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Climate and potential habitat suitability for cultivation and in situ conservation of the black plum (*Vitex doniana* Sweet) in Benin, West Africa

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Abstract

Sustainable management actions are needed for several indigenous agro forestry plant species like the black plum (*Vitex doniana* Sweet) because they are facing increasing pressures due to the rapid human growth and threats such as climate change. By combining species distribution modelling using the Maximum Entropy Algorithm (Max Ent) and representation gap analysis, this study accessed the impacts of current and future (2050) climates on the potential distribution of *Vitex doniana* in Benin with insight on the protected areas network (PAN). The model showed a high goodness-of-fit (AUC = 0.92 ± 0.02) and a very good predictive power (TSS = 0.72 ± 0.01). Our findings indicated annual mean rainfall, annual mean diurnal range of temperature and mean temperature of the driest quarter as the most important predictors driving the distribution of *V. doniana*. Under current climate, about 85 % of Benin area is potentially suitable for its cultivation. This potential suitable area is projected to increase by 3 to 12 % under future climatic conditions. A large proportion (76.28 %) of the national PAN was reported as potentially suitable for the conservation of the species under current climate with increase projections of 14 to 23 % under future climate. The study showed that *V. doniana* can be cultivated in several areas of Benin and that the PAN is potentially suitable for its conservation. These findings highlighted some of the opportunities of integrating *V. doniana* in the formal production systems of Benin and also its potentialities in ecosystems restoration under the changing climate.

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Introduction

Indigenous agro forestry species, formerly considered as less useful and underutilized products are becoming nowadays important resources for many food security policies mainly in developing countries (Garrity, 2004, Oladélé, 2011). These species provide several goods to local communities enhancing then their capacity to face food shortage (Atato *et al.*, 2011) and to alleviate poverty (Akinnifesi *et al.*, 2008, Oladélé, 2011). Moreover, they provide several ecosystem services and contribute to biodiversity conservation (Vodouhè *et al.*, 2011). Unfortunately, most of these agroforestry species are overexploited and threatened in their natural biotopes (Maundu *et al.*, 2006). In fact, habitat and population of these species are facing increasing pressures due to the rapid human population growth (Maundu *et al.*, 2006, Nacoulma *et al.*, 2011, Haarmeyer *et al.*, 2013, Mensah *et al.*, 2014) and this combined with climate change add several uncertainties to their fitness and survival (IPCC, 2007, FAO, 2012). This situation has enhanced the need of developing sustainable management, domestication and conservation strategies for those species with a focus on climate change.

Climate change, one of the biggest challenges for this century, occurs mainly as alterations over time in weather parameters such as temperature, precipitation and wind, and changes in temperature are the most considered facts (de Chazal and Rounsevell, 2009). The implications of these change are significant for the long-term stability of natural ecosystems and for the many benefits and services that humans take from them (Lucier *et al.*, 2009). Several impacts have been reported on biological systems, with species extinction being the most extreme and irreversible negative impact (Bellard *et al.*, 2012). In Africa for instance, more than 5,000 species might lose their natural habitat before 2080 (McClean *et al.*, 2005). To avoid or reduce the amplitude of those effects, biodiversity components must produce adaptive responses which can be of several time-dependent types (Parmesan, 2006, Bellard *et al.*, 2012). Whatever the adaptation mechanism used, species responses to climate change have been observed along three non-exclusive axes: time (e.g. phenology), space (e.g. range) and self (e.g. physiology), with the first two axes being the most easily observable (Parmesan, 2006). In the spatial point of view, through seed dispersal, plant species track appropriate conditions and follow them by shifting their geographical range in order to stay in quasi-equilibrium with the climatic conditions they are adapted to (Bellard *et al.*, 2012). Evidences of such geographical range shifting have been given by several modelling studies and experimental trials on species tolerance. These studies revealed significant changes in the distribution of some species and ecosystems, principally due to increasing temperature and alteration of precipitation regimes (Walther *et al.*, 2002, Campbell *et al.*, 2009).

In this context of a changing climate, assessing spatial dynamics of suitable habitat of useful species is an important steps towards their domestication and integration into formal agricultural production systems especially in developing countries where rural population are still dependent on such resources (Oladélé, 2011). Furthermore, this assessment is relevant for in situ conservation planning strategies taking into account the existing extensive protected areas network. Despite the increasing literature on climate change impacts on plant species distribution and effectiveness of protected areas network in conserving suitable habitat of native plant species (Fandohan *et al.*, 2013), little is known on how climate could affect habitat suitability for cultivation and conservation of several useful indigenous agroforestry species such as the black plum.

The black plum (*Vitex doniana* Sweet) is one of these very important indigenous agroforestry species valued by local communities in many parts of Africa and for which sustainable management and domestication programs are required (Maundu *et al.*, 2009, Achigan-Dako *et al.*, 2011, Mapongmetsem *et al.*, 2012). Beside its potential role in soil fertility improvement by litter production (Mapongmetsem *et al.*, 2005), several parts of the species are used for food, medicine and other purposes (Dadjo *et al.*, 2012). It is known that its leaves are used as fodder for livestock and the young leaves as leafy vegetables in sauces preparation. The blackish pulp of its ripened fruits is edible and used in preparation of some sweet drinks. The wood is suitable for construction and fire (Arbonnier, 2004, Ky, 2008, Orwa *et al.*, 2009, Dadjo *et al.*, 2012). The mature leaves, the bark and the roots have phytotherapeutic properties and are used to heal several diseases (Iwueke *et al.*, 2006, Kilani, 2006, Padmalatha *et al.*, 2009). Given its socio-economic importance, its integration into the formal production systems could foster domestication strategies and reduce anthropogenic pressures on its natural populations. In addition, knowledge on its conservation by protected areas is relevant for designing strategies for plant genetic resources management. It is therefore crucial to assess impacts of climate on the species habitat in order to identify suitable areas for its cultivation and conservation.

