditionally contributes to the resilience of the agricultural production system in terms of food security, source of income, poverty reduction and agro-ecosystem stability. Therefore, it is important to improve knowledge on its density, current and future spatial distribution. The main objective of this study is to evaluate the tree density, the climate change effects on the spatial distribution of the species in the future for better conservation. The modeling of the current and future geographical distribution of the species was based on the principle of Maximum Entropy (MaxEnt) using a total of 286 occurrence points from field work and the Global Biodiversity Information Facility GBIF-Data Portal. Two climatic models (HadGEM2_ES and Csiro_mk3_6_0) were used under two scenarios RCP 2.6 and RCP 8.5 for the projection of the species distribution at the horizon 2050. Correlation analyses and Jackknife test helped to identify seven variables which are less correlated ($r < 0.80$) with highest contribution to the model. Soil, annual precipitation and temperature (diurnal average Deviation) are the variables which have mostly contributed to the models. Currently, 53% of national territory of Benin, spread from north to south is very suitable for *P. biglobosa*.
At the temporal horizon 2050, the scenarios have projected loss of habitats, which are currently very suitable for *P. biglobosa*. 51% and 57% are the highest proportions of this habitat lost, which has been registered with HadGEM2_ES model under two scenarios. In order to limit damages such as decreased in productivity and extirpation, some appropriate solutions must be found. It is important to plan the introduction of *Parkia biglobosa* in reforestation programs and the protection of its potential habitat at national level by the forestry administration which is an asset for a better conservation of this significant NTFP.

Keywords: Benin, locust bean, climate change, MAXENT, scenario RCP.

Introduction

During the past 30 years, the whole world has experienced the climate change through the increase of temperature and the decrease of rainfalls, with West Africa being among the most affected regions (Lugina *et al.,* 2006). Guibert *et al.,* (2010) showed that conventional analysis of rainfall sequences, temperature and wind speed, confirms increase of both maximum and minimum temperatures, but they do not allow to mark the difference in rain distributions, nor they are able to describe the violent winds increasing in north Benin. Fluctuations of climatic conditions are nowadays acknowledged as one of the main threats to food supply systems, integrity of ecosystems, and survival of species, (Fandohan *et al.,* 2013). This brings environmentalists and decision makers to carefully design actions to be taken with regard to the planning and the diversification of agricultural production, as well as the conservation of the species. Indeed, it is quite possible that the variations of climate parameters such as temperature and precipitation may have an impact on the biological diversity and on the geographical distribution of the suitable habitats of the species (IPCC, 2007). It is expected that by 2085, with global warming exceeding 1.5°C to 2.5°C, Africa could lose 90% of native environments for many plants and animals (IPCC, 2007; Busby *et al.,* 2010). This would result in greater extinction risks for 20 - 30% of plant and animal species. To cope with such a drastic change, production and conservation schemes would have to focus on resources that are the most likely to withstand project changes in the climate (Fandohan *et al.,* 2013).

Agroforestry Fruit Tree (AFT) species are very important in terms of their contribution to health care, energy power, monetary income and other aspects of human well-being (Teklehaimanot, 2004; Mahapatra *et al.,* 2005). Local populations maintain a multitude of virtual and intimate relationships with forest ecosystems, principally through the gathering of edible fruits from AFT species. In Benin, over 814 medicinal plant species including 128 AFT species have been identified as highly valued phytogenetic resources by the rural populations (Sinsin and Owolabi, 2001). AFT species are increasingly seen as a good opportunity for African crop production systems to achieve several millennium development goals (Leakey *et al.*, 2005; Fandohan *et al.*, 2011) and to withstand climate change (Fandohan *et al.*, 2013). However, they could also be severely affected by the projected changes in the climate (Fandohan *et al.*, 2015). In this context, it is important to foresee how climate change may impact range of suitable areas for cultivating and/or conserving AFT species with high domestication potential (Fandohan *et al.*, 2013). The growing interest on potential impact of climate change on AFT species has yield substantial information. Most previous works have projected that climate change could rather shrink or extend range of suitable areas for some AFT species such as *Tamarindus indica, Sclerocarya birrea, Chrysophyllum albidum* (Gouwakinnou *et al.,* 2011; Fandohan *et al.*, 2013 ;

Gbesso *et al.,* 2013). Overall, climate change could drive a species specific spatial dynamic of range of suitable habitats (Fandohan *et al.,* 2013). Increasing efforts towards modelling impact of climate change on AFT species could unearth specificities with regards to each species and help better select species that are the most likely to withstand climate changes for future conservation and crop production programs (Fandohan *et al.*, 2015). A recent development of statistical techniques and geographic information systems allows envisaging much more satisfactory species distribution models (Elith and Leathwick, 2009). These models will contribute in either case to a better understanding of the species ecology and a more reliable prediction. Likewise, in our study, Species Distribution Models (SDMs) is combined with density data to examine the links between current/future distribution and density of *Parkia biglobosa*. We hypothesize that as temperature rises and precipitation changes, owing to climate change, some areas in Benin might become less suitable for *P. biglobosa*; its density would represent a significant index to describe its ability to acclimatize. Therefore, relating density to future species distributions, suitable areas for conservation and domestication management strategies will be identified. The general objective of study is thus to contribute to the climate change risk assessment on the spatial distribution of *P. biglobosa* according to the climatic scenario in 2050, and to highlight future favourable habitats to its conservation in Benin.

Materials and Methods

Study area

This study was conducted in Republic of Benin, located between the parallels 6° 30' and 12° 30'of latitude North and the meridians 1° and 3° 40' of longitude East (figure 1) with an area of 114,763 km^2. The climate is tropical or sub-tropical, characterized by two seasons in the North (one rainy season and one dry) and four seasons in the South (two rainy seasons and two dry seasons). The study area includes ten (10) phytogeographical districts that differ from one to another, not only by their environmental conditions such as climate, soils and vegetation (Adomou *et al.*, 2006) but also by human traits and various socio-cultural groups that do several activities like agriculture, breeding, fishing, hunting and handicraft.

Study species

Parkia biglobosa is a species of Soudanian savannah and of Mimosoïdeae sub-family and family of Fabaceae. Its natural occurrence area covers a large region that expands from Senegal, in the West, to Uganda in the East, and encompasses Soudanian and Soudano-Guinean zones. The species is of a great importance in the traditional agro-forestry systems in its occurrence

