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ORIGINAL ARTICLE

Potential geographic distribution and modelling of the ecological niche of *Harrisonia abyssinica*, a priority medicinal tree species in Benin (West Africa)

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Abstract

The modelling of the ecological niche of *Harrisonia abyssinica* in Benin made it possible to have a function of both parameters which predicts the probability of the presence of the species in their respective habitats. This study showed the current distribution of this species and its prediction for 2050. Species occurrence data records were combined with climatic and soil data in Maximum Entropy (Maxent), a species distribution modelling algorithm, to evaluate the impacts of future environmental conditions (under CNRM-CM5 and HadGEM2-ES) on the species' potential distribution in Benin. The result showed that the habitats which are currently very suitable to *H. abyssinica* are mainly located in those agro-ecological zones: Cotton zone of the center (V), Zone of the land of bars (VI), Zone of depression (VII) and the Zone of fisheries (VIII) covering an area of 5339.21 km^2 (4.7%) of the Beninese national territory. CNRM-CM5 model showed a decrease of 510.07 km^2 in the highly suitable area for the species and HadGES-ES model showed an increase of 791.79 km^2. According to the two models, the classified forest of Lama is and will remain the single protected forest moderately suitable to the conservation of *H. abyssinica* in Benin.

Keywords *Harrisonia abyssinica* · Distribution · Modelling and suitable habitat · Ecological niche

Introduction

For decades, in terms of contribution to health care, energy, food, cash income and other aspects of human well-being, Non-Timber Forest Products (NTFPs) have been of paramount importance and are therefore essential (Goussanou et al. 2011; Agbo et al. 2019b). Faced with increasing human population, the availability of these resources depends to a large extent on the management that humans make of them (IUCN 2003).

In Benin, 814 medicinal plant species with different properties have been identified (Sinsin and Owolabi 2001; Déléké Koko et al. 2011; Dougnon et al. 2016). Among these, figured *H. abyssinica*, this is of vital medicinal importance to the population (Emongor 2008; Bene et al. 2015; Ogougbé et al. 2019). Therefore, the demographic growth observed today has led to the modification and fragmentation of the habitats of natural ecosystems with significant pressures leading to isolation and extinction of natural plant populations (Feely and Terborgh 2008). Currently, a significant demographic growth in Benin with all its consequences,

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wild species like *H. abyssinica* subject to disappearance (Agbo et al. 2017; Ogougbé et al. 2019).

Furthermore, climate change is an environmental issue that deserves special attention. According to several studies, climate change, added to anthropogenic pressures, constitutes the first cause of the disappearance of biodiversity (Adjahossou et al. 2016). Indeed, climate change modifies the climatic conditions of suitable habitats of species and anthropic action induces the loss of these. According to (Boko et al. 2007), in Africa, 25 to 42% of plant species could be threatened with extinction due to the loss of 81 to 97% of their suitable habitats by 2085. Global areas of forests primaries have reduced by more than 80 million hectares since 1990 (FAO 2020). According to projections, 20 to 30% of plant and animal species will face a higher great risk of extinction if global warming exceeds 1.5 °C to 2.5 °C in Africa (Busby et al. 2010).

However, today, with threats to biodiversity, some of these species are becoming increasingly rare in their natural habitats. *Harrisonia abyssinica* do not do exception. Especially since the fluctuations of climatic variables, such as precipitation and temperature, have an impact on biological diversity and on the geographic distribution of habitats suitable to species (IPCC 2007), climate change is an environmental issue that deserves special attention to planning and conservation of forest resources. Increasing atmospheric CO_2 concentrations, increasing temperatures, changes in precipitation, floods, frequent droughts and longer durations will have significant effects on tree growth (Elith and Leathwick 2009). The constantly observed climate change associated with increased anthropogenic pressures is becoming more and more worrying for the conservation of our natural resources. It therefore appears urgent to investigate the probable effects of climate change on the geographic distribution of *H. abyssinica* (present and future suitable habitats). However, scientific information relating to the influence of climatic and ecological factors on the spatial distribution of *H. abyssinica* for better monitoring of its dynamics and conservation is still in its infancy in Benin. Knowledge of this information is very important, because to establish a good conservation and management policy for a species, it makes it possible to identify the potential areas where the species is abundant and thus guides the choice of areas where the specific measures for conservation of the species will be undertaken (Wembou et al. 2017).

To this end, statistical techniques have evolved and geographic information systems have been developed to help consider much more satisfactory distribution models (Elith and Leathwick 2009). These models will, on the one hand, provide a better understanding of the ecology of species and, on the other hand, allow more reliable predictions. Among these models are the Maximum Entropy (MaxEnt) models (Phillips et al. 2006). This method has interesting characteristics compared to regression type models for example, in relation to the type of data generally used (Idohou et al. 2017; Agbo et al. 2019a). It is particularly suitable for presence data only (which are more common in ecology than presence-absence data) and for the use of many interacting variables (Elith et al. 2011). These analyses have current and future knowledge of the distribution of species and make sustainable decisions for the conservation of biological diversity, especially those species that enjoy almost no conservation status and whose population is suspected to be declining (Agbo et al. 2019a). The aim of this work is to study the influence of climate change on the geographic distribution of *H. abyssinica* in Benin and to highlight the present and future habitats suitable for the conservation of this species. This idea is coming after several research questions. The questions are, (i) what is the current state of the natural populations of *H. abyssinica*? (ii) What are the environmental factors that influence its distribution? (iii) Where can we keep it? To satisfy this curiosity and also to fill this scientific information gap, we set ourselves the following specific objectives to:

(i) Characterize the areas of occurrence of *H. abyssinica* in Benin;
(ii) Assess the effectiveness of current network of protected areas for the conservation of *H. abyssinica* in Benin;
(iii) Modelling the present and potential ecological niche by 2050 of the species in Benin.

Materials and methods

Materials

The material used takes into account the study site, the occurrence data of *Harrisonia abyssinica* and the environmental and bioclimatic variables which participate in its distribution.