Thus, through species distribution modelling using the Maximum Entropy Algorithm "MaxEnt" (Phillips *et al.*, 2006) and representation gap analysis, this study aimed at assessing impacts of current and future (2050) climates on *V. doniana*'s habitat suitability for its cultivation and in situ conservation in Benin. Specifically, it addressed the following research questions: i) what are the bioclimatic variables controlling *V. doniana*'s potential distribution? ii) How will the species' habitat suitability change with climate? iii) How far the national protected areas network might conserve the species' suitable habitat under current and future climates?

Material and methods

Target species and study area

The black plum (*Vitex doniana* Sweet) is a deciduous plant species occurring in tropical Africa from Senegal to Somalia and to South Africa, also in Comoros and Seychelles (Arbonnier, 2004, Ky, 2008). It was formerly classified in the Verbenaceae family but based upon several phylogenetic studies, it has been transferred to the Lamiaceae family (Cantino *et al.*, 1992, Harley *et al.*, 2004). It colonises various habitats from forests to savannahs, often in wet localities and along rivers, and on termite mounds, up to 2000 m altitude. It occurs in regions with a mean annual rainfall between 750-2000 mm and temperature ranging from 10 to 30°C (Arbonnier, 2004, Ky, 2008, Orwa *et al.*, 2009). It has been mentioned as naturally occurring in all the three climatic zones of Benin (Assogbadjo *et al.*, 2012).

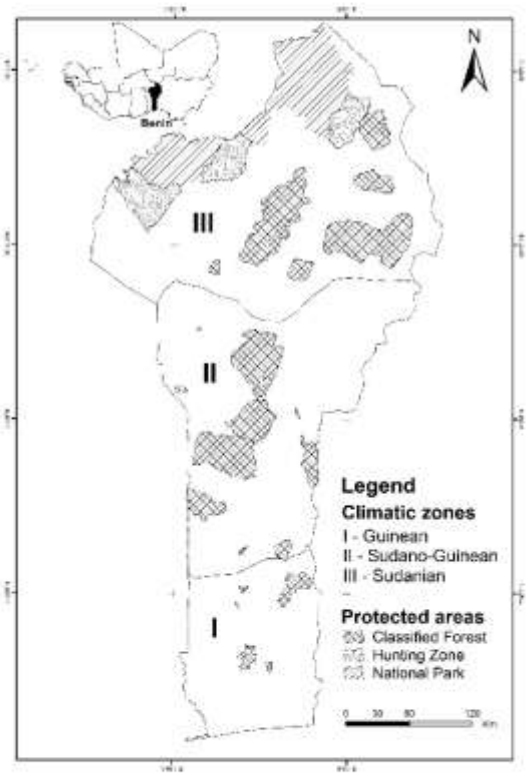

Fig. 1. Climatic zones and protected areas network of Benin.

The study was carried out in Benin republic (114,763 km²), located between 6°10' and 12°50' N and 1° and 3°40' E in West Africa (Fig. 1). The country's climatic profile shows two contrasting climatic zones (Guinean vs. Sudanian) and a transitional zone (Sudano-Guinean). The Guinean zone (between 6°25' and 7°30' N) is characterised by a subequatorial climate with four seasons (two rainy and two dry). The rainfall of about 1200 mm per year is bimodal mostly from March to July and September to November. The temperature varies between 25 and 29 °C, and the relative humidity varies between 69 % and 97 %. The

Sudanian zone (9°45' - 12°25' N) has a tropical dry climate with two equal length seasons (rainy and dry). The mean annual rainfall in this zone is often less than 1000 mm and occurs mainly from May to September. The relative humidity varies from 18% to 99% and temperature from 24 to 31°C. The Sudano-Guinean (from 7°30' to 9°45' N) is a transitional zone with two rainy seasons merging in a unimodal regime. The annual rainfall fluctuate between 900 and 1110 mm, the temperature is between 25 and 29°C and relative humidity from 31 % to 98 % (Fandohan *et al.*, 2011, Gnanglè *et al.*, 2011, Assogbadjo *et al.*, 2012).

About 24 % of the country (approximately 27,310.47 km²) is legally protected by the national protected areas network constituted of two parks (Pendjari in the North-western part and W in the extreme Northern part of the country, Fig. 1) and several classified forests (IUCN and UNEP-WCMC, 2015).

Data collection

A total of 227 occurrence points (longitude and latitude) were obtained from fieldwork in Benin and from the Global Biodiversity Information Facility portal (GBIF, 2015) for the West African region (Fig. 2).

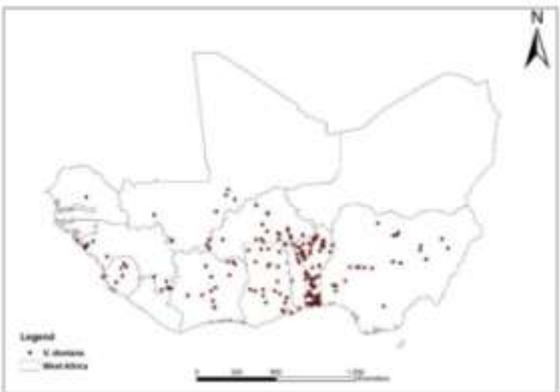

Fig. 2. Occurrence of *V. doniana* in West Africa (Data source: GBIF and fieldwork).

Bioclimatic data for current (1950-2000) and projections for 2050 were extracted from World Clim (available at www.worldclim.org/bioclim), Version 1.4 database (Hijmans *et al.*, 2005) at 2.5-minute grid resolution (approximately 4.62 x 4.62 km² in West Africa). This database includes 19 bioclimatic variables (Bio1 to Bio19) which are derived from average minimum and maximum temperature and rainfall data (Hijmans *et al.*, 2005).