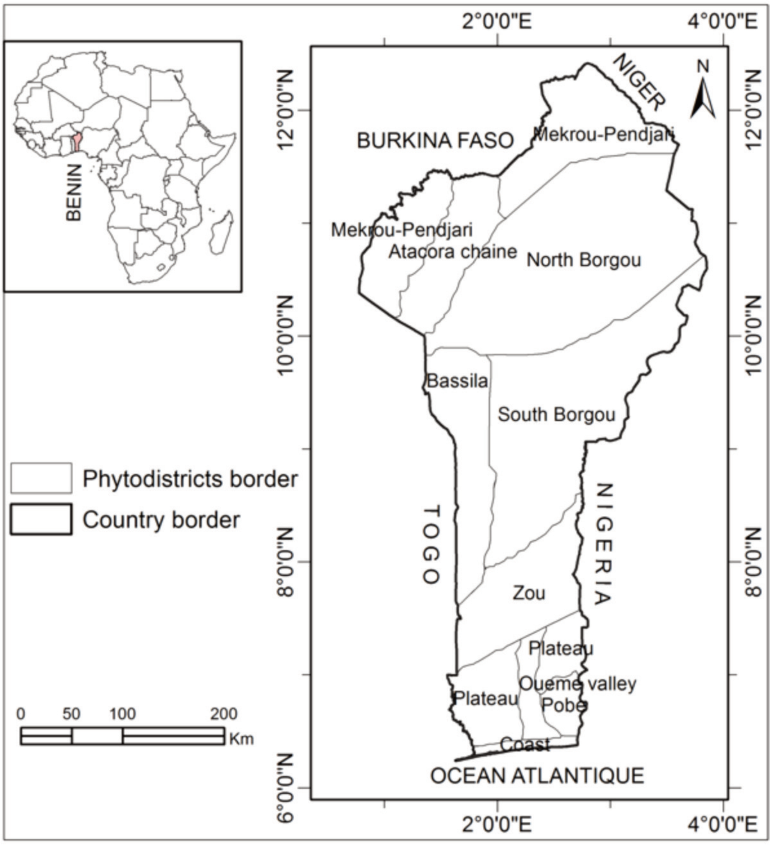

Figure 1 - Location of study area showing phytogeographical districts

area, and has high economic potential. For the local populations of Benin, *P. biglobosa* is a species used essentially for food, medicinal, cultural, economic and magico-therapeutic purposes (Koura *et al.*, 2011). The pulp and fruits of *P. biglobosa* are amino-acid-rich and constitute a good source of protein that could be used in food.

Data collection

To collect data on trees density, the number of individuals of *P. biglobosa* was noted in 4 hectares plots from the two main zones of species: Soudano-guinean zone-and Soudanian zone. Six (6) plots were established in each ecological region and all *Parkia biglobosa* trees with DBH superior or equaling 5 cm were inventoried. In Guinean zone, because of the scarcity of species, no plot was installed. For each plot, tree density was computed using the equation (1) below, and then, the mean density was calculated for each

$$Ni = \frac{ni}{S}$$

Where
Ni is the density in the plot *i*;
ni is the number of individuals observed in the plot *i*
S is the area of 4 hectares

Geographic coordinates of *P. biglobosa* occurrence points, which were used in this study, were collected through field work, carried out in the agroforestry systems of the 77 administrative districts of Benin. To obtain a good accuracy of modeling results, the occurrence of the studied species should cover the most possible area where it is influenced by the same climatic factors (Fitzpatrick *et al.,* 2009). This area is known as background where additional occurrence of species is recorded and pseudo-absence are selected during modeling process (Philips et *al*., 2009). In this study, occurrences of *P. biglobosa* out of Benin but in areas covered approximately by the same climatic conditions have been collected as additional data throughout its occurrence area in west Africa by exploring the database of GBIF (*Global Biodiversity Information Facility*: www.gbif.org).

The current and future climate data were downloaded from the site of Wordclim (www.worldclim.org) to predict the suitable conditions for *Parkia biglobosa* (Elith *et al*., 2006). The current climatic data obtained from Worlclim web site are derived from interpolation of average monthly, maximum and minimum of temperature and rainfall, considering the historical series 1950-2000 (Hijmans *et al.,* 2005). Using Arcgis 10.1, nineteen (19) bioclimatic variables were processed and saved in format consistent with Maximum Entropy Modeling (MaxEnt) tool used in this study. The latter is enable to estimate the distribution probability of the species by simulating the most uniform distribution (Maximum Entropy) and the nearest to the model (Philips *et al.*, 2006).

Regarding future climatic projections, two Global Circulation Models (GCMs) have been used (Brands *et al*., 2013): HadGEM2-ES (*Met Office climate model*) and Csiro_mk3_6_0 (*Commonwealth Scientific and Industrial Research Organization*). These models provide a global representation of system climatic and constitute the ones among the most-used models currently available for simulating the global climate response to increasing greenhouse gas concentration. Climatic models are research tools for the study and simulation of climate and are also useful for operational purposes, especially for monthly and seasonal climatic previsions. Projections run by 2050 under two IPCC-scenarios (IPCC) about the Fifth Assessment Report (AR5): Representative Concentration Pathway (RCP) 2.6 and 8.5. These scenarios are used of preference because, in particular, the RCP 8.5 as an extreme scenario is the most pessimistic in terms of gas emission. Its temperature increase is a little stronger than the old SRES A2 scenario, which has been qualified as best and it is the most-used. The RCP 2.6 scenario is instead the most optimistic in terms of reduction of temperature. Without ambiguity with the old propositions of IPCC, it takes into account the effects of emissions reduction that are likely to limit the planetary warming to 2°C (Meinshausen *et al.,* 2011). All climatic layers used in this study have a cell size of 2.5-minute grid (spatial resolution of approximately 4.62 * 4.62 Km) in West Africa region. Strictly, bioclimatic models are often used to forecast the suitable habitats for *Parkia biglobosa* since climate is the principal factor conditioning ecological niche at large scale like continent (Parviainen *et al.,* 2008). However, environmental factors (direct and indirect) act differently according to the modeling scale. While direct factors, i.e those that have physiological effect on the species (e.g. temperature, rainfall or sunshine) are determinant at large scale (e.g. regional scale), other environmental factors (e.g. soil, altitude and landcover) could be also determinative at small scale (Guisan and Zimmerman, 2000). Pearson *et al.,* (2003) proposed to take into account for soil factors when the study area extends on a distance inferior to 2000 km. As such, data on soil type are combined to bioclimatic data to refine results (Faure *et al.,* 1998).

Modeling and models validation

Various statistical methods are used to model plant species distribution or to estimate the probability of presence/absence of a given plant species at a given geographical location (Guisan *et al.,* 2000). MaxEnt (*maximum entropy modeling*) constitutes one of modeling methods the most powerful that is likely to generate good bio-geographical information by offering a good discrimination of suitable and non-suitable areas for a plant species (Phillips *et al.,* 2006). It applies the principle of maximum entropy to the plant species presence-only data. It estimates both a set of functions that relate environmental variables to habitat suitability and the potential geographical distribution of a plant species (Philips *et al.,* 2006). The interest of this method for the study is that it combines presence data of a given plant species with current bioclimatic characteristics coming from observations points. It is able to generate: (i) a map of potential habitat suitability of the plant species in the considered area, and (ii) a map of future suitable habitats distribution according to the projected climatic conditions. Moreover, Maxent is prone to overfitting, resulting in predicted distributions that are clustered around location points. Therefore, a relaxation component, called regularization, has been added to Maxent to constrain the estimated distribution thereby allowing the average value of each sampled variable to approximate its empirical average but not equal it. This regularization component can be adjusted for each sampling area (Philips *et al.,* 2006). The MaxEnt has been used in this study to estimate *P. biglobosa* habitats suitability for current conditions and future projections of climatic scenarios. In total, 286 occurrence points of *P. biglobosa* have been used (Figure 2). Bioclimatic variables have been submitted to a correlation test with Environmental niche modeling tools (ENMtools) (Warren *et al.*, 2010) to select those less correlated (r < 0.80) because of the bias that correlations could induce on future projections (Elith *et al.,* 2011). A Jacknife test has been performed on considered bioclimatic variables to determine those that best contribute to the models projections. To validate models outputs, 20% of occurrence points of *P. biglobosa* were used, where as 80% was used for models calibration. Models are cross-validated using five replicates runs by averaging their results. The predictive power of model has been assessed by computing the average value of AUC (*Area Under the Curve*) and TSS (*True Skill Statistics*). A model is said to be of good quality if the AUC value is greater than 0.90 (Swets, 1988). A TSS measures the capacity of the model to accurately detect true presences (sensitivity) and true absences (specificity).