Study area

Benin is made up of eight agro-ecological zones. The classification of these areas is based on the definition of relatively homogeneous areas using agro-pedological parameters, cropping systems, spatial distribution of the population and vegetation (PNUD / ECVR 1996). Concerned geographic distribution of the species, four zones have been selected (GBIF website: Global Biodiversity Information Facility: www.gbif.org; Flore Analytique du Benin: De Souza 2009). Zone V which is the cotton zone of Central Benin grouping the municipalities of Bassila, Parakou, Tchaourou, Ouessè, Bantè, Savè, Savalou, Glazoué, Kétou, Djidja, Dassa and

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Aplahoué where are produced twice a year Cereals, tubers, legumes and cotton. Zone VI which is the bar lands zone grouping the municipalities of Abomey-Calavi, Allada, Kpomassè, Tori-Bossito, Zè, Djakotomé, Dogbo, Klouékanmey, Houéyogbé, Toviklin, Adjarra, Ifangni, Missérété, Avrankou, Porto-Novo, Sakété, Abomey, Agbangnizoun, Bohicon, Covè, Zakpota and Zagnanado where corn is mainly grown at the head of rotation, cassava, cowpea and peanut. In this area, the rain regime is often disturbed, leading to changes in the annual production cycles. Zone VII is the depression zone comprising the municipalities of Adja-Ouèrè, Pobè, Toffo, Lalo and Zogbodomey. Corns associated with cassava, cowpea, tomato, chilli, etc. constitute their basis of the production system. Zone VIII, which is the fisheries zone, abounds in the municipalities of Athiémé, Grand-Popo, Bopa, Comé, Lokossa, Ouidah, So Ava, Sèmè-Podji, Aguégués, Dangbo, Adjohoun, Bonou, Ouinhi and Cotonou. We mainly have fishing in this area, followed by the cultivation of maize at the head, cassava, cowpea and vegetable crops. The very low availability of land limits the expansion of agriculture (PANA 2007).

Data

Occurrence data for the species

The geographic coordinates (longitude and latitude) of the presence of *H. abyssinica* were recorded using a GPS (Global Positioning System) within the probable distribution areas (classified forests, fields, fallows and others) of the species. To these data, have been added the coordinates of points of presence of the species available on the GBIF website (Global Biodiversity Information Facility: www.gbif.org). A total of 94 points of occurrence were recorded.

Environmental data

The climatic data used in this study were imported from the site www.worldclim.org/bioclim at a spatial resolution of 30 arc sec (1 km square). These are 19 climatic variables (Table 1) generated from raw climatic data (precipitation and temperature) which can have an influence on the distribution of the species (Gbesso et al. 2013; Wembou et al. 2017). Indeed, the distribution of the species does not only depend on the climate, but also on the type of soil, we then added data relating to the imported soil in the form of layers in the world database of soils (Harmonized World Soil Database version 1.2 (FAO/IIASA/ISSCAS/JRC 2012) previously used by (Beck 2013) and (Agbo et al. 2019a) at a resolution of 30 s. The soil layers used are: cec_1 (exchange capacity, horizon 0–5 cm), cec_2 (capacity cation exchange, horizon 5–15 cm), cec_3 (cation exchange capacity, horizon 15–30 cm), cec_4 (cation exchange capacity, horizon 30–60 cm), cec_5 (cation exchange capacity, horizon 60–100 cm), clay_1 (clay, horizon 0–5 cm), clay_2 (clay, horizon 5–15 cm), clay_3 (clay, horizon 15–30 cm), clay_4 (clay, horizon 30–60 cm), clay_5 (clay, horizon 60–100 cm), oc_1 (organic carbon, horizon 0–5 cm), oc_2 (organic carbon, horizon 5–15 cm), oc_3 (organic carbon, horizon 15–30 cm), oc_4 (organic carbon, horizon 30–60 cm), oc_5 (organic carbon, horizon 60–100 cm), ph_1 (Ph, horizon 0–5 cm), ph_2 (Ph, horizon 5–15 cm), ph_3 (Ph, horizon 15–30 cm), ph_4 (Ph, horizon 30–60 cm), ph_5 (Ph, horizon 60–100 cm), sand_1 (sand, horizon 0–5 cm), sand_2 (sand, horizon 5–15 cm), sand_3 (sand, horizon 15–30 cm), sand_4 (sand, horizon 30–60 cm), sand_5 (sand, horizon 60–100 cm), silt_1 (silt, horizon 0–5 cm), silt_2 (silt, horizon 5–15 cm), silt_3 (silt, horizon 15–30 cm), silt_4 (silt, horizon 30–60 cm), silt_5 (silt, horizon 30–100 cm).

Table 1 Bioclimatic variables used in the model

Code	Bioclimatic variables	Code	Bioclimatic variables
Bio_1	Annual average temperature	Bio_11	Average temperature of the coldest quarter
Bio_2	Average daily temperature variation (monthly average)	Bio_12	Annual precipitation
Bio_3	Ratio of daily thermal range to annual thermal range	Bio_13	Wettest month precipitation
Bio_4	Seasonality of temperature (standard deviation * 100)	Bio_14	Driest month precipitation
Bio_5	Maximum temperature of the hottest month	Bio_15	Seasonality of precipitation (coefficient of variation)
Bio_6	Minimum temperature of the coldest month	Bio_16	Wettest quarter precipitation
Bio_7	Annual temperature variation	Bio_17	Precipitation of the driest quarter
Bio_8	Average temperature of the wettest quarter	Bio_18	Precipitation of the hottest quarter
Bio_9	Average temperature for driest quarter	Bio_19	Precipitation of the coldest quarter
Bio_10	Average temperature of the hottest quarter		

