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Potential climate change favored expansion of a range limited species, *Haematostaphis barteri* Hook f.

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Abstract: Understanding impact of climate change on range breadth of rare species can improve the ability to anticipate their decline or expansion and take appropriate conservation measures. *Haematostaphis barteri* is an agroforestry species of the Sudanian centre of endemism in Africa. We investigated impact of climate change on range of suitable habitats for this species in Benin,using the Maximum Entropy algorithm under R software. Five environmental variables were used with the regional climate model under the new Representation Concentration Pathways (RCP). Moisture Index of the Moist Quarter and Slope variability had the greatest predictive importance for the range of suitable habitats for *H. barteri*. Its Potential breadth was found to be currently limited to the Atacora Mountain Chain (AMC) and covers 0.51% of national territory. Climate change was projected to favor a slight expansion of suitable habitats for *H. barteri* by 0.12% and 0.05%, respectively for the RCP4.5 and RCP8.5. These habitats were however mostly out of the local protected areas network. Observed protection gaps suggest need for integrating this species into formal in situ, on-farm or ex situ conservation schemes.

Keywords: species distribution modeling, Haematostaphis barteri, *climate change, Benin*

Introduction

Over the past two decades, effect of global warming on range of plant species have gained increasing interest (IPCC 2014). Critical change in bioclimatic variables could drive important disturbances in the ecophysiology and reproduction of plants. About 15-37% of modelled species in various areas of the world are expected to become extinct by 2050 (Thomas *et al.*, 2004). Similarly, quantitative estimates of the range loss of Mountain plants under climate change predict average range size reduction of 44-50% by the end of the twenty-first century (Dullinger *et al.*, 2012).

Range limited species can be expected to be at a higher risk of extinction under current land use dynamics coupled with the climate change threat. However, response of these species to climate change are likely to be species-specific. Some may become rare or face a high risk of extinction while others may have the ability to adapt and could persist over time in isolated populations (Domisch *et al.,* 2011). Some others could just be favored by projected changes in the climate and extend their range. Therefore, setting priorities for conservation and designing effective conservation schemes require tuning species-specific models (Mckinney and Lockwood, 1999).

Species distribution models have been used recently to address a huge range of questions in ecology including, estimation of range of suitable areas for several species and setting priority areas for their conservation (Gouwakinnou, 2011; Fandohan *et al.*, 2015a; Idohou *et al.*, 2016). Many of these models use a correlative approach. Such approach consists of estimating the potential range of a given species based on a set of its known locations records and some environment covariates (Austin, 2006). MaxEnt (Maximum Entropy Modeling) is one of these modelling methods which can generate useful biogeographic information about the range of a species, while distinguishing between suitable and non suitable habitats for species, using environmental layers (Phillips et al. 2006). Despite its well documented weaknesses, it has undergone some improvements and still represents to some extent a robust approach for modelling potential range of suitable habitats for plant species (Elith *et al.*, 2011).

This study was to (i) estimate potential current and future range of suitable areas for *Haematostaphis barteri* using environmental covariates; and, (ii) assess conservation gaps of the species in Benin. Final results were used to suggest implications for conservation of the target species.

Materials and methods

Study area and vegetal material

The aim of this study was conducted from July to September 2013 within the Atacora Mountains Chain (AMC) where *H. barteri* is endemic in Benin (Adomou, 2005; Akoègninou *et al.*, 2006)). The AMC spans from Benin to Ghana in West Africa. Biogeographically, the AMC is within the Sudanian regional endemism center (White 1986). It is located in the North West of Benin (between 1° and 2° of longitude and 10°40 and 11°28 of latitude North) (Figure 1), with an altitude ranging from 300m to 650m. The climate is Sudanian with two seasons: the rain season and the dry season. As a result of the presence of the mountain chain, rainfall is locally