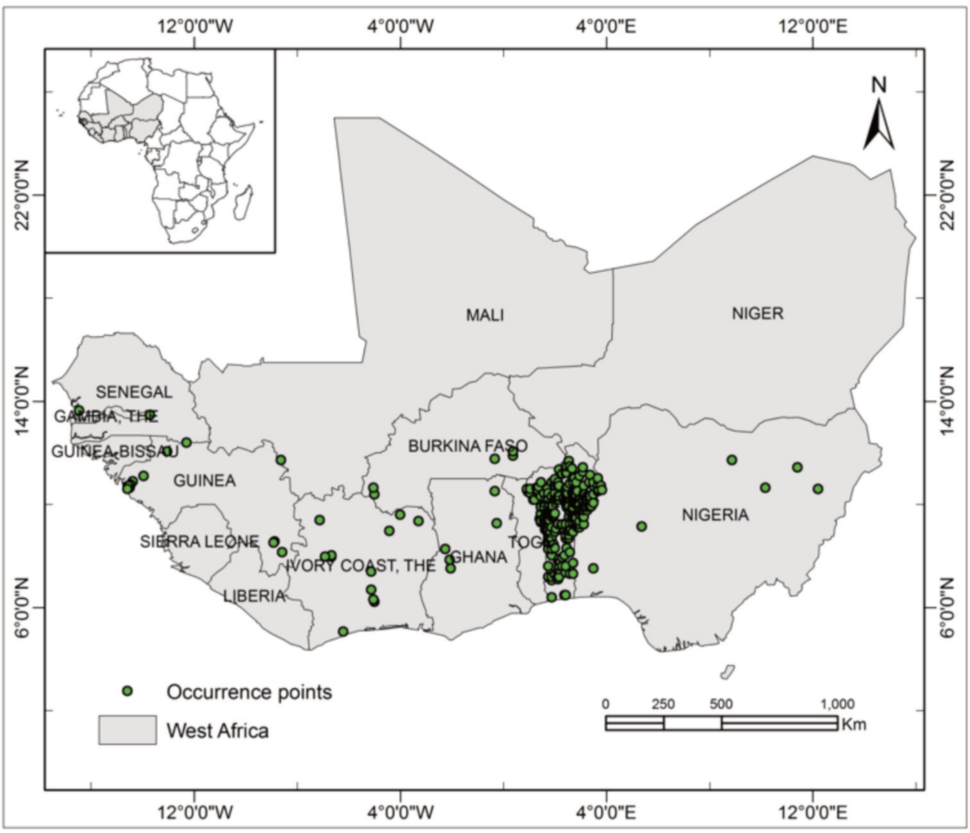

Figure 2 - Geographical distribution of occurrence points used for modeling.

A TSS ≥ 0 indicates a random prediction while a value close to 1 (TSS > 0.5) suggests good predictive power (Allouche *et al.,* 2006).

Data Analysis

Models validation: MaxEnt outputs were processed in Argis 10.1 to the map suitable areas of the species for both current and future climatic conditions. The logistic probability value generated by MaxEnt has been considered as indicator of quality of habitats suitability of the species. For an occurrence probability inferior to « *maximum training sensitivity and specificity threshold* » value, the habitat is considered as poorly suitable for *P. biglobosa;* between this value and the « *10 percentile logistic threshold* », the habitat is said to be moderately suitable and probability above the last value is deemed to be highly suitable for cultivation and conservation of *P. biglobosa.* The area of each suitability habitat type was estimated using the « *spatial analyst*» tool of Argis 10.1 (Martínez *et al.,* 2006). Then, the proportion of current highly suitable habitats that are likely to become poorly suitable in the future and *vice versa* was estimated for each climatic model and scenario.

Results

Density analysis

A significant difference in density was observed in both agro-ecological zones (Figure 3). The density is highest in the North comparatively the South.

Variables contribution and model validation

The results from correlations analysis and Jacknife test permitted to identify seven (7) less correlated variables (r < 0.80) considered for the modeling. Soil, annual precipitations (bio12), mean diurnal range: max temp – min temp (monthly average) (bio2), isothermally (bio3) and precipitations seasonality (bio19) are variables that have mostly contributed to the models (Table 1 and Figure 3). The environmental variable that decreases the gain the most when it is omitted from the model is the soil. It had also the highest gain of all bioclimatic variables when fitted in the model in insolation and therefore appears to be having the most informative variable (figure 3). The TSS value is 0.77 with a standard deviation of 0.04. This value denotes a very good predictive power of models to predict the geographical distribution of the suitable habitats for cultivation and conservation of *P. biglobosa.* The AUC value is 0.92 with a standard deviation of 0.015 and a projection significantly different from a random projection (p < 0.0001; one-sided binomial test); this confirms a very good

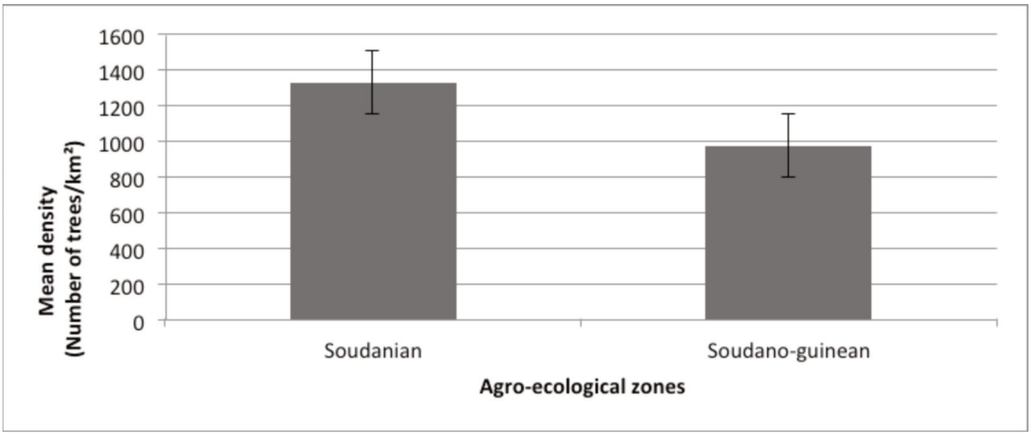

Figure 3 - Variation in tree density in different agro-ecological zones (showing standard error).

capacity of model to predict habitats suitability for *P. biglobosa*. The probabilities threshold values used for defining habitats suitability are respectively 0.3 and 0.5 for the *Maximum test sensitivity and specificity logistic threshold* and *10 percentile training presence logistic thresholds.*

For each environmental variable, the green bar that represents *without variable* in the Jacknife test of regularized training gain, shows how much the total gain is decreased if this specific variable is excluded from the analysis. On the contrary, the blue bar representing *with only variable* shows the obtained gain if the considered variable is used in isolation and the other ones are excluded from the model.

Table 1 - Bioclimatic variables used and them contributions to the model.