According to the future climate (2050), projections from two models of the Coupled Model Intercomparison Project phase 5 (CMIP5) were preferred because of their commonness use and satisfactory features for simulating the global climate response to increasing greenhouse gas concentration (Fandohan *et al.*, 2015, McSweeney *et al.*, 2015). These models were the Met Office climate model (HadGEM2-ES) and the Model for Interdisciplinary Research on Climate Change (MIROC5). They were considered under two of the four Representative Concentration Pathway (RCP) developed by the Intergovernmental Panel on Climate Change (IPCC) in its Fifth Assessment Report: RCP 4.5 and RCP 8.5. These RCP were preferred because they projected the most divergent trends for the West African region compared to the others (IPCC, 2013). With this divergent trend (low vs. high emissions scenario), the range of emissions uncertainty is well captured (Harris *et al.*, 2014). For instance, temperature is projected to rise above industrial level by at least 1.4°C under RC 4.5 in West Africa by mid-21st century, with atmospheric CO_2 reaching 500 ppm and by 2°C with atmospheric CO_2 over 550 ppm under the more drastic RCP 8.5 (IPCC, 2013).

The Protected Area Network (PAN) map of Benin was obtained from the World Database on Protected Areas (IUCN and UNEP-WCMC, 2015) and used to assess the in situ conservation of the species in the country under current and future climates.

Data analysis

The Maximum Entropy species distribution model algorithm (MaxEnt, version 3.3.3k" Princeton University, Princeton, New Jersey, USA) was used for the habitat suitability modelling. This modelling tool requiring presence-only data is one of the best-performing algorithm among those using climate modelling approaches (Phillips *et al.*, 2006) and is relatively robust for small sample sizes (Pearson *et* *al.*, 2007). It is a machine learning method that estimates species' distribution across a study area by calculating the probability distribution of maximum entropy subject to the constraint that the expected value of each feature under this estimated distribution should match its empirical average (Phillips *et al.*, 2006). Although there are several conceptual ambiguities and uncertainties about bioclimatic envelope modelling (Schwartz, 2012), MaxEnt remains an important modelling tool in assessing potential impacts of climate change on species distribution (Elith *et al.*, 2011a).

During the modelling process, presence data were cleaned up by removing duplicate records in grids in order to reduce sampling bias which may result from the over sampling of some sites in the study area (Elith *et al.*, 2006). Only the less-correlated ($r < 0.85$) bioclimatic variables were selected with the environmental niche modelling tools (ENMTs) and used for the modelling (Elith *et al.*, 2011b). During these bioclimatic variables selection process, priority was given to those reflecting water availability since plants distribution in the study area is known to be under the influence of mainly soil moisture, total rainfall, air humidity and the length of the dry season (Adomou *et al.*, 2006). MaxEnt's internal Jackknife test was performed to assess the contribution of the selected variables in the distribution of the species (Pearson *et al.*, 2007).

Twenty five percent (25%) of the occurrence points was used for model testing and 75% for model calibration in five replicates. The five replicates were averaged through cross-validation. Two criteria were used to evaluate the performance i.e. goodness-of-fit and predictive power of the model: (i) the area under the receiver operating characteristic curve (AUC) and the true skill statistic (TSS) (Allouche *et al.*, 2006, Elith *et al.*, 2006, Pearson *et al.*, 2007). The AUC is the probability that a randomly chosen presence point of the species will be ranked as more suitable than a randomly chosen absence point (Elith *et al.*, 2006). A model is considered as having a good fit when its AUC is close to one (AUC ≥ 0.75) (Elith *et al.*, 2006). The TSS is the capacity of the model to accurately detect true presences (sensitivity) and true absences (specificity). A model with TSS ≤ 0 indicates a random prediction, while a model with a TSS close to 1 (TSS > 0.5) has a good predictive power (Allouche *et al.*, 2006).

To capture the correct range of each bioclimatic factor, we performed the modelling process using occurrence and climatic data for the whole West Africa. The outputs of MaxEnt were then clipped on Benin, to mark out the study area. The potential habitat suitability across the study area was assessed based on the logistic probability distributions generated by Ma x Ent using the 10 percentile training presence logistic threshold. Thus, areas with occurrence probability above the threshold value were considered as suitable for the species and areas with occurrence probability below the threshold value were taken as unsuitable habitats (Scheldeman and van Zonneveld, 2010, Fandohan *et al.*, 2015). Suitable/unsuitable habitats of the species under current and future climates were mapped in ArcGIS 10.3 (ESRI, 2014).

Representation gap analysis was used to assess how far the national protected areas network conserve the species (Fandohan *et al.*, 2013, Tantipisanuh *et al.*, 2016). For that, PAN of Benin was overlain on the present and future habitat suitability maps and proportions of suitable and unsuitable areas within the PAN were estimated in ArcGIS 10.3 (ESRI, 2014).

Results

Bioclimatic variables importance and model performance

Five of the 19 bioclimatic variables were selected as less-correlated ($r < 0.85$) and used for the species potential habitat modelling. Annual mean rainfall, annual mean diurnal range of temperature and mean temperature of the driest quarter were the most important predictors driving the species' distribution (Table 1). These variables have significant effect on the gain when used in isolation or removed from the modelling process (Fig. 3). Annual mean rainfall was the most uniquely informative predictor because its presence/absence in the model considerably affects the gain; its contribution and permutation importance were around 50 % (Table 1). The five bioclimatic variables used for the modelling showed significant variation (Wilcoxon signed-rank test, p-value < 0.05) between current climate and future projections with the most important changes reported in the Sudanian and Sudano-Guinean zones (Table 2). Annual mean rainfall, annual mean temperature and mean temperature of the driest quarter were projected to increase in all zones whatever the climatic scenario. Meanwhile, precipitation of the driest month is projected to significantly decrease in the Guinean zone and to remain stable in the other zones.

Table 1. Variables contribution and permutation importance (%).

Varia-bles	Definition	Contri-bution (%)	Permutation importance (%)
bio12	Annual mean rainfall	48.7	52.1
bio2	Annual mean diurnal range of temperature	28.6	21.3
bio9	Mean temperature of the driest quarter	15	17.8
bio1	Annual mean temperature	5.4	6.8
bio14	Precipitation of the driest month	2.3	2.0

Fig. 3. Jackknife of regularized training gain for V. doniana.

Table 2. Current and future projections of selected bioclimatic variables in Benin (mean ± standard deviation).