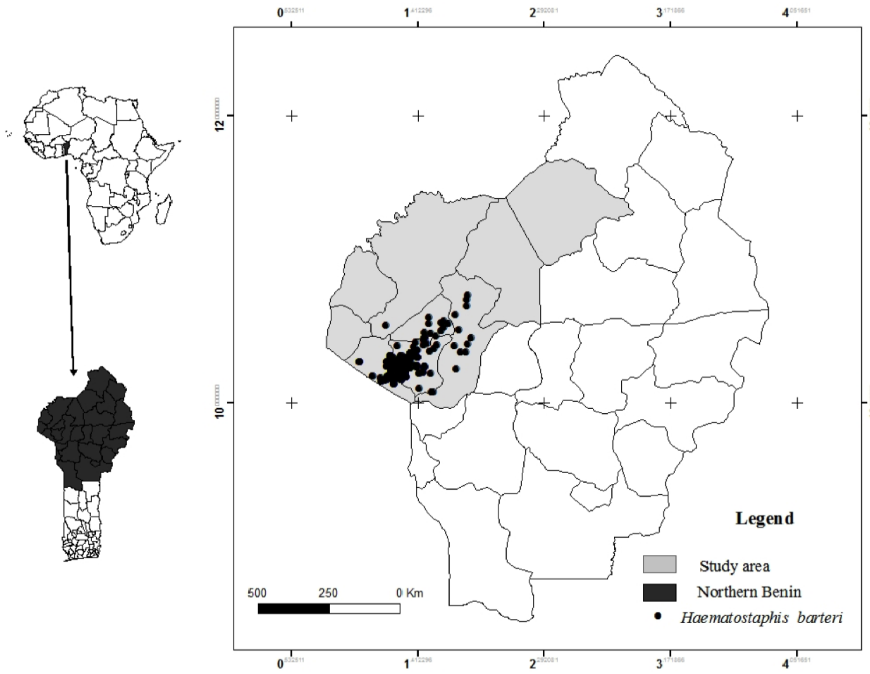

Figure 1 - Geographic distribution of Haematostaphis barteri *records in Benin*

higher as compared to adjacent areas within the same ecological region (from 1350 mm *vs.* 1200 mm). The average annual temperature is 28°C (Sinsin and Kampmann, 2010). According to Adomou (2005) this is a fragile ecosystem which should be taken into account in conservation priorities due to its biodiversity and its overexploitation by surrounding human populations.

Arbonnier (2002), described *Haematostaphis barteri* as a shrub tree belonging to the Anacardiaceae Family which can reach a height of 8 m. *Haematostaphis barteri* is not well studied but is known to belong to the sudanian centre of endemism where it is mainly found on rocky soils or hill tops in dry savannas. It is an agroforestry fruit tree species with several uses including, traditional medicine, food, firewood, charcoal. Fruits of *H. barteri* are also potential raw material for jam, wine and alcohol. In addition, *H. barteri* contribute to carbon sequestration in the AMC. Knowledge of the suitable habitats for this species is an asset to its domestication, cultivation, and integration in other to form conservation strategies where poverty and food insecurity are prevalent.

Data

Species occurrence records

In Benin, Natitingou and Boukombe are the two administrative districts where *H. barteri* was previously recorded (Adomou, 2005; Akoègninou *et al.*, 2006). In each of these rural districts, key informants were interviewed (forests management workers, traditional healers, farmers and women) to locate places where there are natural populations of this species. To be sure that the species is well recognized, a sample of it leaves and fruits was presented to the interviewees. Based on the information we had collected, we defined and realized transects to confirm the occurrence or absence of the species. The geographic coordinates (longitude and latitude) of each tree were systematically collected with a GPS (Global Positioning System). To these data, the geographic coordinates of occurrence provided by the Global Biodiversity Information Facility (GBIF) database (http://data.gbif.org) were added. A total of 529 coordinates were used to model suitable habitats for the species.

Environmental data and climatic scenario

Two types of environmental variables were used in this study: bioclimatic variables and slope variability. In the study area, it has been shown that distribution of plants is essentially a function of water availability and aridity gradient (Fandohan *et al.*, 2015b). Based on this information, a subset of bioclimatic variables which better reflect the aridity gradient were selected for calibrating the model: potential evapotranspiration (pet), temperature seasonality (BIO4), the moist index of moist quarter (mimq) and the length of the longest dry season (LLDS) (Platts *et al.*, 2014). To reduce co-linearity among selected variables, we use Variance Inflation Factor (vifstep) in R with usdm package.