VARIABLES	NAME OF VARIABLES	VARIABLE CONTRIBUTION IN PERCENT
SOIL		60
BIO2	Mean diurnal range (max temp – min temp) (monthly average)	8.8
BIO12	Annual Precipitation	13.8
BIO3	Isothermality (BIO1/BIO7) * 100	8
BIO19	Precipitation of Coldest Quarter	6.7
BIO17	Precipitation of Driest Quarter	1.5
LANDCOVER		1.2

Bio1: Average annual temperature
Bio7: Annual temperature difference

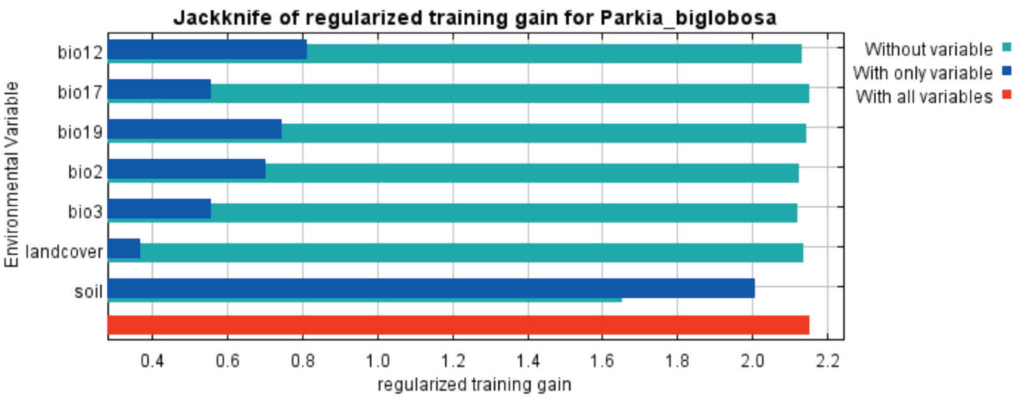

Figure 4 - Jacknife test on importance of individual variables in models calibration.

Current suitable habitats distribution and projections by 2050 of suitable habitats for cultivation and conservation of* P. biglobosa *in Benin under climatic scenarios

From the spatial analysis results, it comes out that about an area of 60,000 km^2, corresponding to about 53% of Benin (114,763 Km^2) are currently very suitable to the cultivation and conservation of *P. biglobosa* (table 2; figure 5 and 6-A), while about 30 % of Benin is revealed to be moderately suitable for *P. biglobosa.* These suitable areas are mainly located in phytogeographical districts of North Borgou, South Borgou, Bassila and the west part of Zou (Figure 1). According to the bioclimatic projections, the suitable areas for *P. biglobosa* in Benin differ from the two RCP scenarios. Indeed, the model Csiro_mk3_6_0 predicts under its scenario RCP 2.6 a loss of only 4% of the current highly suitable habitats and about 8% of those moderately suitable for *P. biglobosa.* Likewise, for this model but under the scenario 8.5, the species could lose by 2050 about 18% of its highly suitable habitats and 13% of its moderately suitable habitats (table 2, figure 5-B and 5-C). These habitats will be converted into poorly suitable habitats increasing then their areas to about 67%. Contrary to the Csiro_mk3_6_0 model, the trend is projected to be very severe with the model HadGEM2_ES. The Projections of the model HadGEM2_ES suggested, respectively, a loss of 50.52% and 56.50% in highly suitable habitats for *P. biglobosa* under the scenarios RCP 2.6 and 8.5 by 2050, especially in phytodistricts of Plateau, Zou, a part of Atakora chain, North and South Borgou and Bassila. The suitable areas will be converted into moderately suitable and poorly suitable habitats of which the areas will be respectively increase of 65.55% and 33.68% for the RCP 2.6, and 65.11% and 50% for the RCP 8.5 (table 2).

Table 2 - Dynamics of suitable areas for cultivation and conservation of P. biglobosa.

Models	Scenarios	High		Moderate		Poor	
		Area (Km²)	Trend (%)	Area (Km²)	Trend (%)	Area (Km²)	Trend (%)
Current		59,614.9092		34,321.7952		22,625.064	
Csiro_mk3_6_0	RCP2.6	57,224.3364	-4.01	31,632.4008	-7.84	27,705.0312	+22.45
	RCP8.5	48,942.7092	-17.90	29,860.8156	-13.00	37,758.2436	+66.89
HadGEM2_ES	RCP2.6	29,497.9608	-50.52	56,818.7928	+65.55	30,245.0148	+33.68
	RCP8.5	25,933.446	-56.50	56,669.382	+65.11	33,958.9404	+50.09

The sign (-) indicates a loss of suitable areas and the sign (+) a gain in habitat suitability

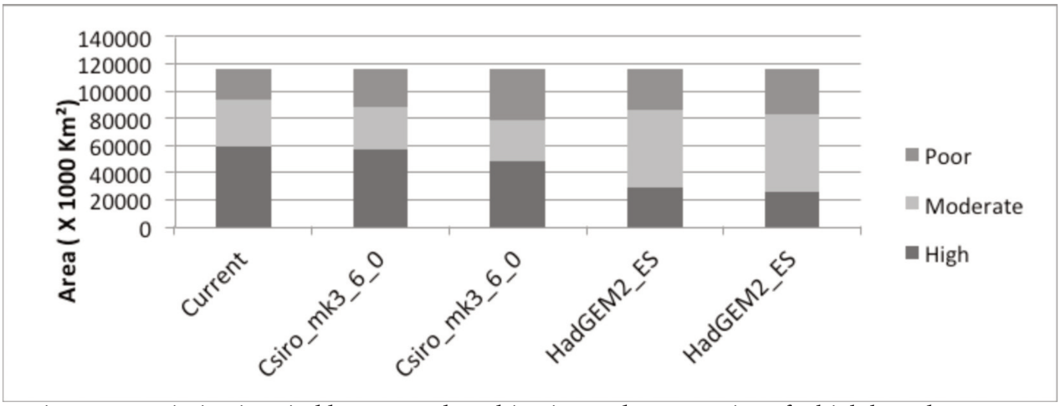

Figure 5 - Variation in suitable areas to the cultivation and conservation of P. biglobosa *by 2050, according to the two scenarios used in the two models Csiro_mk3_6_0, HadGEM2_ES.*

Discussions

Density of Parkia biglobosa

The observed mean density of *Parkia biglobosa* varied weakly between the two investigated agro-ecological zones. However, a relatively high among plots variation was noticed in the Soudano-Guinean zone (CV=63.21%). Smaller within plot variation occurred in the Soudanian zone: that could be imputable to more strict conservation measures enforced by local communities utilizing the species (mainly, Baribas, sociolingustic groups). In contrast, conversion of agroforestry parks of *P. biglobosa* into palm trees plantations, or for charcoal production is a common