Climatic zones	Climate	Bio12	Bio2	Bio9	Bio1	Bio14
Guinean	Current	1136.92a ± 59.56	82.95a ± 15.54	279.91a ± 1.96	273.82a ± 2.34	9.49a ± 3.84
	He4.5	1137.54a ± 59.24	79.11b ± 13.78	300.29b ± 3.00	293.11b ± 3.46	7.42b ± 2.49
	He8.5	1135.98b± 61.53	78.92b ± 13.80	306.60b ± 3.58	299.10b ± 3.63	6.41b ± 2.35
	Mi4.5	1231.52b ± 65.83	82.50b ± 14.89	297.10b ± 2.42	288.93b ± 2.46	7.08b ± 2.90
	Mi8.5	1214.40b ± 61.77	79.94b ± 13.49	298.92b ± 3.06	290.82b ± 2.11	7.15b ± 2.91
Sudano-Guinean	Current	1096.08a ± 51.52	121.36a ± 7.05	270.82a ± 4.22	269.80a ± 3.58	3.21a ± 1.24
	He4.5	1149.18b ± 70.28	114.45b ± 8.57	295.06b ± 4.29	292.35b ± 3.65	3.23b ± 1.26
	He8.5	1152.14b ± 75.71	113.31b ± 7.68	301.94b ± 3.99	299.01b ± 3.41	3.17b ± 1.17
	Mi4.5	1201.67b ± 63.17	120.40b ± 7.45	290.18b ± 4.14	286.30b ± 2.79	2.28b ± 1.01
	Mi8.5	1233.80b ± 73.76	115.69b ± 8.62	292.94b ± 2.78	289.03b ± 2.22	2.19b ± 0.96
Sudanian	Current	1054.32a ± 94.99	131.05a ± 1.97	268.49a ± 8.27	273.04a ± 6.64	0.20a ± 0.40
	He4.5	1167.59b ± 78.19	128.66b ± 1.94	294.00b ± 6.95	295.52b ± 7.06	0.20a ± 0.40
	He8.5	1190.36b ± 80.81	125.14b ± 1.78	301.27b ± 7.18	303.63b ± 7.26	0.20a ± 0.40
	Mi4.5	1173.18b ± 98.35	131.53b ± 2.10	287.37b ± 9.20	291.70b ± 6.70	0.20a ± 0.40
	Mi8.5	1206.60b ± 110.07	131.02a ± 2.44	294.92b ± 7.61	297.30b ± 6.89	0.20a ± 0.40

Values were extracted from Worldclim database Version 1.4 at 2.5-minute grid resolution (approximately 4.62 x 4.62 km² in West Africa) based on the occurrence points of *V. doniana* in Benin. In each climatic zone, significant differences between current and each future scenario are shown by letters following mean values (Wilcoxon signed-rank test, p-value < 0.05). He4.5 & He8.5: HadGEM2-ES under respectively RCP 4.5 and 8.5. Mi4.5 & Mi8.5: MIROC5 under respectively RCP 4.5 and 8.5. Bio12 =

Annual mean rainfall (mm); Bio2 = Annual mean diurnal range of temperature (10 x °C); Bio9 = Mean temperature of the driest quarter (10 x °C); Bio1 = Annual mean temperature (10 x °C); Bio14 = Precipitation of the driest month (mm).

The model had a very goodness-of-fit (cross-validated average AUC = 0.92 ± 0.02) and a very good predictive power (TSS = 0.72 ± 0.01). The 10^{th} percentile training presence logistic threshold for the habitat suitability discrimination was 0.22. Areas with occurrence probability above this threshold were then considered as suitable for the species, the remaining been considered as unsuitable areas.

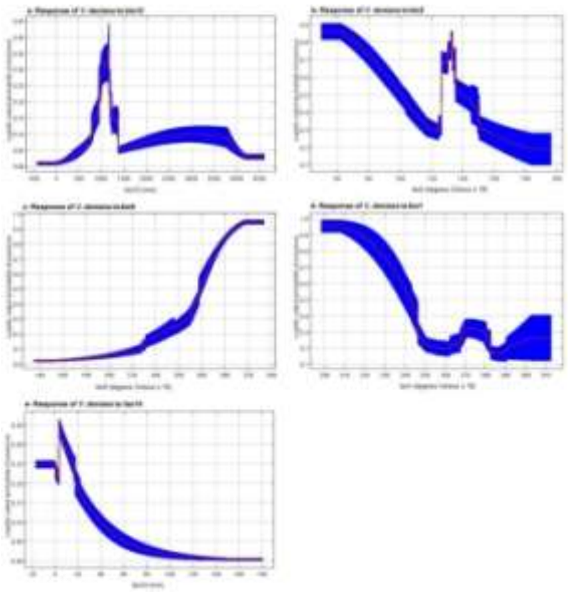

Fig. 4. Response curves of V. doniana to bioclimatic predictors in the habitat suitability modelling.

Responses of V. doniana to the selected bioclimatic predictors

Vitex doniana preferred areas with the annual mean rainfall between 800 and 1200 mm (Fig. 4a). Occurrence probability of the species was at its highest level for annual mean diurnal range of temperature around 6°C and decreased progressively when the range increased up to 12°C. Areas with diurnal range of temperature between 12.5 and 15°C were also suitable for the species (Fig. 4b). Globally, habitat suitability of the species increased with the mean temperature of the driest quarter (Fig. 4c), but it decreased with the annual mean temperature (Fig. 4d). Similarly, increases in the precipitation of the driest month reduced the habitat suitability of *V. doniana* (Fig. 4e).

Logistic output is the occurrence probability of *V. doniana*. a- Annual mean rainfall (bio12, mm); b- Annual mean diurnal range of temperature (bi 02,°C x 10); c- Mean temperature of driest quarter (bi 09,°C x 10); d- Annual mean temperature (bio1, °C x 10); e- Precipitation of driest month (bio14, mm).