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Methods

Spatio-temporal analysis of *Harrisonia abyssinica*

The applied methodological approach is that of environmental modelling with the Maximum Entropy (Maxent) algorithm. To this end, the data collected were entered in an Excel file and then converted into csv format, compatible with the MaxEnt algorithm of the model. The geographic coordinates were recorded and processed using the Excel spreadsheet and any errors (duplicate records) identified were eliminated with tools for modelling the ENM ecological niche (www.ENMTools.com) (Warren et al. 2010). These occurrence data were projected into the map of Benin using ArcGis software version 10.3 (ESRI 2014), to determine the distribution of *H. abyssinica* in Benin. The MaxEnt algorithm was used to analyze geographic (species occurrence data) and bioclimatic data to model the current and future potential distribution of *H. abyssinica.*

Presentation of the model

Various statistical methods are used to model the distribution of species, the distributions of habitats that are suitable to them, or to estimate the probability of the presence/absence of a given species at a given geographic position (Guisan et al. 2000). MaxEnt is one of the most powerful modelling methods capable of generating very good biogeographic information while offering good discrimination of suitable habitats and unsuitable to a species from a bioclimatic point of view (Phillips et al. 2006). The advantage of this method for this study is that it combines the observed presence data of a given species with the current bioclimatic characteristics at the observation points to generate:

- A global map of the potential habitats of the species in the area considered;
- A global map of the future distribution of these suitable habitats vis-à-vis the climate projections made for the area studied.

Modelling and validation of the MaxEnt model

The bioclimatic variables were subjected to a Jackknife test in MaxEnt to determine which ones contribute most to the modelling (Gbesso et al. 2013; Agbo et al. 2019a). To assess the model, the presence points of the species was used (Fandohan et al. 2013). Cross-validation of the model was repeated five times to produce very significant estimates of model performance. The performance of the model is evaluated using the AUC (Area Under the Curve) statistic. AUC can be interpreted as the likelihood that a randomly selected point of presence is located in a raster cell with a greater probability of occurrence of the species than a randomly generated point (Phillips et al. 2006). According to (Gnagbo et al. 2015), a model is said to be of good quality if the AUC value is greater than 0.80 (Table 2). The type of repetition with the highest AUC value was used for the modelling of the ecological niche of *H. abyssinica* species.

Data mapping and analysis

The probability distribution generated by the model was taken as a measure of the probability of the species occurring. The modelling results produced by MaxEnt obtained in the form of ASCII format files were imported into ArcGis version 10.3 to classify the different habitat levels suitable to *H. abyssinica* (Ayihouénou et al. 2016; Agbo et al. 2019a). Based on the exit from the classification carried out as part of this study, three priority habitat classes have been defined. The class having a probability below the threshold of 0.23 was considered to belong to a habitat very little suitable to the species, that situated between 0.23 and 0.45 would correspond to the moderately suitable habitat and that comprised between 0.45 and 1 represents the very suitable habitat for the species. Furthermore, with the spatial analysis tool of ArcGis, the extent of each habitat level under both current and future conditions (horizon 2050) according to the models CNRM-CM5 and HadGEM2-ES was calculated from the number of pixels occupied by each type of habitat to assess the gain or loss in the area suitable to the species to the country scale (Benin) according to climate projections. To assess the current and future effectiveness of protected areas in the conservation of the species, a gap analysis of the areas suitable to the species in protected areas (Gap analysis) was carried out by superimposing the national network map of protected areas in Benin to the distribution maps obtained. The extent of suitable habitats and their spatio-temporal dynamics were estimated using the "spatial analyst" tool in ArcGIS 10.3 software.

Table 2 Validity of the MaxEnt test according to the values of the Area Under the Curve (AUC)

AUC values	Interpretations
$0,90 \leq AUC \leq 1,00$	Excellent
$0,80 \leq AUC \leq 0,90$	Good
$0,70 \leq AUC \leq 0,80$	Acceptable
$0,60 \leq AUC \leq 0,70$	Bad
$0,50 \leq AUC \leq 0,60$	Invalid

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Results

Geographical distribution of *Harrisonia abyssinica* in Benin

The distribution map of *H. abyssinica* constructed showed that the species is not widely distributed in Benin. It is found in twelve (12) municipalities, namely: Ouidah, Pobè, Lalo, Sakété, Ifangni, Dassa-zoumè, Allada, Torri-Bossito, Zogbodomè, Dangbo, Toffo and Kétou distributed in agro-ecological zones: Central cotton zone (V), Zone bar earth (VI), depression zone (VII) and the fisheries zone (VIII) and is almost absent in the other four agro-ecological zones. Figure 1 showed that *H. abyssinica* is found in populations more in plant formations (Savannahs, dense semi-deciduous forests, gallery forests, fallows, etc.) than in classified forests.