Current and future values for bioclimatic variables were downloaded from https://webfiles.york.ac.uk/KITE/AfriClim/. Current climatic conditions were averages computed over fifty years (from 1950- 2000). For future climate projections, the regional circulation model "AFRICLIM *3.0: High-resolution climate projections for Africa*" was used. This model is refined when compared to global circulation models and is more appropriate for analyzes including mountainous regions (Platts *et al.*, 2014). Future projections for the year 2055 under the Radiative Concentration Pathway scenarios RCP 4.5 and RCP 8.5 were used. The first scenario stipulates a moderate increase in greenhouse gas emissions while the second projects a more dramatic increase in emissions (IPCC, 2014). The other scenarios (RCP 2.6 and 6.2) were not used given the small variation between scenarios by the year 2055 for the study area (Stocker 2014). Bioclimatic data layers used are those of 30-second resolution (*i.e.* a grid resolution of approximately 1 km x 1 km). In addition to bioclimatic variables, Slope Variability (SV) was included in the model, given the importance of mountains for this species (Adomou, 2005). SV also stands as a proxy for effect of solar radiation on the distribution of *H. barteri*. This variable was calculated from the Digital Elevation Model (available on htttp://strm.csi.cigiar.org). Its integration in the model also limits possible biologically unrealistic extrapolations of range of suitable areas for this species (Fandohan *et al.*, 2013).

Model Building

The Model for predicting suitable habitats for *H. barteri* was built as described by (Fandohan *et al.*, 2015b). Data were prepared and put under raster format using R software (dismo and raster packages). MaxEnt models estimate suitable areas for a species according to the following principle. Given a set of occurrence records of *H. barteri* in an environment (E), where this species has been observed. Let consider that "y=1" refers to the presence of *H. barteri* and "v" is a vector which contains environmental covariates characterizing "E". Assume that all possible environmental conditions in "E" represent the background of the model. Let assume that f(v) is the probability density of predictive environmental covariates through "E", and $f_1(v)$ is the probability density of the predictive covariates at the locations where *H. barteri* was observed. Combining the presence records of this species and the background, MaxEnt estimates the probability of occurrence of the species according to environmental conditions as:

$$\Pr(y=1\mid v)=\Pr(y=1)\times\frac{f_1(v)}{f(v)}$$

Pr(y=1|v) is the probability of occurrence of the species depending on environmental conditions, and Pr (y = 1), the proportion of occupied site.

Several models of validation methods exist. However, most are basically not appropriate (Merow *et al.,* 2013). It was recently shown that the inclusion of a large number of background points (>100.000) is required to get a good convergence of models, a stable calibration and a good discriminatory power (Renner *et al.*, 2015). To improve validity of outputs from the model, the basic setting of MaxEnt (*Default setting*) considering 10000 background points of "E" was set to 112622 (i.e., the whole study area). Moreover, in order to interpret the results as probabilities of occurrence of this species, the raw outputs of the model were used instead of the conventional logistic transformation (Renner *et al.*, 2015).

Mapping and analysis

Outputs from the modelling steps were imported into ArcGIS 10.1 in order to map geographic distribution of current and future suitable habitats for *H. barteri*.

The probabilities generated by the model were considered to be the measure of the habitat quality of the species. The span of each habitat quality (area and percentage) was estimated using "spatial analyst " of ArcGIS 10.1. The proportion of currently suitable habitat which are susceptible to become less suitable in the future and vice versa were also estimated.

Result

Model validation

Collinearities among the selected covariates was weak (VIFmin=1.02-VIFmax=6.65). Based on overall contribution to the model, SV and Moisture index of the moist quarter (mimq) had the greatest importance in predicting the probability of occurrence of *Haematostaphis barteri* in Benin with a contribution of 40% and 35%, respectively (Figure 2). Then comes Potential Evapotranspiration and Temperature Seasonality. Because contributions are sensitive to the order of integration of covariates in the model, another statistic was used to appreciate covariates importance, the permutation importance, i.e., how much the predictive power of the model decreases when a given covariate is not included. Using the permutation importance, mimq, bio4 and pet stood as the most important covariates. Length of the longest dry season poorly contributed to the model (Figure 2).