Suitable areas for cultivation of V. doniana in Benin

Under current climatic conditions, about 85 % (≈ 98,005 km²) of Benin's area was potentially suitable for the cultivation of *V. doniana* (Table 3). This suitable habitat consisted of two blocks: a southern block and a northern block. The first block covered the Guinean zone and the lower part of the Sudano-Guinean zone; the second block included the upper part of the Sudano-Guinean zone and the Sudanian zone except its extreme northern part which is not actually suitable for the species (Fig. 5a). The habitat suitability was projected to increase by 3 to 12 % (about 3,512 to 14,278 km²) under future climatic conditions for the year 2050 (Table 3; Fig. 5b, c, d & e). For instance, the extreme northern part of the country will become suitable for the cultivation of the species under all the considered future climatic projections. For the RCP 4.5 projections, the increase of the suitable habitat will be two times more important for MIROC5 than for HadGEM2-ES. Meanwhile, when considering RCP 8.5, the most important increase of the suitable area will be noted under Had GEM2-ES (Table 3).

Conservation of V. doniana by protected areas network under current and future climate

Under current climate, about 76 % (≈ 20,832 km²) of the national PAN was suitable for the conservation of *V. doniana* (Table 3). Regarding the two national parks, the major part of the W national park was not currently suitable for the conservation of the species (Fig. 5a). Future climate will slightly ameliorate the in situ conservation of the species by the national PAN. Indeed, the proportion of the conserved suitable habitat will increase under the future climatic projections with HadGEM2-ES showing the greatest variation (thus, +20.71 and +23.27 % for RCP 4.5 and RCP 8.5 respectively). The most important change will likely occur in the W National Park in the Sudanian zone (Fig. 5).

Table 3. Dynamic of suitable areas for cultivation and conservation of V. doniana

Climate		Cultivation			Conservation by PAN		
		Area (Km²)	Area (%)	Variation (%)	Area (Km²)	Area (%)	Variation (%)
Current		98,005.21	85.40	-	20,832.46	76.28	-
RCP 4.5	HadGEM2-ES	103,522.26	90.21	+4.81	26,487.87	96.99	+20.71
	MIROC5	108,502.07	94.54	+9.15	25,603.57	93.75	+17.47
RCP 8.5	HadGEM2-ES	112,283.42	97.84	+12.44	27,187.08	99.55	+23.27
	MIROC5	101,517.94	88.46	+3.06	24,760.40	90.66	+14.38

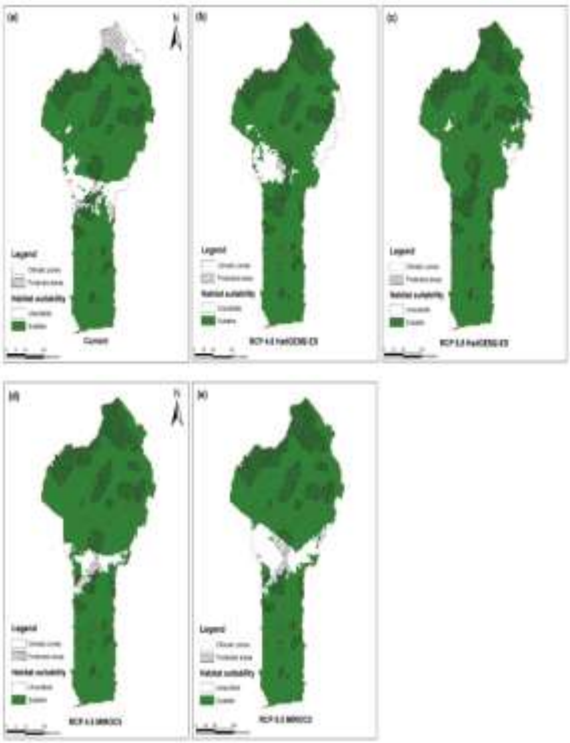

Fig. 5. Potential suitability maps for cultivation and conservation of V. doniana under current and future climate in Benin.

a. Current climatic conditions; b. Future projection according to HadGEM2-ES under RCP 4.5; c. Future projections HadGEM2-ES under RCP 8.5; d. Future projections with MIROC5 under RCP 4.5 and e. Future projections according to MIROC5 under RCP 8.5.

Discussion

Species potential distribution is driven by biotic and abiotic factors with climate playing a determinant role (Walther, 2003, Adomou *et al.*, 2006, Sommer *et al.*, 2010). There are evidences that change in climate will affect distribution of several species (IPCC, 2007, Busby *et al.*, 2010). Species distribution modelling (SDM) are widely used to determine habitat suitability patterns at large spatial scales and to produce spatially explicit and comprehensive maps that are particularly useful for identifying areas where conservation efforts are most needed or effective. Generally, these SDM techniques taking into account information on habitat requirements derived from known occurrence sites are widely used to predict potential habitat of species under current or possible future conditions. Even if these models can not indicate the realised niche, they provide relevant habitat suitability information for a given species and can guide sustainable management plans (Phillips *et al.*, 2006, Sommer *et al.*, 2010, Schwartz, 2012). This information on the derived distribution map are useful in identifying suitable areas for cultivation and assessing conservation status of target species by protected areas network (Schwartz, 2012, Fandohan *et al.*, 2013, Tantipisanuh *et al.*, 2016).

Here, Maximum entropy algorithm (Ma x Ent), one of the most used SDM techniques, was used to assess habitat suitability for cultivation and in situ conservation of *V. doniana* by PAN under current and future (2050) climatic conditions. The future climatic conditions considered were the projections of the Met Office climate model (Had GEM2-ES) and the Model for Interdisciplinary Research on Climate Change (MIROC5) under RCP 4.5 and RCP 8.5. These climatic models projected significant changes in the study area (Table 2). by mid-21st century (Hijmans *et al.*, 2005, IPCC, 2013).

Findings indicated annual mean rainfall, annual mean diurnal range of temperature and mean temperature of the driest quarter as the most important predictors driving the distribution of *V. doniana* (Table 1). Among these predictors, mean annual rainfall showed the greatest contribution confirming the importance of water availability in plants distribution (Adomou *et al.*, 2006). The ecological optimum of the species regarding this climatic predictor is from 800 to 1200 mm (Fig. 4a), and it is effectively within the range of 750-2000 mm indicated by the literature (Arbonnier, 2004, Ky, 2008, Orwa *et al.*, 2009). Regarding temperature factor, it is mainly annual mean diurnal range of temperature and mean temperature of the driest quarter that mostly controlled the species distribution (Table 1).