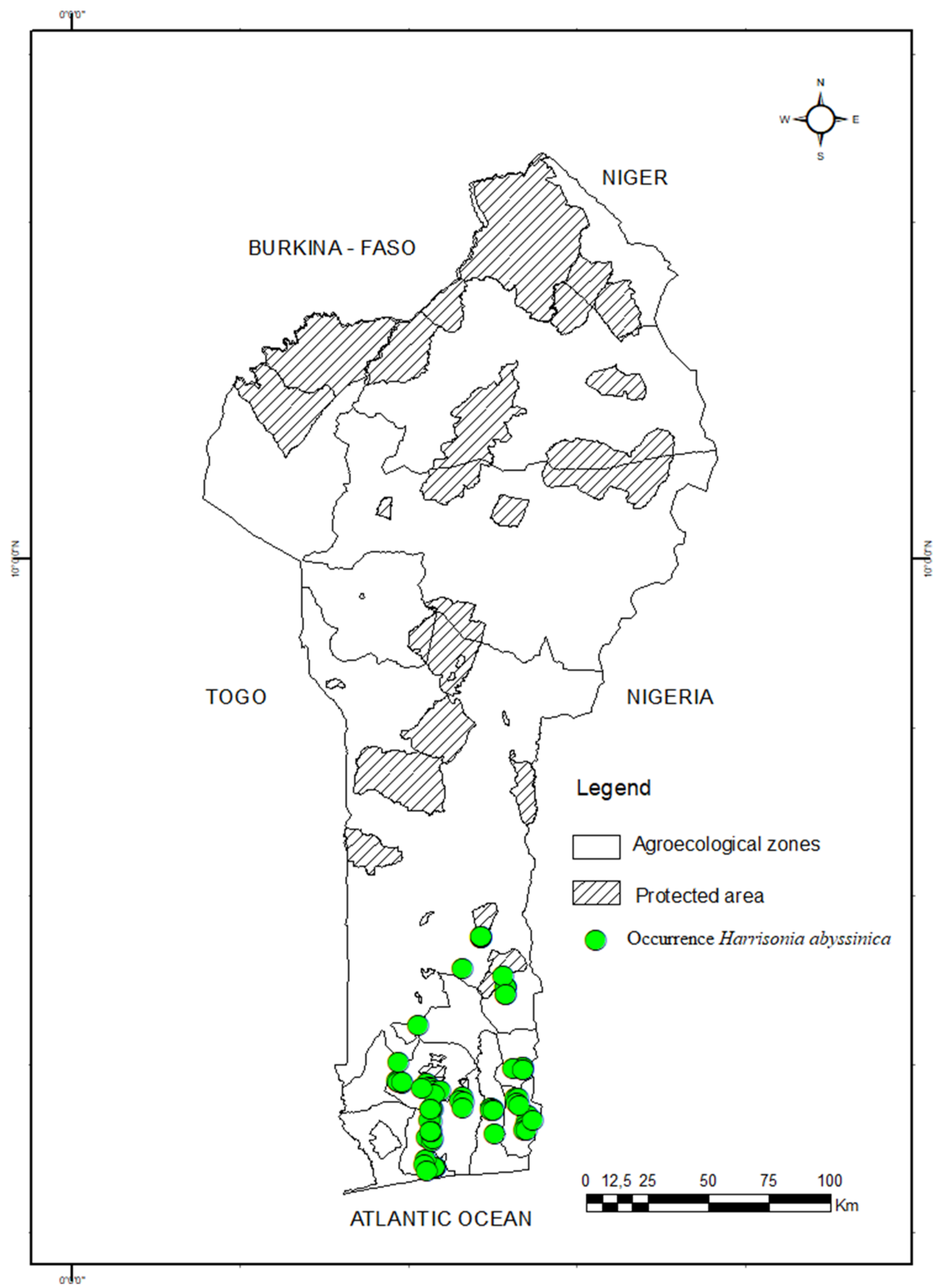

Fig. 1 Geographic distribution of *Harrisonia abyssinica* in Benin

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Table 3 Bioclimatic variables used and contributions to the model

Code	Variables	Contribution (%)
Bio_17	Precipitation of the driest quarter	66
Bio_2	Average daily temperature variation (monthly average)	14.4
Bio_13	Wettest month precipitation	1.6
ph_5	pH (horizon 60–100 cm)	1.8
silt_2	silt (horizon 5–15 cm)	9.5
silt_3	silt (horizon15–30 cm)	6.7

Modelling of the current and by 2050 potential ecological niche of *H. abyssinica* in Benin

Selection of environmental variables and validation of the model

In total, three environmental variables and three edaphic characteristics were selected to turn the model. This is (Bio_17; Bio_13 and Bio_2; ph_5; silt_2 and silt_3). The (Table 3) presents the contribution of the six selected variables. From the analysis of this table, it appears that the variables Bio_17 contributed more to the construction of the model. Figure 2 is the characteristic operating curve of the receiver (ROC) with the means and with several repetitions. The average training AUC for repetitions is 0.961 and the standard deviation was 0.003. Also, the analysis of Jackknife presented (Fig. 3), showed that the variables that contributed most to the development of the model when used in isolation are Bio_17 and silt_3.

This suggested a good performance of the MaxEnt algorithm in capturing variations in environmental data. For each environmental variable, the green bar shows by how much the total gain is reduced if this specific variable is excluded from the analysis. On the contrary, the blue bar shows the gain obtained if a variable is used in isolation and the remaining variables are excluded from the analysis. The red band indicates the performance of the model shot with all the variables.

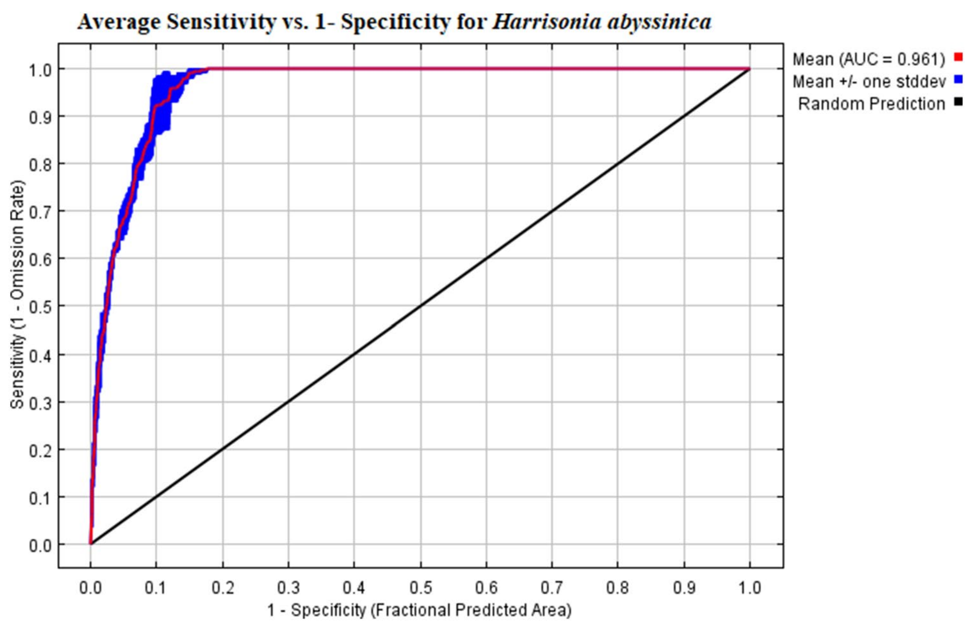

Fig. 2 Curve of the average AUC value of the distribution model of *Harrisonia abyssinica*