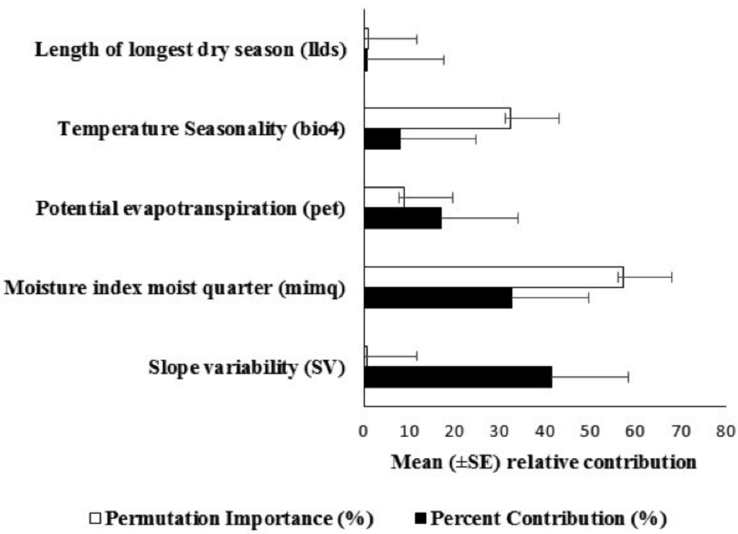

Figure 2 - Environmental covariates and their contribution to the model for H. barteri

Suitability was poor in areas with SV smaller than 1% and greater than 5% (Figure 3A). bio4 and mimq seemed to restrict the range of this species, with habitat suitability decreasing critically for mimq values exceeding or lower than 180 mm and for bio4 values greater or smaller than 1.7°C (Figure 3B;C). Similarly, habitat suitability increased significantly in area with pet higher than 1900mm (Figure 3D).