Following our findings, approximately 85% of Benin's area is potentially suitable for the cultivation of *V. doniana* and about 76% of the national PAN is suitable for its conservation. Significant increases were projected under future climatic (2050) scenarios with several currently unsuitable areas becoming suitable under all the climatic models mainly in the Sudanian and Sudano-Guinean zones. This increase in habitat suitability can be explained by the significant changes projected for the bioclimatic parameters in 2050 (Table 2). Indeed, according to the climatic models used in this study, the extreme northern part of the country (annual mean rainfall mostly below 700 mm) are projected to become wetter with annual rainfall reaching 900 mm (Hijmans *et al.*, 2005). These changes in the rainfall will likely make the areas suitable for *V. doniana* since its ecological optimum is between 750 and 2000 mm/year (Arbonnier, 2004, Ky, 2008, Orwa *et al.*, 2009). The high plasticity of the species in habitat selection also support our findings (Arbonnier, 2004, Ky, 2008, Orwa *et al.*, 2009).

Although models in both RCP showed similar increasing trend of the habitat suitability for cultivation and conservation of the species, some particularities were noted. For instance, the most important variations were noted under the projection of the drastic scenario i.e. RCP 8.5 (Table 3). This climatic scenario is more likely than the second because even though important mitigation actions are being undertaken, the Earth's climate system will still be facing the 'committed warming' (Harris *et al.*, 2014). However, because of the important uncertainties regarding the climatic models (Harris *et al.*, 2014), one should be cautious regarding these projections.

Even though habitat suitability for cultivation and conservation of *V. doniana* are projected to have significant increases in the country, its productivity under future climate might be affected either positively or negatively. In fact, the species may have undergone several physiological adaptations in response to past climates, but under the current rapid climate change, the expansion of the species in new areas will likely require important energy-dependant adjustments in morphological, physiological or behavioural traits of the species and this could have negative impacts on its productivity (Challinor *et al.*, 2006). Long term studies are then required on the physiology, phenology and productivity of the species through its climatic range in order to build a consistent database for the sustainable management of the species under the changing climate.

Conclusion and implications of the study

Findings of this study suggested that *Vitex doniana*, a key agroforestry species for local communities in tropical Africa can be cultivated in a wide range of areas in Benin. Moreover, the national protected areas network offered a large extent of favourable areas for its in situ conservation. With the apparently positive impact of future climate on its habitat suitability, *V. doniana* can be considered as a good candidate for ecological restoration of degraded ecosystems with regard to challenges like climate change.

Conflict of interest

No conflicts of interest to declare.

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Abbreviations

AUC: Area under the receiver operating characteristic curve

CMIP5: Coupled Model Intercomparison Project phase 5

ENMTs: Environmental niche modelling tools

GBIF: Global Biodiversity Information Facility

HadGEM2-ES: Met Office climate model

IPCC: Intergovernmental Panel on Climate Change

MaxEnt: Maximum Entropy

MIROC5: Model for Interdisciplinary Research on Climate Change

PAN: Protected Area Network

RCP: Representative Concentration Pathway

SDM: Species distribution modelling

TSS: True skill statistic

References

Achigan-Dako EG, N'Danikou S, Assogba-Komlan F, Ambrose-Oji B, Ahanchédé A, Pasquini MW. 2011. Diversity, geographical, and consumption patterns of traditional vegetables in sociolinguistic communities in Benin: Implications for domestication and utilization. Economic Botany **65(2),** 129-145. http://dx.doi.org/10.1007/s12231-011-9153-4

Adomou AC, Sinsin B, Van der Maesen LJG. 2006. Phytosociological and Chorological Approaches to Phytogeography: A Meso-Scale Study in Benin. Systematics and geography of plants **76(2),** 155-178.

Akinnifesi FK, Sileshi G, Ajayi OC, Chirwa PW, Kwesiga FR, Harawa R. 2008. Contributions of agroforestry research and development to livelihood of smallholder farmers in Southern Africa: 2. Fruit, medicinal, fuel wood and fodder tree Systems. Agricultural Journal **3(1),** 76-88.

Allouche 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. http://dx.doi.org/10.1111/j.1365-2664.2006.01214.x

Arbonnier M. 2004. Trees, shrubs and lianas of West African dry zones. France: Editions Quae.

Assogbadjo AE, Glèlè Kakaï R, Vodouhê FG, Djagoun CAMS, Codjia JTC, Sinsin B. 2012. Biodiversity and socioeconomic factors supporting farmers' choice of wild edible trees in the agroforestry systems of Benin (West Africa). Forest Policy and Economics **14,** 41-49. http://dx.doi.org/10.1016/j.forpol.2011.07.013

Atato A, Wala K, Batawila K, Lamien N, Akpagana K. 2011. Edible wild fruit highly consumed during food shortage period in togo: State of knowledge and conservation status. Journal of Life Sciences **5,** 1046-1057.

Bellard C, Bertelsmeier C, Leadley P, Thuiller W, Courchamp F. 2012. Impacts of climate change on the future of biodiversity. Ecology Letters **15,** 365-377. http://dx.doi.org/10.1111/j.1461-0248.2011.01736.x

Busby JW, Smith TG, White KL, Strange SM. 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.

Campbell A, Kapos V, Scharlemann JPW, Bubb P, Chenery A, Coad L, Dickson B, Doswald N, Khan MSI, Kershaw F, Rashid M. 2009. Review of the literature on the links between biodiversity and climate change: Impacts, adaptation and mitigation. Montreal, Canada: Secretariat of the Convention on Biological Diversity.

Cantino PD, Harley RM, Wagstaff SJ. 1992. Genera of Labiatae: Status and Classification. In: Harley RM, Reynolds T, Ed. Advances in Labiate Science. Kew: Royal Botanic Gardens.

Challinor AJ, Wheeler TR, Osborne TM, Slingo JM. 2006. Assessing the vulnerability of crop productivity to climate change thresholds using an integrated crop-climate model. In: Schellnhuber JEA, Ed. Avoiding dangerous climate change. Cambridge, UK: Cambridge University Press.