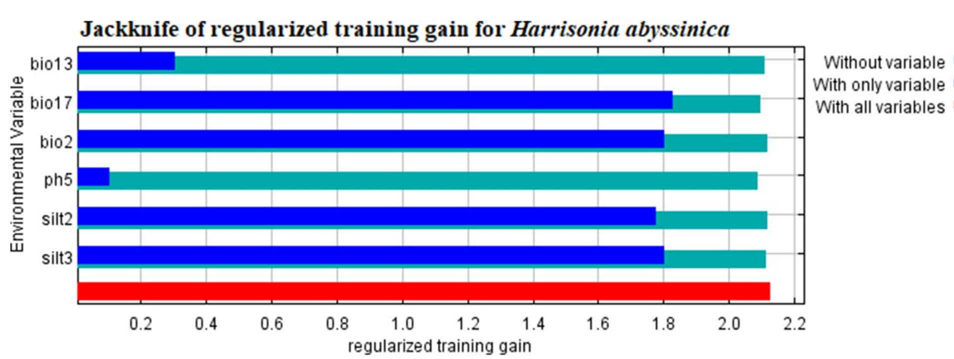

Fig. 3 Jackknife test result on contribution of models

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Current and future distribution of suitable habitats for *H. abyssinica*

Globally, the modelling results showed that the habitats which are currently very suitable to *H. abyssinica* are mainly located in South Benin in the agro-ecological zones Cotton zone of the center (V), Bar lands zone (VI), Depression zone (VII) and the Fisheries Zone (VIII) while the unsuitable habitats or not are located in the regions of the central and northern parts of Benin corresponding to the agro-ecological zones Extreme north zone, North cotton zone, Food zone of South Borgou and the West Atacora Zone) (Fig. 4).

With regard to future projections to 2050, the CNRM-CM5 and HadGEM2-ES models showed a different variation in very suitable habitat levels (Figs. 5, 6). The model CNRM-CM5 showed a decrease in the area very suitable to the species, an increase in the area moderately suitable and a decrease in the area not very suitable. However, HadGES-ES model showed an increase in the very suitable area, a decrease in the moderately suitable area and a slight increase in the unsuitable area.