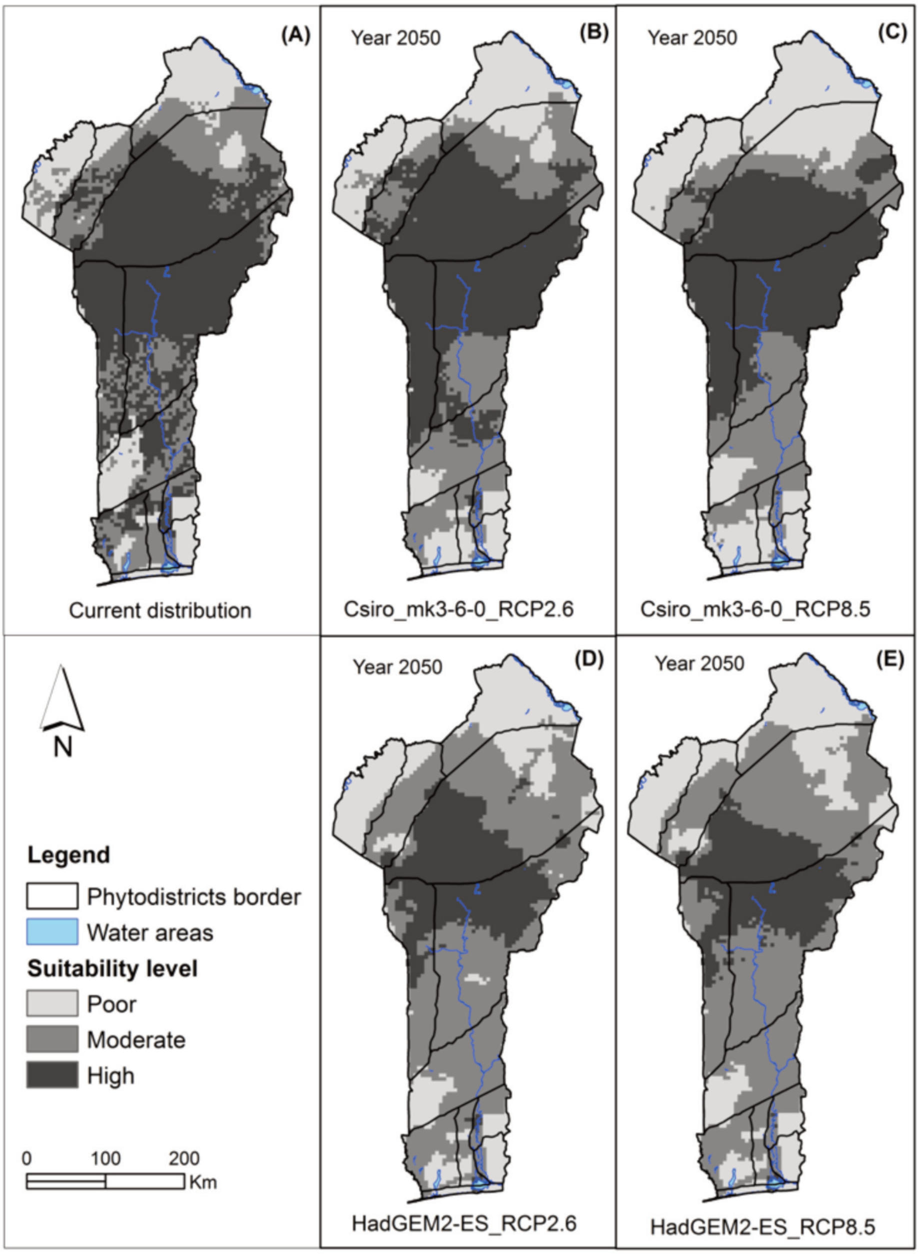

Figure 6 - Projection in 2050 of P. biglobosa distribution area according to scenarios 2.6 and 8.5 with Csiro_mk3_6_0 and HadGEM2_ES models in Benin.

practices in the lower southern part of the Soudano-Guinean zone (Koura *et al.,* 2011). These practices could explain because the *P. biglobosa* density in this agro-ecological zone is lowest, whereas its variability is high.

Modeling and reliability of the model

Predictive models are generally used by scientists for plant species protection, in order to estimate their spatial distribution (Loiselle *et al.* 2003), to determine plants location, which are in danger of extinction, (Ortega-Huerta and Peterson 2004) to calculate the probabilities of species invasion (Fandohan *et al.*, 2015) and to assess the impact of climate change on the species distribution (Beaumont, Hughes and Poulsen, 2005; Thuiller, Lavorel and Araujo, 2005). These models participate in uniting statistically the observed distributions of a species for a given period to the different ecological factors and climate able to arrange its area of observed distribution (Piedallu *et al.,* 2009). Therefore, the modeling of ecological niches has been introduced and cited as a powerful tool for mapping of the current and the future species distribution and prediction of the impact of climate change on their distribution (Van Zonneveld *et al.,* 2009; Nakao *et al.,* 2010). However, few perplexities related to models used are observed: difficulties to parameterize the ecological interactions, limitations of scattering specific to each species, physiological plasticity limits and the adaptive responses of disseminators agents (Elith *et al.,* 2006; Schwartz, 2012).

The modeling of ecological niches has many applications and is especially used in order to propose scenarios for sustainable use of the environment (Carpenter, 1993; Thuiller *et al.,* 2005; Beaumont *et al.,* 2007), assess the impacts of climate change on biodiversity (Pearson, 2003; Araújo, 2005 and 2007), delimit the possible itinerary of infections and diseases (Peterson, 2002b), indicate priority property conservation (Soberon *et al.,* 2005), and define new places of species reintroductions (Stockman *et al.,* 2006). Fandohan *et al.,* (2013) argued that it is possible that at the time of the establishment of the species in its areas of current occurrence, the climate could have been very different (more humid or drier). Thus, its current presence implies several millennia of adaptation to different climate change.

Concerning the geographic repartition area of *P. biglobosa*, the literature mentioned it on three continents: Africa, Asia and South America. The twentieth parallel North and South are its distribution limits. Information in literature confirm the results of the present study according to which 53% of Beninese national territory, (not including the islands on the Niger river) is currently very suitable for the production of *P. biglobosa* (Figure 4, table 2). Nevertheless, it would be interesting to conduct a typology study on the distribution of P.*biglobosa* on these three continents. This would allow standardizing the contained information in the literature since one or two a century.

Analysis of the contribution of environmental variables

Seven (07) environmental variables have contributed to the prediction of the geographical distribution of *P. biglobosa* at different percentages. Soil, the precipitation and the average diurnal range (maximum temperature - minimum temperature - monthly average) have mostly contributed to this prediction. Soil contributed the most to the species prediction in 2050 with a rate of 60 %. Its degradation through human action could dangerously compromise the species distribution in the future. These results are conform with those obtained by Badeau *et al.* (2005), and Berry *et al.* (2007), whose models integrated, for the first time, weather, trophic and water, giving results which were coherent with the current knowledge regarding Fir tree and the Spruce species, in France. Our result moreover confirm the work of Ayihouenou (2013), which has shown that the bioclimatic variables such as soil and vegetation, best contribute to the prediction of the geographical distribution of *P. biglobosa.* The contribution of edaphic variables allows making these models more functional, in avoiding that a part of the information concerning the soil is taken into account in a statistical and purely fortuitous way, by the climatic variables that are correlated. Therefore, the soil (biophysical variable) has been revealed as the variable which would most influence the distribution of *P. biglobosa* by 2050. This finding reaffirm the results of Badeau *et al.* (2005) and Berry *et al. (*2007), who, in general, have shown that the parameters associated with the ground play a regional and local filtering effect, within the envelope climate suitable to the species. Similarly, result of this study is also corroborated by the findings of Sober n and Peterson (2005) who have affirmed that abiotic conditions, including the climatic factors and soil, are distinguished as one of the most important factors that determine the presence of a plant species in the environment. The distribution map of *P. biglobosa* in Benin show that *P. biglobosa* is widely distributed throughout the country, but does not occur widely in the southern areas (Fig. 2). This is likely to be due to the low temperatures and high levels of precipitation. Temperature seasonality and maximum temperatures were identified as important variables explaining *P. biglobosa* distribution. Thus, the average diurnal range, annual precipitation, Precipitation of Coldest Quarter and Precipitation of Driest Quarter were identified as important variables explaining *P. biglobosa* distribution out of soil (Fig. 6).