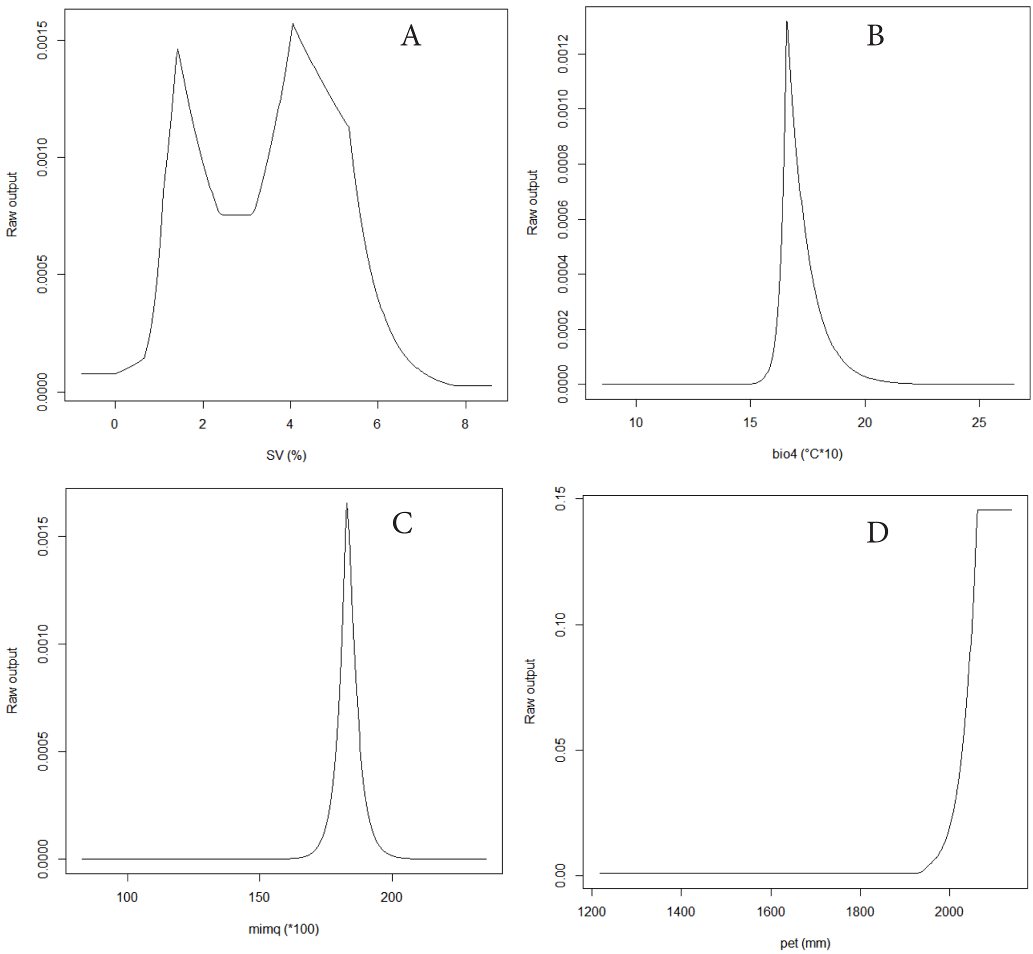

Figure 3 - Response curves for Haematostaphis barteri to different covariates. A) Slope variability (SV), B) Temperature Seasonality (bio4) C) Moisture index moist quarter (mimq) D) Potential evapotranspiration (pet). Raw output is showed as the probability of Haematostaphis barteri *presence*

Current breadth of suitable habitats

Currently, breadth of suitable habitats for *H. barteri* cover only 0.51% of the national territory (not including Niger river's islands). These suitable areas were confined to the Atacora chain of Mountains, with the highest probability of occurrence conditional to the scale of the study area, being 0.0032, (Figure 4a). In addition, the majority of suitable area is out of the national protected areas network.

Projections for future climate

Projections of suitable habitats for 2055 climate change scenarios under the representation concentration pathways (RCP4.5 and RCP8.5) suggested that range of suitable areas for *H. barteri* would slightly increase towards north-east (by 0.12% for RCP4.5 and 0.05% for RCP8.5) (Figure4b and 4c). The predictions for RCP8.5 scenarios showed a more limited distribution range than those for RCP4.5. Although suitable habitats for *H. barteri* were projected to increase in the future, the probability of occurrence would decrease under the moderate scenario RCP4.5 (Figure 4B) and would show little change upwards under the most pessimist scenario RCP8.5 (Figure 4C).

Discussion and Conclusions

Among the multitude of software and program for ecological niche modelling and habitat suitability prediction, MaxEnt is one of the most popular. Indeed, it allows to use occurrence only records, and also showed its efficiency for many endemic species (Kumar and Stohlgren, 2009). Moreover, the maps that are made give an idea of the conservation areas which should be prioritized, and this is very important for decision makers. However, MaxEnt is often criticized for some of its weaknesses. These include uncertainties related to the projections (Elith *et al.*, 2006; Schwartz, 2012), failure to account for relevant variables or for geographic barriers (Anderson, 2016), bias due to unequal sampling effort (Fourcade *et al.*, 2014), overfitting and issues related to evaluation data and methods (Radosavljevic and Anderson 2014). Integration of some of these parameters like geographic barriers and biological tolerances requires the availability of good quality data about species eco-physiological tolerance. Such data are not yet available for *H. barteri*. Other important variables not included here such as soil and vegetation are available at high resolution (e.g. 30s resolution) and could have been accounted for. However, because vegetation and soil data are available as categorical variables, accounting for their variability in the sampling scheme would have been required to avoid blind exclusion of some areas from suitable habitats.