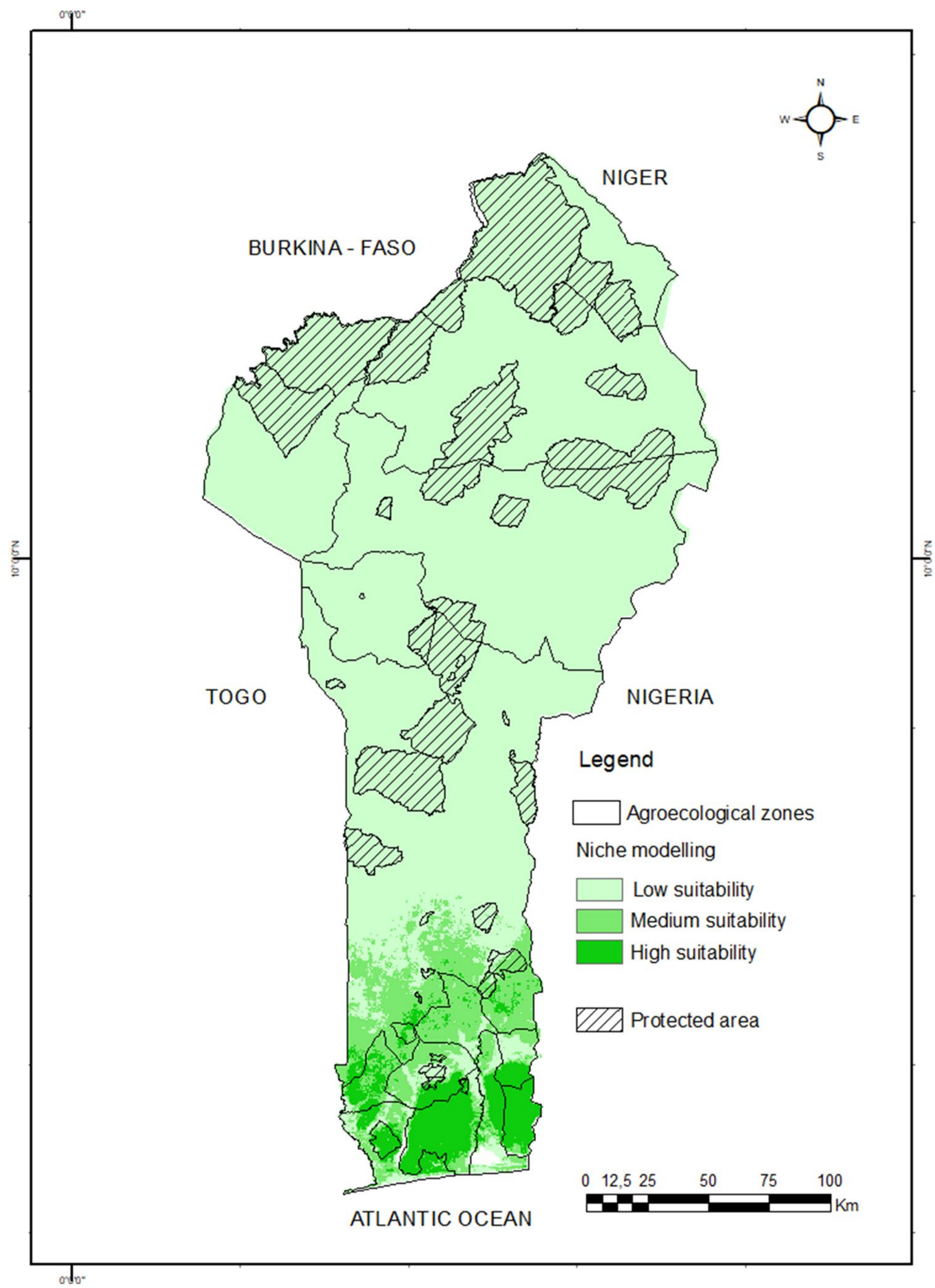

Fig. 4 Present-day suitable habitats of *Harrisonia abyssinica* in Benin

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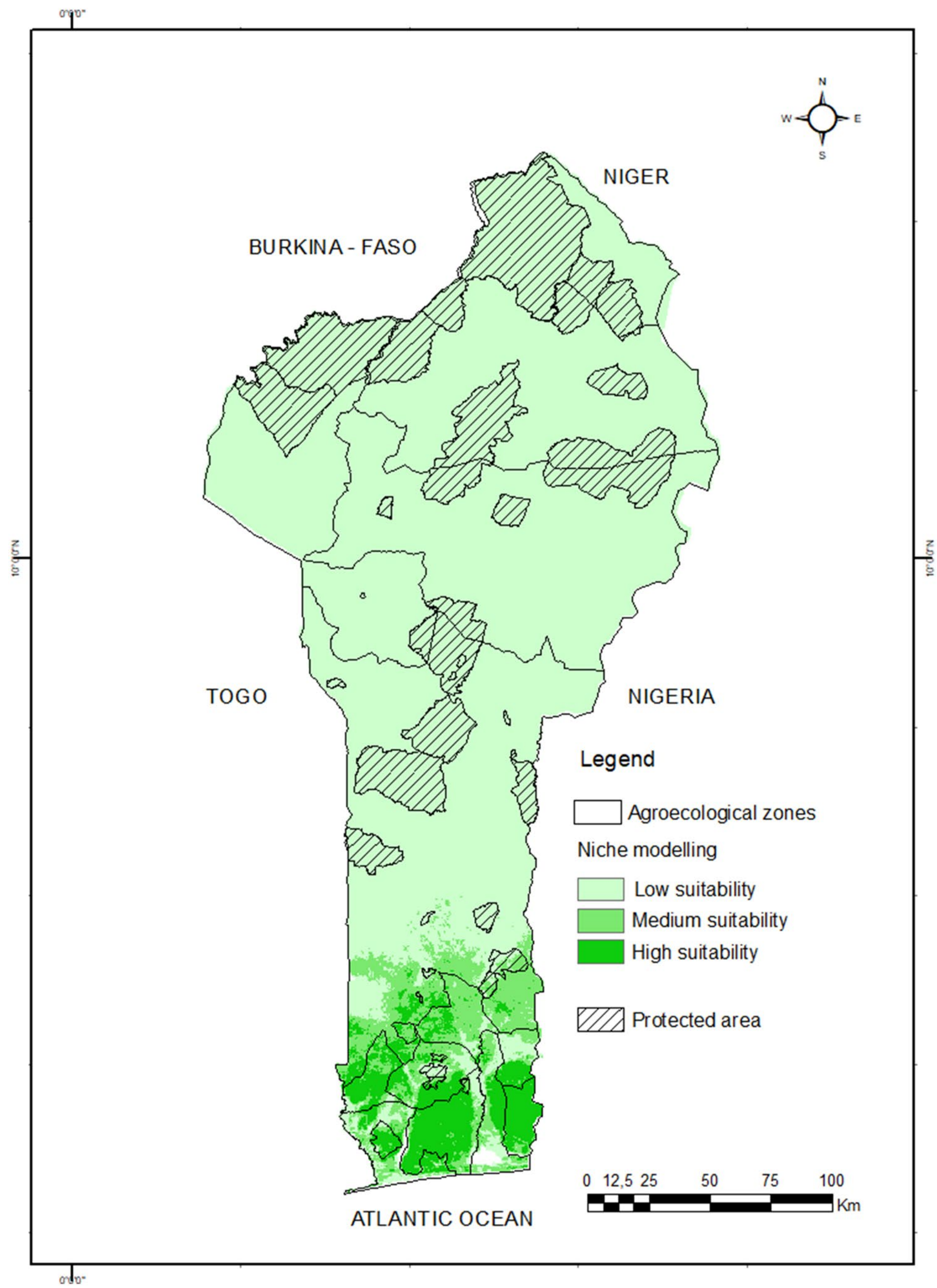

Fig. 5 Suitable future habitats (Horizon 2050) for *Harrisonia abyssinica* in Benin under a CNRM-CM5 model

Indeed, at the end of the analysis of the extents of the different levels of habitats suitable to the species, it appears that about 5339.21 km^2 (4.7%) of the national territory (islands not included), are currently very suitable to *H. abyssinica*. The moderately suitable and not very suitable habitats, respectively, occupy approximately 9798.22 km^2 (8.5%) and 99,626.57 km^2 (86.8%) of the national territory (Table 4).

Discussion

Contribution of climatic variables and performance of the algorithm

Ecological niche modelling is one of the effective ways to assess the distribution of suitable habitats and project the impact of climate change on a species. It makes it possible

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Fig. 6 Suitable future habitats (Horizon 2050) for *Harrisonia abyssinica* in Benin under a HadGES-ES model