Impact of climate change on the distribution of P. biglobosa in 2050

According to bioclimatic projection of Csiro mk3_6_0 model, under the scenario RCP 2.6, *P. biglobosa* will only lose small portion of its habitats (Table 2), which are currently very favourable (High) to its distribution, and small proportion of those relatively suitable (Moderate) by 2050. Thus, according to the same model and under

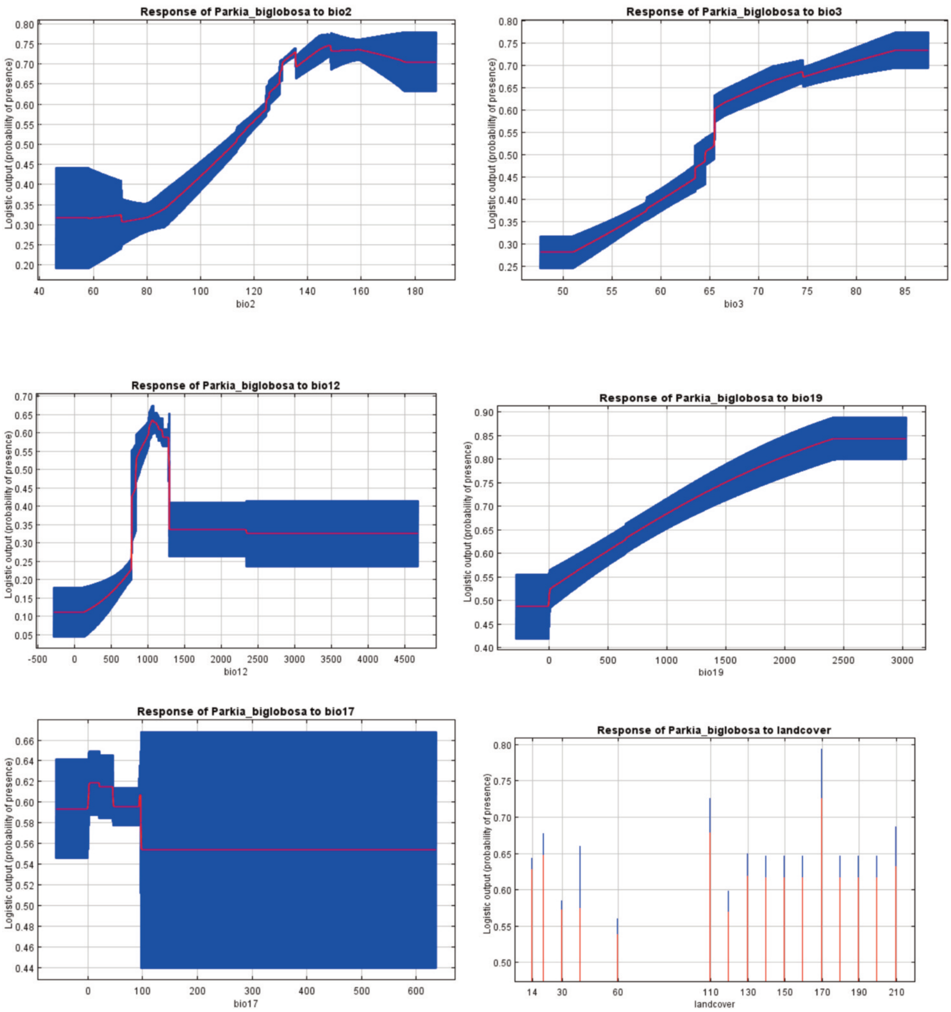

Figure 7 - Curves showing the responses of predicted presence probability of Parkia biglobosa to environmental variables.

the scenario RCP 8.5, the species will lose a proportion more high of very suitable habitats (High), and a proportion more high of relatively favorable (Moderate) habitats. Very suitable (High) and relatively suitable (Moderate) habitats will be converted to little favorable (Poor) habitats by 2050. The climate change is recognized as a threat to the *P. biglobosa* survival; the model Csiro_mk3_6_0_ under the two scenarios predicts a weak decrease in the habitat suitability of *P. biglobosa* by 2050 and therefore constitutes a conservative model for the species.

Furthermore bioclimatic projections of the HadGEM2_ES model under the scenario RCP 2.6, show that *P. biglobosa* will lose up a very big portion of its habitats, which are currently very suitable (High), and a very big proportion of its habitat under the scenario RCP 8.5 by 2050. These very suitable habitats (High) will be essentially converted to moderately suitable (Moderate) habitats by 2050, according to the two scenarios. These two scenarios predict increases respectively nearly 34% and 50% of the little suitable (Poor) habitats. The HadGEM2_ES model forecasts high reduction of the species areas: about 60% of the very suitable (High) habitats of *P. biglobosa* will be convert to the moderately suitable (Moderate) and little suitable (Poor) habitats. These results confirm the work of Moss et *al.,* (2010), who have shown that the scenario RCP 8.5 will produce three times the CO_2 emissions of today by 2100, with a rapid increase of methane emissions, an increased use of cropland and pasture which is likely to increase the world population to 12 billion by 2100. On the contrary, the scenario RCP 2.6 will participate in ambitious reductions of greenhouse gas emissions over time, at decline of petroleum use, at low energy intensity and a world population of 9 billion in 2100. The reduction of methane emissions is 40% while CO_2 emissions will remain at the current level until 2020, and then there will be a decline that will become negative by 2100.

Our results confirm the work of Ayihouenou (2013), who found that with the bioclimatic projections of the MIROC model, under the scenario RCP 2.6, *P. biglobosa* would lose close to 22% of currently very suitable (High) habitats by 2050, and it would has an increase of almost 123% of weakly suitable habitats (Poor) . They are also in agreement with the findings of many research studies that have modeled the evolution of potential distribution areas of the species under the assumption of a rapid climate change (Skyes *et al.,* 1996; Thuiller, 2003; Badeau *et al.,* 2005; Guisan A. et Thuiller, 2005). Considering the variability in the projections of suitable areas to *P. biglobosa* conservation in 2050, this study in summary shows the reduction of suitable areas. Therefore, the assumption that climate change could alter the area of distribution of the species as proven by several studies (Hannah *et al.*, 2002; Thuiller 2004; van Zonneveld *et al.*, 2009; Gouwakinnou *et al.,* 2011; Bourou *et al.*, 2012; Fandohan *et al.*, 2013) is here confirmed. Though these variations can raise an unavoidable uncertainty in climate projections, risks associated to climate change are obvious (Pittock, 2009). Consequently, rather than predicting what is really going to happen in the future, the climate projection is a procedure to provide a general idea of what could happen. As such, it can allow taken a decision more robust in a context of uncertainty and it must offer tracks for the conservation planning (Araujo and New, 2007).

Implications of the modeling for the conservation of P. biglobosa

The current suitable conditions to the cultivation and conservation of P. biglobosa are related to environmental variables: soil by its physico-chemical characteristics, annual precipitation, and the diurnal average temperature, seasonal of the temperature and seasonal of precipitation. The variation of these bioclimatic conditions can over the time transform the following currently very suitable areas such as Bassila, Borgou south and north, a range of the Atacora, Zou, Plateau, a small portion of the valley of the Oueme, in moderately suitable areas for P. biglobosa conservation and cultivation. In some cases, areas which are today weakly suitable to the P. biglobosa conservation-can become very suitable. Indeed, the fluctuations of climate variables such as precipitation and temperature will have an impact on biological diversity and on the geographical distribution of suitable habitats of Parkia biglobosa (IPCC, 2007). The emission of greenhouse gases is very low in Benin. To conserve the species and avoid that it suffer the enormous losses predicted by models, it is important to protect the suitable environment through the promotion of agroforestry, the sustainable use of soil, the control during land clearing and vegetation fires.