Dadjo C, Assogbadjo AE, Fandohan B, Glèlè Kakaï R, Chakeredza S, Houehanou TD, Damme PV, Sinsin B. 2012. Uses and management of black plum (*Vitex doniana* Sweet) in Southern Benin. Fruits **67(4),** 239-248. http://dx.doi.org/10.1051/fruits/2012017

de Chazal J, Rounsevell MDA. 2009. Land-use and climate change within assessments of biodiversity change: A review. Global Environmental Change **19,** 306-315.http://dx.doi.org/10.1016/j.gloenvcha.2008.09.007

Elith J, Graham CH, Anderson RP, Dudik M, Ferrier S, Guisan A, Hijmans RJ, Huettmann F, Leathwick JR, Lehmann A, Li J, Lohmann LG, Loiselle BA, Manion G, Moritz C, Nakamura M, Nakazawa Y, Overton JM, Peterson AT, Phillips SJ, Richardson K, Scachetti-Pereira R, Schapire RE, Soberon J, Williams S, Wisz MS, Zimmermann NE. 2006. Novel methods improve prediction of species' distributions from occurrence data. Ecography **29,** 129-151. http://dx.doi.org/10.1111/j.2006.0906-7590.04596.x

Elith J, Kearney M, Philips S. 2011a. The art of modeling range-shifting species. Methods Ecology and Evolution **1,** 330-342. http://dx.doi.org/10.1111/j.2041-210X.2010.00036.x

Elith J, Philips SJ, Hastie T, Dudik M, En Chee Y, Yates CJ. 2011b. A statistical explanation of MaxEnt for ecologists. Diversity and Distribution **17,** 43-57. http://dx.doi.org/10.1111/j.1472-4642.2010.00725.x

ESRI. 2014. ArcGIS Desktop. Version 10.3 ed. USA: World Shaded Relief, ESRI.

Fandohan AB, Oduor AMO, Sode AI, Wu L, Cuni-Sanchez A, Assede E, Gouwakinnou GN. 2015. Modeling vulnerability of protected areas to invasion by *Chromolaena odorata* under current and future climates. Ecosystem Health and Sustainability **1(6)**. http://dx.doi.org/10.1890/EHS15-0003.1

Fandohan B, Assogbadjo AE, Glèlè Kakaï RL, Sinsin B. 2011. Effectiveness of a protected areas network in the conservation of *Tamarindus indica* (Leguminosea–Caesalpinioideae) in Benin. African Journal of Ecology **49,** 40-50. http://dx.doi.org/10.1111/j.1365-2028.2010.01228.x

Fandohan B, Gouwakinnou GN, Fonton NH, 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. Biotechnology, Agronomy, Society and Environment **17(3)**.

FAO. 2012. Forest Management and Climate Change: a literature review. In: Fao (ed.) Forests and Climate Change. Rome, Italy: FAO.

Garrity DP. 2004. Agroforestry and the achievement of the Millennium Development Goals. Agroforestry systems **61,** 5-17. http://dx.doi.org/10.1023/B:AGFO.0000028986.37502.7c

GBIF. 2015. GBIF Occurrence Download. Denmark: Global Biodiversity Information Facility.

www.gbif.org/occurrence/download/0004919-150922153815467

Gnanglè CP, Glèlè Kakaï R, Assogbadjo AE, Vodounnon S, Yabi JA, Sokpon N. 2011. Tendances climatiques passées, modélisation, perceptions et adaptations locales au Bénin. Climatologie **8**, 27-40. http://dx.doi.org/10.4267/climatologie.259

Haarmeyer DH, Schumann K, Bernhardt-Romermann M, Wittig R, Thiombiano A, Hahn K. 2013. Human impact on population structure and fruit production of the socio-economically important tree *Lannea microcarpa* in Burkina Faso. Agroforestery Systems **87,** 1363-1375. http://dx.doi.org/10.1007/s10457-013-9644-7

Harley RM, Atkins S, Budntsev PD, Cantino PD, Conn BJ, Grayer R, Harley MM, De Kok R, Kresstovskaja T, Morales R, Paton AJ, Ryding O, Upson T. 2004. Labiatae. In: Kubitzki K, Ed. The Families and Genera of Vascular Plants: Flowering Plant-Dicotyledons. Germany: Springer-Verlag.

Harris RMB, Grose MR, Lee G, Bindoff NL, Porfiri LL, Fox-Hughes P. 2014. Climate projections for ecologists. Wiley Interdisciplinary Reviews: Climate Change **5,** 621-637. http://dx.doi.org/10.1002/wcc.291

Hijmans RJ, Cameron SE, Parra JL, Jones PG, Jarvis A, others. 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology **25(15),** 1965-1978. http://dx.doi.org/10.1002/joc.1276

IPCC. 2007. Climate change: synthesis report. New York, USA: Intergovernmental Panel on Climate Change (IPCC).

IPCC. 2013. Climate change 2013: the physical science basis. Contribution of Working Group I to the fifth assessment report of the intergovernmental panel on climate change. New York, USA: Intergovernmental Panel on Climate Change.

IUCN, UNEP-WCMC. 2015. The World Database on Protected Areas (WDPA). Cambridge, UK. www.protectedplanet.net

Iwueke AV, Nwodo OFC, Okoli CO. 2006. Evaluation of the anti-inflammatory and analgesic activities of *Vitex doniana* leaves. African journal of biotechnology **5(20),** 1929-1935. http://dx.doi.org/10.5897/AJB2006.000-5086

Kilani AM. 2006. Antibacterial assessment of whole stem bark of *Vitex doniana* against some enterobactriaceae. African journal of biotechnology **5(10),** 958-959. http://dx.doi.org/10.5897/AJB06.085

Ky KJM. 2008. *Vitex doniana* Sweet. In: Louppe D, Oteng-Amoako AA, Brink M, Ed. Prota: Timbers/Bois d'oeuvre. Wageningen, Pays Bas: Backhuys Publishers, Leiden/CTA, Wageningen, PROTA Foundation.