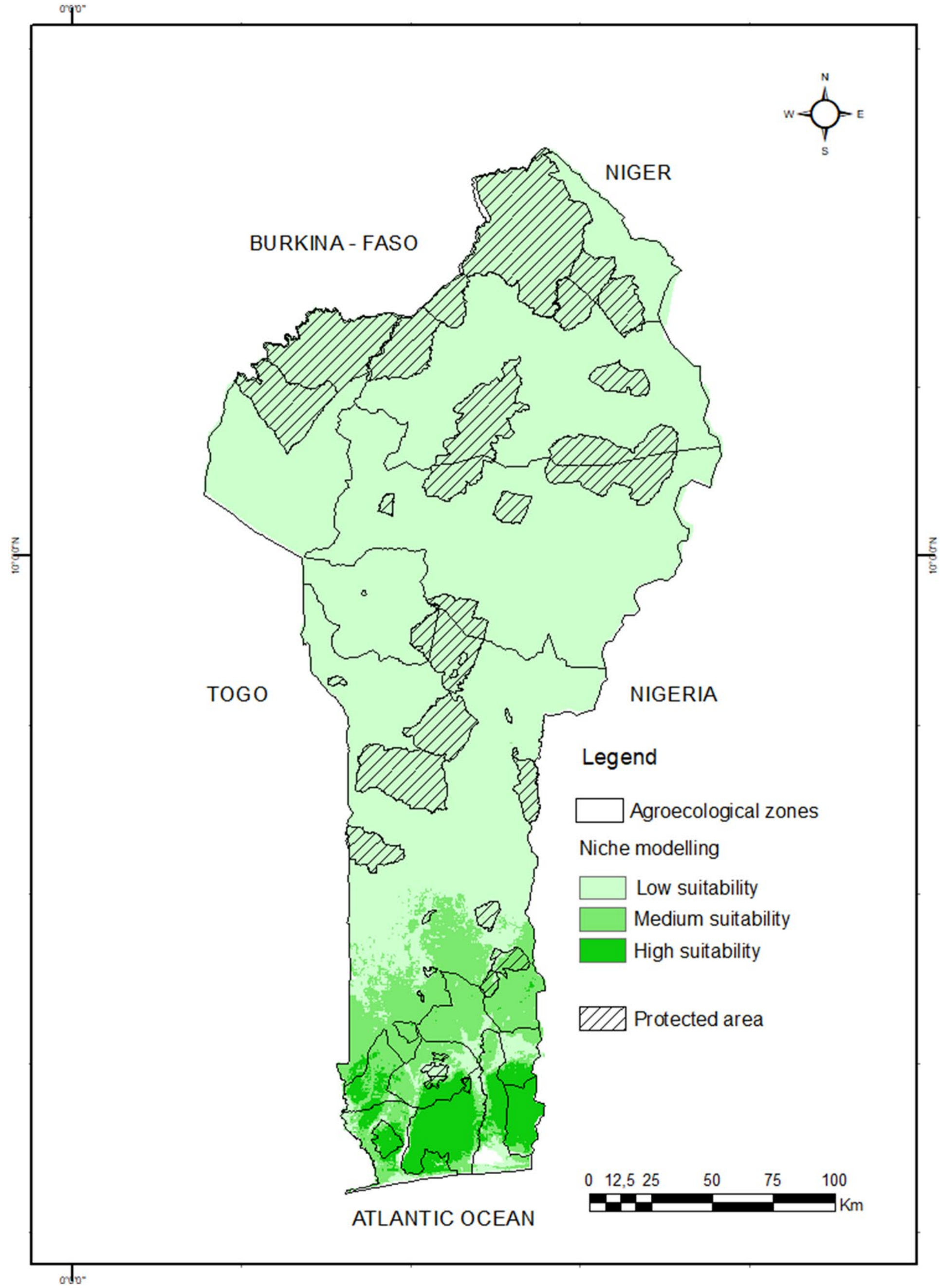

Table 4 Dynamic of suitable areas of *H. abyssinica* for the present and the two future models in Benin

Period habitats	Present	Future	
		(CNRM-CM5)	(HadGES-ES)
Low suitability	99,626.57 Km^2	99,000.34 Km^2	100,679.22 Km^2
Medium suitability	9798.22 Km^2	10,934.52 Km^2	7953.78 Km^2
High suitability	5339.21 Km^2	4829.14 Km^2	6131 Km^2

to conduct complex analyzes combining different sources of spatial data and generate readable maps, facilitating the assimilation of results by curators and decision-makers, thus encouraging the development and implementation of conservation and management policies. That not only the climatic variables which predict the distributions of the species, there are also edaphic variables. This assumes that at the national level, the distribution of *H. abyssinica* is mainly influenced by climatic and edaphic factors. This result is corroborated by the work of other authors who have shown that climate and soil factors have a global

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influence on the distribution of forest species (Bourou 2012; Fandohan et al. 2015). However, among the climatic variables, precipitation and temperature showed a very high predictive power, it should be noted that these results justify the ecological characteristics of the species. *Harrisonia abyssinica* is a plant, which during the dry season almost loses its foliage and this is renewed immediately after the first rains. We should therefore expect a strong contribution from them. This result is contrary to that of Gbesso et al. (2013) on *Chrysophyllum albidum* (Sapotaceae) who showed that despite the fact that the species is wetland; the precipitation variable did not present a very high selective power in the distribution model of the species.

In addition to the climatic variables, the edaphic variables have a physiological action on the development of plants and guide the distribution of these according to their ecological requirements (Agbo et al. 2019a). Thus, the integration of these soil-related variables in the modelling makes these models more functional and more precise (Ayihouénou et al. 2016). The MaxEnt model used in this work estimates the most uniform/extended distribution (maximum entropy) of the points of occurrence within the study area, taking into account the constraint that, the expected value of each variable predictor factor under this estimated distribution, matches its empirical mean (mean values for the occurrence data set) (Gbesso et al. 2013). It is one of the most powerful modelling methods likely to generate very good biogeographic information while offering good discrimination of suitable habitats and unsuitable to a species from a bioclimatic point of view (Phillips et al. 2006). The performance of MaxEnt has also been highlighted by (Hernandez et al. 2008) for predicting the distribution of species. The result of the model is a forecast map where each pixel of the geographic space studied is evaluated with regard to the possibility that its environmental conditions are appropriate for the species studied (Elith et al. 2006). The advantage of this part of the study is that it makes it possible to make a projection into the future of the suitable habitats of the species in the study area.