Conclusion

Climate change is to date known as one of the main factors contributing to the alteration of the overall structures of *P. biglobosa* in practicing modifications in its spatial distribution. To assess the importance of such changing, the present study has attempted to provide some useful information on its distribution. Through the MaxEnt software, the modeling about *P. biglobosa* distribution area helped to link statistically the present distribution to the future scenarios by 2050. This species is currently present in almost all phytodistricts of Benin (Figure 1) with some exceptions such as Coast, Pobè and Mekrou-Pendjari. The northern phytogeographical districts (South Borgou and North Borgou, and Bassila) represent the most suitable habitat for the *P. biglobosa* cultivation and conservation. Bioclimatic variables (soil, temperature and precipitation) predict the geographical distribution of *P. biglobosa* at different percentages. According to the bioclimatic models Csiro_mk3_6_0 and HadGEM2_ES projections and the two (02) scenarios (RCP 2.6 and RCP 8.5), the favorable area to the conservation of *P. biglobosa* in Benin is varying over the time. For the two scenarios, the model Csiro_mk3_6_0 predicts a loss relatively weak comparatively to the HadGEM2_ES model, which predicts a very high loss in areas currently very suitable by 2050. This information could be used in the development of strategies for the conservation of the species and to improve adaptive capacities of local populations in order to reduce their vulnerability to the effects of climate change.

References

Adomou A.C., Sinsin B., van der Maesen L.J.G., 2006. Phytosociological and chorological approaches to phytogeography: a study at meso-scale in Benin. Syst. Geogr. *Pl*., 76**,** 155-178.

Allouché O., Tsoar A., Kadmon R., 2006. Assessing the accuracy of species distribution models: prevalence, kappa and the true skill statistic (TSS). Journal of Applied Ecology 43, 1223–1232.

Araújo M.B., Pearson R.G., Thuillers W., Erhard M., 2005. Validation of species-climate impact models under climate change. Global Change Biology 11, 1504-1513.

Araújo M.B., Luoto M., 2007. The importance of biotic Interactions for modelling species distributions under climate change. Global Ecological Biogeography 16, 743-753.

Araùjo M.B., New M., 2007. Ensemble forecasting of species distributions. Trends in Ecology and Evolution, 22, 42-47.

Ayihouénou B., 2013. Impact des changements climatiques sur la répartition géographique des aires favorables à la culture et à la conservation du *Parkia biglobosa* (Jack.) R. Br. ex. Don., au Bénin. Mémoire de Master en gestion des ressources naturelles.

Badeau V., Dupouey J.L., Cluzeau C., Drapier J., 2005. Aires potentielles de répartition des essences forestières d'ici 2100. Forêt-Entreprise, vol. 162, avril 2005, pp. 25-29.

Beaumont L.J., Hughes L., Poulsen M., 2005. Predicting species' distributions: use of climatic parameters in BIOCLIM and its impact on predictions of species' current and future distribution. Ecological Modelling, 186, 250–269.

Beaumont L.J., Pitman A.J., Poulsen M., Hughes L., 2007. Where will species go? Incorporating new advances in climate modelling into projections of species distributions. Global Change Biology 13, 1368-1385.

Berry P. M., Jones, A. P., Nicholls, R. J., VOS, C. C., 2007. Assessment of the vulnerability of terrestrial and coastal habitats and species in Europe to climate change, Annex 2 of Planning for biodiversity in a changing climate - BRANCH: project Final Report, Natural England, UK, 2007.

Bourou S., Bowe C., Diouf M., Van Damme P., 2012. Ecological and human impacts on stand density and distribution of tamarind (*Tamarindus indica*L.) in Senegal. Afr. J. Ecol., 50, 253-265.

Brands S., Herrera S., Gutiérrez J.J. M., 2013. How well do CMIP5 Earth System Models simulate present climate conditions in Europe and Africa? Springer-Verlag Berlin Heidelberg 2013.

Busby J.W., Smith T.G., White K.L., Strange S.M., 2010. Locating climate insecurity:

where are the most vulnerable places in Africa? Austin, TX, USA: University of Texas, The Robert Strauss Center for International Security and Law, Climate Change and African Political Stability (CCAPS) Programme.

Carpenter G., Gilison A.N., Winter J., 1993. DOMAIN : A flexible modelling procedure for mapping potential distributions of animals and plants. Biodiversity and Conservation 2, 667- 680.

Elith J., Graham C.H., Anderson R.P., Dudı K.M., Ferrier S., Guisan A., Hijmans R.J., Huettmann F., Leathwick J.R., Lehmann A.L.J., Lohmann L.G., Loiselle B.A., Manion G., Moritz C., Nakamura M., Nakazawa Y., Overton J.M.C., Peterson A.T., Phillips S.J., Richardson K.S., Scachetti-Pereira R., Schapire R.E., Soberon J., Williams S., Zimmermann N.E., 2006. Novel methods improve prediction of species' distributions from occurrence data. Ecography, 29, 129-151.

Elith J., Leathwick J.R., 2009. Species Distribution Models: Ecological Explanation and Prediction Across Spaceand Time. Annual Review of Ecology Evolution and Systematics, 40: 677-697.

Elith J., Kearney M., Philips S., 2011. The art of modeling range-shifting species. Methods Ecol. Evol., 1, 330-342.

Fandohan B., Assogbadjo A.E., Kakaï Glèlè R., Sinsin B., 2011. Geographical distribution, tree density and fruit production of *Tamarindus indica* L. (Fabaceae) across three ecological regions in Bénin. Fruits, vol. 66 (2).

Fandohan B., Gouwakinnou G.N., Fonton N.H., Sinsin B., Liu J., 2013. Impact des changements climatiques sur la répartition géographique des aires favorables à la culture et à la conservation des fruitiers sous-utilisés : cas du tamarinier au Bénin. Biotechnol. Agron. Soc. Environ. (inpress).

Fandohan B, Oduor A.M., Sodé I., Wu L., Cuni-Sanchez A., Assédé E., Gouwakinnou N.G., 2015. Modeling vulnerability of protected areas to invasion by *Chromolaena odorata* under current and future climates. Ecosystem Health and Sustainability 1(6):20. 10.1890/EHS15-0003.1

Faure P., Volkoff B., 1998. Some factors affecting regional differentiation of the soils in the Republic of Benin (West Africa). Catena, 32, 281-306.

Fitzpatrick M.C., Hargrove W.W., 2009. The projection of species distribution models and the problem of non-analog climate. Biodivers. Conserv., 18, 2255-2261.

Gbesso F.H.G., Tenté B.H.A., Gouwakinnou N.G., Sinsin B.A., 2013. Influence des changements climatiques sur la distribution géographique de *Chrysophyllum albidum* G. Don (Sapotaceae) au Benin. International Journal of Biological and Chemical Science 7(5): 2007-2018

Gouwakinnou G.N., Assogbadjo A.E., Lykke A.M., Sinsin, B. 2011. Phenotypic variations in fruits and potential for selection in *Sclerocarya birrea* subsp. *birrea. Scientia Horticulturae,* 129: 777 – 783.