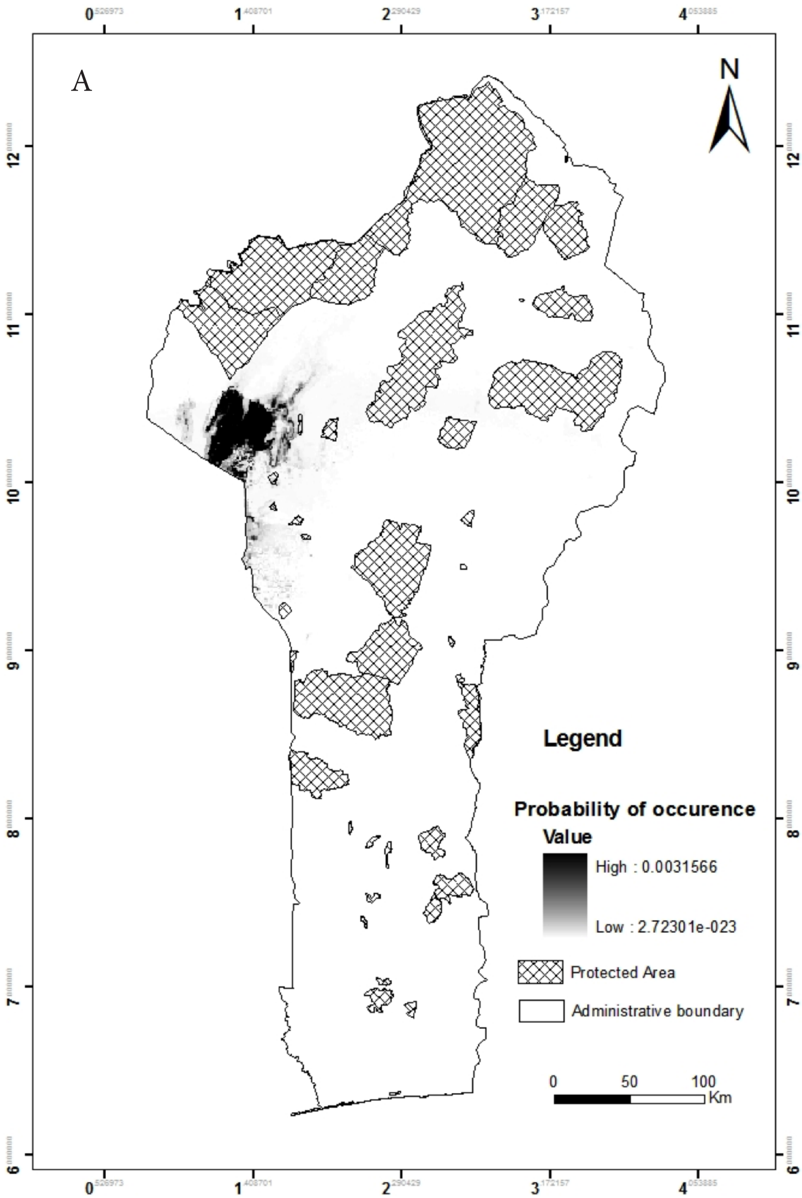

Figure 4 - Maps showing suitable habitats for Haematostaphis barteri *and the national protected areas network: (A), Current; Predicted situation in 2055, RCP 4.5 (B), RCP 8.5 (C)*