Potential geographic distribution of *Harrisonia abyssinica*

Climate projections for the future indicate that a significant increasing of the suitable areas for *H. abyssinica* by 2050 with the model HadGES-ES and a decreasing with the model CNRM-CM5. This observed variation can be linked to climate change and also to several variables including the estimated variables, the process of applying the models or the modelling technique which can however influence the output of these models (Gouwakinou 2011). For natural environments, climatic and soil conditions are the most important factors, although at the same time, intense disturbances can determine a particular distribution pattern or cause the complete disappearance of species (Natta 2003). The two models used for the distribution of the ecological niche of *H. abyssinica* have at least made it possible to refine and give more details with regard to the distribution of the species in Benin. The absence of *H. abyssinica* is noted in the commune of Touncountouna in the North-West of Benin on the other hand, the presence of the species was mentioned on the GBIF website (Consulted in March 2017). This can be explained by the action of anthropogenic pressure on plant species because the data available on GBIF is older than those from our prospecting. Several studies have shown that excessive use of plants poses a threat to their survival and can lead to their disappearance (Agbo et al. 2017). Indeed, to the very suitable and moderately suitable regions of the species theoretically described by the models, correspond, respectively, the areas with high, medium and low density of the species identified during our field exploration.

Conservation and management measures for *Harrisonia abyssinica* in Benin

Overall, the results of the present study demonstrate that no bioclimatic model has predicted a total decline in the range of *H. abyssinica* in Benin; which is in agreement with the work of Agbo et al. (2019a), which found a slight increase in the extent of habitats very suitable for the development of *Detarium microcarpum* (Caesalpiniaceae) with two climate models by 2050, but these results seem somewhat upset by the previous work which announces the negative impact of climate change on biological diversity (Fandohan et al. 2013; Assongba et al. 2014). In our case, the conservation challenge of the species remains minor with regard to climate change; on the contrary, one of the models predicts an increase in the potential area of the species by 2050. The greatest conservation constraint remains the patterns of land use. As pointed out by Ogougbé et al. (2019), the threats to the population of *H. abyssinica* in Benin are largely linked to anthropogenic actions, which are the corollary of population growth. The second worrying factor is that the species is almost not found in protected areas and it is more distributed in South Benin which is full of these protected areas (classified and sacred forests). This part of the country, which according to Oloukoi (2006), the dynamic of land use already suggests a decline in the natural environments of species (forest remains for example) to the detriment of housing and other infrastructure. It should therefore be noted that climate change does not constitute a threat to the sustainable conservation of *H. abyssinica* but rather anthropogenic actions. Thus, to increase the chances of conservation of this species in the long term, it is important to develop actions not only of in-situ conservation of the species in

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agro-forest systems in the South of Benin to save it from pressure from land use following urbanization, but also provide for ex-situ conservation of the species by building gene banks.

Implications of the study for the sustainable conservation of *H. abyssinica*

The present study highlights that the areas currently suitable to the cultivation of the species in Benin are mainly located in agro-ecological zones (located in southern Benin) in the Guinean climatic zone. Regardless of the model used, only one classified forest (Lama classified forest) located in the agro-ecological zone of bar lands will always remain very suitable for the cultivation and conservation of *H. abyssinica* in 2050. According to Houinato et al. (2001), protected areas are the only reserves that still promote the conservation of biodiversity. It is often reported that a species present in a protected area has a high probability of surviving without any other form of intervention or management measure once the protected area is managed properly (Heywood 2008; Agbo et al. 2017). Consequently, it is this area which seems likely to provide *H. abyssinica* with adequate climatic and physical conditions for its cultivation and conservation without major consequences in the face of the effects of climate change by 2050. With this in mind, given the morphological aspect of the species, it can be introduced in certain agroforestry systems and also in house gardens. We can cite the introduction into an oil palm field. But also in food crop systems unless it is pruned so as not to provide shade for crops. This could prevent correct photosynthesis of these. However, the very suitable areas of the species which according to the model (CNRM-CM5) become moderately suitable should attract more attention in terms of conservation. The decrease in the population density of the species in this area could be linked to the genetic factors of the species. This statement is linked to our observations on the ground in relation to the fruiting of the feet of the species. In this perspective, the morphological variability of the species would also be decisive for better domestication.

Conclusion

Climate change is one of the main factors contributing to the alteration of global biodiversity structures by bringing about changes in the spatial distribution of species. It is to assess the significance of such changes in wild species whose populations are suspected of declining that the present study has attempted to provide some useful information on the distribution of *Harrisonia abyssinica*. For this fact, this study is based on the use of recent occurrence data for *H. abyssinica*, the reliability and the efficiency of the prediction model used and has shown that the species is unevenly distributed across the Beninese territory because of its ecological requirements. It is more abundant in the South, weakly represented in the center and almost absent in the North of the country. The suitable habitats to its culture and its conservation throughout the territory of Benin have varied over time depending on the two climate models used (CNRM-CM5 and HadGEM2-ES). Under current environmental conditions, 4.7% of Benin's territory has proven to be very suitable for the cultivation of *H. abyssinica*. The moderately suitable and very unsuitable habitats are, respectively, 8.5% and 86.8% of the area of Benin.

This information can be used to develop conservation and management strategies for the species and to improve the adaptive capacities of local populations to reduce their vulnerability to the effects of climate change. However, other factors influencing the distribution of species, such as biotic interactions, genetic adaptation and the dispersal capacities of the species, must be taken into account to draw relevant conclusions which should allow better decision-making in conservation. In the meantime, we can already think of a method of domestication of the species for its in-situ conservation.

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Authors' contributions REO designed the study, collected and drafted the manuscript. RIA read the protocol, analysed the data and improved the manuscript drafted. BA read the protocol and improved the manuscript drafted. SD read the protocol and improved the manuscript drafted. GJD validated the research project and significantly contributed to the manuscript. All authors have read and approved the final manuscript.

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Declarations

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

Ethics approval No ethical approval was needed for this study.

Consent to participate Prior to data collection, participants gave oral consent to participate in the study.

Consent for publication The respondents were informed that their opinions were to be published in a scientific paper and gave their approval.

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