Guibert H, Allé U.C., Dimon R.O., Dédéhouanou H., Vissoh P. V., Vodouhé S. D., Tossou R. C., Agbossou E.K. 2010. Correspondance entre savoirs locaux et scientifiques: Perceptions des changements climatiques et adaptations au Bénin. ISDA 2010, Montpellier, 1-12.

Guisan A., Zimmermann N. E., 2000. Predictive habitat distribution models in ecology. Ecol. Model., 135, 147-186.

Guisan A., Thuiller W., 2005. Predicting species distribution: offering more than simple habitat models. Ecol. Lett. 8: 993-1009.

Hannah L., Midgley G.F., Millar D., 2002. Climate change integrated conservation strategies. Global Ecol. Biogeogr., 11, 485-495.

Hijmans R.J., Cameron S.E., Parra J.L., Jones P.G., Jarvis A., 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology, 25, 1965–1978.

IPCC, 2007. Climate change: synthesis report. New York, USA: Cambridge University Press.

Koura K., Ganglo C.J., Assogbadjo A.E., Agbangla C., 2011. Ethnic differences in use values and use patterns of Parkia biglobosa in Northern Benin. Journal of Ethnobiology and Ethnomedicine 2011, 7:42.

Leakey R.R.B., Pate K., Lombard C., 2005. Domestication potential of Marula (*Sclerocarya birrea* subsp. caffra) in South Africa and Namibia: Phenotypic variation in nut and kernel traits. Agrofor. Syst., 64: 37-49.

Loiselle B.A., Howell C.A., Graham C.H., Goerck J.M., Brooks T., Smith K.G., Williams P.H., 2003. Avoiding pitfalls of using species distribution models in conservation planning. Conservation Biology, 17, 1591–1600.

Lugina K.M., Groisma, P.Y., Vinnikov K.Y., Koknaeva V.V., Speranskaya N.A., 2006. Monthly surface air temperature time series area-averaged over the 30-degree latitudinal belts of the globe*, 1881–2005*. In Trends: a compendium of data on global change. Oak Ridge, TN: Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy. See

Mahapatra A.K., Albers H.J., Robinson E. J.Z., 2005. The impact of NTFP sales on rural

household's cash income in India's dry deciduous forest. Environmental Management 35(3): 258-265.

Martínez I., Carreño F., Escudero A., Rubio A., 2006. Are threatened lichen species well-protected in Spain? Effectiveness of a protected areas network. Biol. Conserv., 133, 500-511.

Meinshausen M., Wigley T., Raper S., 2011. The RCP greenhouse gas concentrations and their extensions from 1765 to 2300. Clim. Change, 109, 213-241, doi:10.1007/s10584-011-0156-z.

Moss R. H., Edmonds J.A., Hibbard K.A., Manning M.R., Rose S.K., van Vuuren

D.P., Carter T. R., Emori S., Kainuma M., Kram T., 2010. The next generation of scenarios for climate change research and assessment. Nature 2010, 463:747–756.

Nakao K. *et al.,* 2010. Assessing the impact of land use and climate change on the evergreen broad-leaved species of *Quercus acuta* in Japan. Plant Ecol., 212, 229-243.

Ortega-Huerta M.A., Peterson A.T., 2004. Modelling spatial patterns of biodiversity for conservation prioritization in north-eastern Mexico. Diversity and Distributions, 10, 39-54.

Parviainen M., Luoto M., Ryttari T., Heikkinen R.K., 2008. Modelling the occurrence of threatened plant species in taiga landscapes: methodological and ecological perspectives. J. Biogeogr., 35, 1888-1905.

Peterson A.T., Sanchez-Cordero V., Beard C.B., Ramsey, J.M., 2002b. Ecological niche modelling and potential reservoirs for Chagas diseases, Mexico. Emerging Infectious Diseases 8, 662-629.

Pearson R.G., Dawson T.P., 2003. Predicting the impacts of climate change on the distribution of species: are bioclimatic envelope models useful? Global Ecol. Biogeogr., 12, 361-371.

Phillips S.J., Dudik M., Schapire R.E., 2004. A maximum entropy approach to species distribution modeling. In: Proc. of the 21st International Conference on Machine Learning, Banff, Canada.

Phillips S.J., Anderson R.P.,Schapire R.E., 2006. Maximum entropy modelling of species geographic distributions. Ecol. Model., 190, 231-259.

Phillips, S.J.; Dudík, M.; Elith, J.; Graham, C.H.; Lehmann, A.; Leathwick, J.; Ferrier, S. 2009. Sample selection bias and presence-only distribution models: Implications for background and pseudo-absence data. Ecol. Appl. 19: 181–197.

Piedallu C., Perez V., Gégout J.C., Lebourgeois F., Bertrand R., 2009. Impact potentiel du changement climatique sur la distribution de l'Epicéa, du Sapin, du Hêtre et du Chêne sessile en France. Revue Forestière Française, Ecole nationale du génie rural, LXI (6), pp.567-593. hal-00835897.

Pittock B.A., 2009. Climate change: the science, impacts and solutions. Collingwood, Australia: CSIRO Publishing; London: Earthscan.

Schwartz M.W., 2012. Using niche models with climate projections to inform conservation management decisions. Biol. Conserv., 155, 149-156.

Sinsin B., Owolabi L., 2001. Monographie nationale de la diversité biologique. Rapport de synthèse. Ministère de l'Environnement, de l'Habitat et de l'urbanisme (MEHU), Cotonou, Bénin, p. 41.

Sykes M.T., Prentice I.C., Cramer W., 1996. A bioclimatic model for the potential distributions of north European tree species under present and future climates.

Journal of Biogeography, 23, 203-233.
Soberon J., Peterson A.T., 2005. Interpretation of models of fundamental ecological niches and species' distributional areas. Biodiversity Informatics 2, 1-10.
Stockman A.K., Beamer D.A., Bond B.J.E., 2006. An evaluation of a GARP model as an approach to predicting the spatial distribution of non-vagile invertebrate species. Diversity and Distrib. 12, 81-89.
Swets J.A., 1988. Measuring the accuracy of diagnostic systems. *Science*, 240, 1285-1293.
Teklehaimanot Z., 2004. Exploiting the potentiel of indigenous agroforestry trees: *Parkia biglobosa* and *Vitellaria paradoxa* in sub-Saharan Africa. Agroforestry Systems 61: 207-220.
Thuiller W., 2003. BIOMOD: Optimizing predictions of species distributions and projecting potential future shifts under global change. Global Change Biology, vol. 9, 2003, pp. 1353-1362.
Thuiller W., 2004. Patterns and uncertainties of species' range shifts under climate change. Global Change Biology, 10, 2020-2027.
Thuiller W., Lavorel S., Araújo M.B., 2005. Niche properties and geographical extent as predictors of species sensitivity to climate change. Global Ecology and Biogeography, 14, 347–357.
Thuiller W., Richardson D.M., Pysek P., Midgley G.F., Hughes G.O., Rouget M., 2005. Niched-based modelling as a tool for predicting the global risk of alien plant invasion. Global Change Biology 11, 2234-2250.
Van Zonneveld M., Koskela J., Vinceti B., Jarvis A., 2009. Impact of climate change on the distribution of tropical pines in Southeast Asia. Unasylva, 231/232, 24-29.
Warren D., *et al.* 2010. ENMTools: a toolbox for comparative studies of environmental niche models. Ecography 33: 607-611.