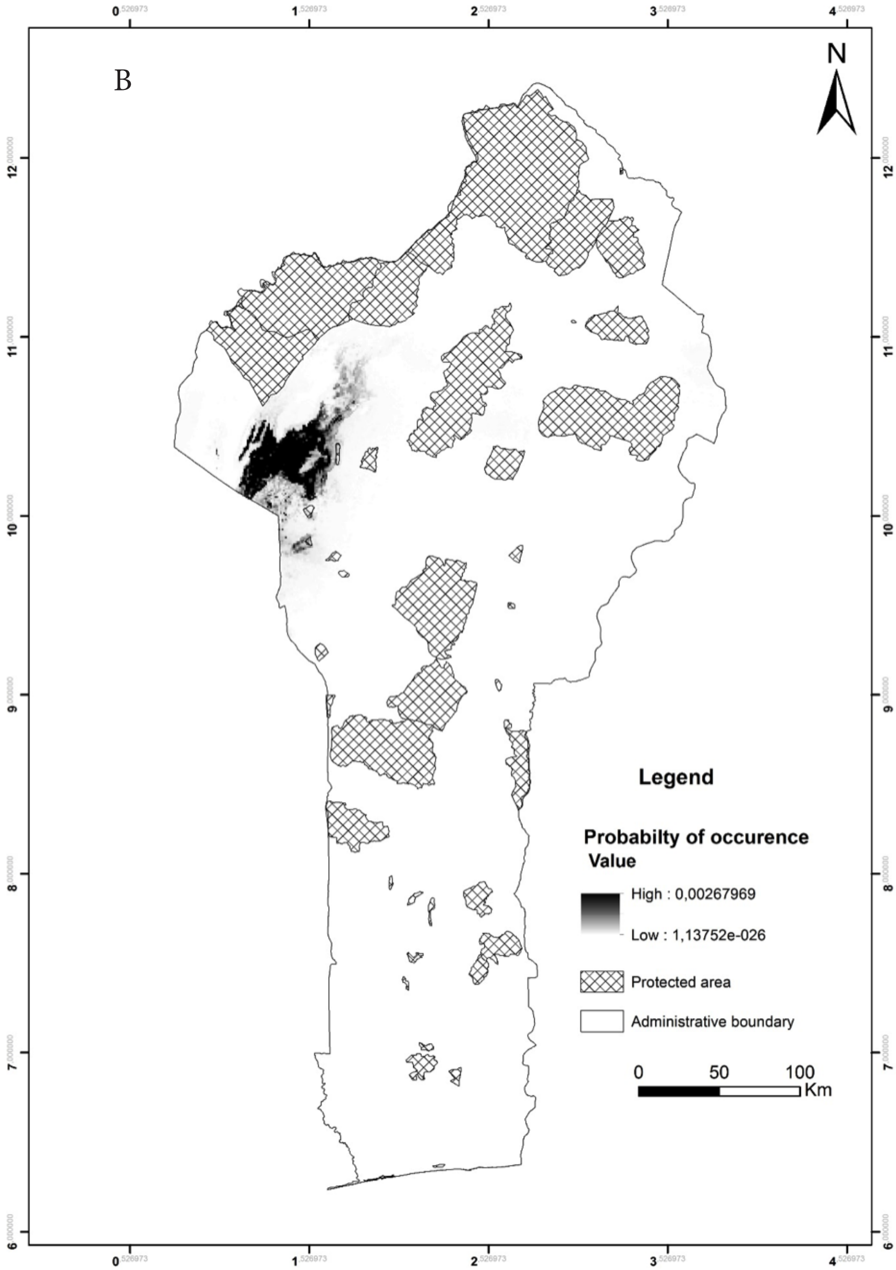

Figure 4 - continued

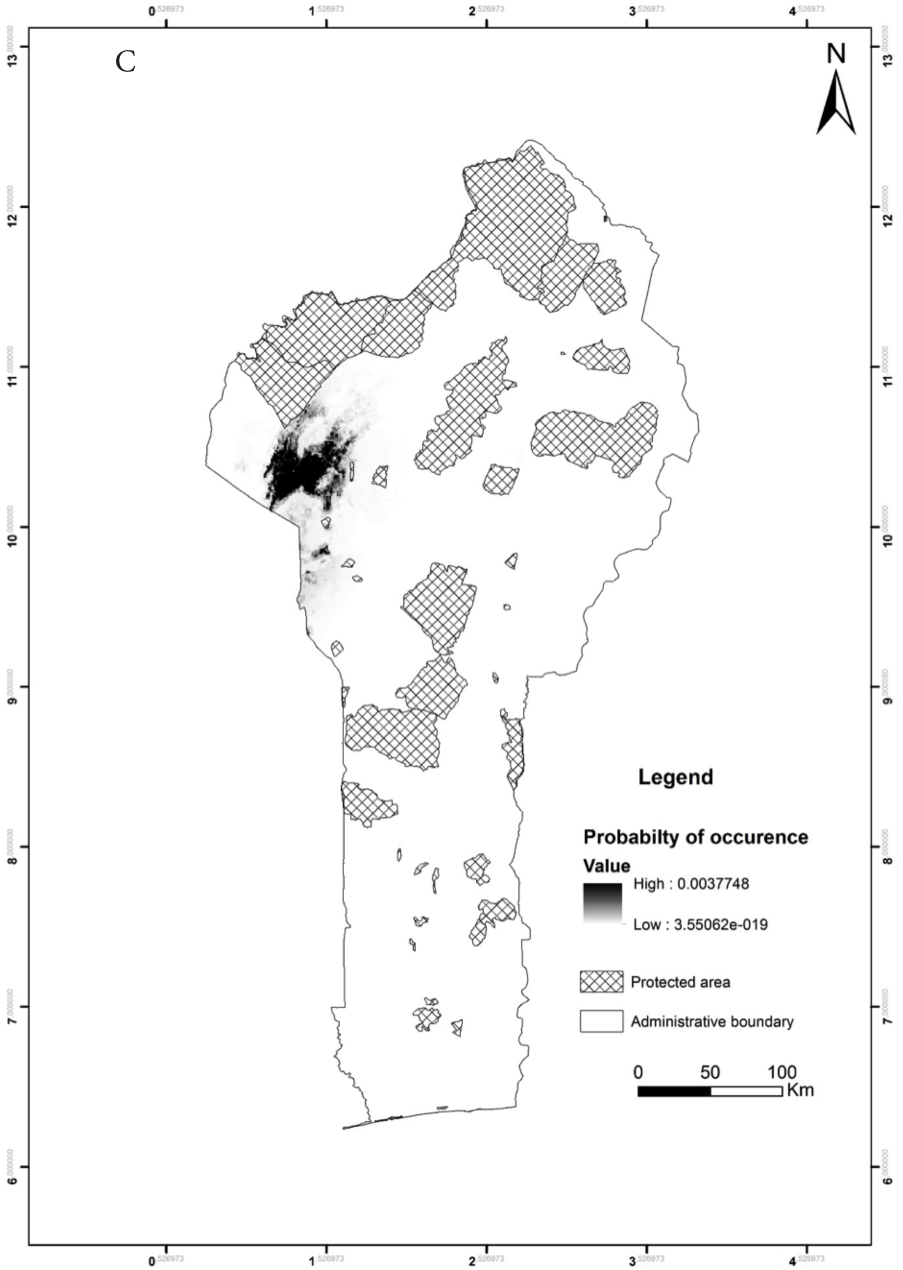

Figure 4 - continued

Available data on these variables are also known to carry several errors that would have increased errors associated to our models. Finally, vegetation and soil are correlated to moister index, which has been accounted for in our models. Importance of slope variability, Moisture index of the moist quarter and Temperature Seasonality is in agreement with previous report on the *preferendum* of this species. In fact, *H. barteri* is said to favor rocky areas precisely top of hills (Akognénihou *et al*., 2006) where the annual rainfall exceeds 1200mm (Sinsin and Kampmann 2010), in the Sudanian phytochoria.

This study revealed that suitable areas for *Haematostaphis barteri* Hook f. are confined within the Atacora Mountain Chain and are mostly present in three small districts i.e. Natitingou, Boukombé and Toucoutouna.

Suitable areas for this species currently represent only 0.51% of the national territory. Considering that calibrating distribution range models using bioclimatic variables and slope variability only, may still lead to overestimation of species range (Pearson *et al*., 2007), the actual range of *H. barteri* could even be shorter. As far as future projections are concerned, when the emission of carbon dioxide is expected to be up to three folds from the present until 2100 (Moss *et al*., 2010), what would have been foreseeable, would be the drastic lost of suitable habitat for *H. barteri*. This was not the case as suitable habitats for this species were projected to slightly increase by 2055 under climate change. Indeed, while it is predicted to drive extirpation of some species from their native habitats, climate change could also favor some species. Whether or not this species will be positively or negatively affected by