Lucier A, Ayres M, Karnosky D, Thompson I, Loehle C, Percy K, Sohngen B. 2009. Forest responses and vulnerabilities to recent climate change. In: Seppala R, Buck, A. And Katila, P. (ed.) Adaptation of forests and people to climate change. IUFRO.

Mapongmetsem PM, Benoit LB, Nkongmeneck BA, Ngassoum MB, Gübbük H, Baye–Niwah C, Longmou J. 2005. Litterfall, Decomposition and Nutrients Release in *Vitex doniana* Sweet. and *Vitex madiensis* Oliv. in the Sudano–Guinea Savannah. Akdeniz Üniversitesi Ziraat Fakültesi Dergisi **18(1),** 63-75.

Mapongmetsem PM, Djoumessi MC, Yemele MT, Fawa G, Doumara DG, Noubissie JBT, Tientcheu A, Louise M, Bellefontaine R. 2012. Domestication de *Vitex doniana* Sweet. (Verbenaceae): influence du type de substrat, de la stimulation hormonale, de la surface foliaire et de la position du nœud sur l'enracinement des boutures uninodales. Journal of Agriculture and Environment for International Development **106(1),** 23-45. http://dx.doi.org/10.12895/jaeid.20121.50

Maundu P, Achigan-Dako EG, Morimoto Y. 2009. Biodiversity of African vegetables. In: Shackleton CM, Pasquini MW, Drescher AW, Ed. African Indigenous Vegetables in Urban Agriculture. Earthscan, London, UK.

Maundu P, Kariuki P, Eyog-Matig O. 2006. Threats to medicinal plant species-an African perspective. In: Miththapala S, Ed. Conserving medicinal species: Securing a healthy future. Asia: Ecosystems and Livelihoods Group (IUCN).

McClean CJ, Lovett JC, Kuper W, Hannah L, Sommer JH, Barthlott W, Termansen M, Smith GE, Tokamine S, Taplin JRD. 2005. African plant diversity and climate change. Annals of the Missouri Botanical Garden **92,** 139-152.

McSweeney CF, Jones RG, Lee RW, Rowell DP. 2015. Selecting CMIP5 GCMs for downscaling over multiple regions. Climate Dynamics **44,** 3237-3260. http://dx.doi.org/10.1007/s00382-014-2418-8

Mensah S, Houehanou TD, Sogbohossou EA, Assogbadjo AE, Glèlè Kakaï R. 2014. Effect of human disturbance and climatic variability on the population structure of *Afzelia africana* Sm. ex pers. (Fabaceae–Caesalpinioideae) at country broad-scale (Benin,West Africa). South African Journal of Botany **95,** 165-173. http://dx.doi.org/10.1016/j.sajb.2014.09.008

Nacoulma BMI, Traoré S, Hahn K, Thiombiano A. 2011. Impact of land use types on population structure and extent of bark and foliage harvest of *Afzelia africana* and *Pterocarpus erinaceus* in Eastern Burkina Faso. International Journal of Biodiversity and Conservation **3(3),** 62-72.

Oladélé OI. 2011. Contribution of indigenous vegetables and fruits to poverty alleviation in Oyo State, Nigeria. Journal of Human and Ecology **34(1),** 1-6.

Orwa C, Mutua A, Kindt R, Jamnadass R, Simons A. 2009. Agroforestree Database: a tree reference and selection guide version 4.0. http://www.worldagroforestry.org/af/treedb/

Padmalatha K, Jayaram K, Raju NL, Prasad MNV, Arora R. 2009. Ethnopharmacological and biotechnological significance of *Vitex*. Bioremediation, Biodiversity and Bioavailability **3(1),** 6-14.

Parmesan C. 2006. Ecological and evolutionary responses to recent climate change. Annual Review of Ecology, Evolution and Systematics **37,** 637-669. http://dx.doi.org/10.1146/annurev.ecolsys.37.091305.110100

Pearson RG, Christopher J, Raxworthy MN, Peterson AT. 2007. Predicting species distributions from small numbers of occurrence records: a test case using cryptic geckos in Madagascar. Journal Biogeography **34,** 102-117. http://dx.doi.org/10.1111/j.1365-2699.2006.01594.x

Phillips SJ, Anderson RP, Schapire RE. 2006. Maximum entropy modelling of species geographic distributions. Ecological Modelling **190,** 231-259. http://dx.doi.org/10.1016/j.ecolmodel.2005.03.026

Scheldeman X, van Zonneveld M. 2010. Training manual on spatial analysis of plant diversity and distribution. Rome, Italy: Bioversity International.

Schwartz MW. 2012. Using niche models with climate projections to inform conservation management decisions. Biological Conservation **155,** 149-156. http://dx.doi.org/10.1016/j.biocon.2012.06.011

Sommer JH, Kreft H, Kier G, Jetz W, Mutke J, Barthlott W. 2010. Projected impacts of climate change on regional capacities for global plant species richness. Proceedings of the Royal Society of London B: Biological Sciences **277,** 2271-2280. http://dx.doi.org/10.1098/rspb.2010.0120

Tantipisanuh N, Savini T, Cutter P, Gale GA. 2016. Biodiversity gap analysis of the protected area system of the Indo-Burma Hotspot and priorities for increasing biodiversity representation. Biological Conservation **195,** 203-213. http://dx.doi.org/10.1016/j.biocon.2015.12.043

Vodouhè R, Dansi A, Avohou HT, Kpèki B, Azihou F. 2011. Plant domestication and its contributions to in situ conservation of genetic resources in Benin. International Journal of Biodiversity and Conservation **3(2),** 40-56.

Walther G-R. 2003. Plants in a warmer world. Perspectives in Plant Ecology, Evolution and Systematics **6,** 169-185. http://dx.doi.org/10.1078/1433-8319-00076

Walther G-R, Post E, Convey P, Menzel A, Parmesan C, Beebee TJC, Fromentin J-M, Guldberg OH, Bairlein F. 2002. Ecological responses to recent climate change. Nature **416,** 389-395. http://dx.doi.org/10.1038/416389a.