climate change will at the end strongly depend on its intrinsic capacity to adapt (Estrada *et al*., 2015). Indeed, although Species Distribution Models are being extensively used to project local extinction or spread of species, it should be noted that these results should be further confirmed by thorough ecophysiological studies.

Whatever the case (current or future), predicted ranges mainly fall out of the national protected areas network. This exposes the species to habitats loss due to other factors such as land clearing for agricultural purposes. In addition, *H. barteri* is neither on the Benin nor the International Union for Conservation of Nature red list of endangered species to be prioritized for conservation. Our results would thus suggest local populations of *H. barteri* to be at high risk of extirpation from their habitats.

***Implications for conserving* H. barteri**

Species distribution models and mapping are powerful tools to inform prioritization of areas for conservation. Though our results predict positive effect of climate change on the range of suitable areas for *H. barteri*, other factors such as anthropic pressure could drive local extirpation of this species from its habitats. It was reported that almost 50% of African greenhouse emissions between 2000 -2005 were due to land use and land cover changes (Midgley and Bond 2015). Because demands for agricultural lands are expected to increase in West Africa, and provided the importance of this species in traditional agroforestry systems, on-farm and *ex situ* conservation actions stand as more realistic solutions for its long term maintenance in the study area. Additional actions may include attempts to extend the national protected areas network to Atacora Mountain Chains as previously suggested (Adomou 2005; Fandohan *et al*., 2015b).

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