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Predicting Habitat Suitability for Cultivation and Conservation of *Prosopis africana* and *Caesalpinia bonduc* in Benin through Species Distribution Modeling

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Abstract

Benin, a country in West Africa renowned for its diverse forest ecosystems and protected areas, harbors a rich biodiversity including numerous threatened plant species. Through comprehensive phytosociological surveys, analysis of herbarium records, flora databases, and assessment of rarity indices, 280 plant species facing threats have been identified within Benin. The use of Maximum Entropy (MaxEnt) modeling stands out as a robust method to predict species distributions and assess habitat suitability, particularly advantageous when only presence data is available and absences are difficult to ascertain. MaxEnt's capability to perform well with limited sample sizes further enhances its utility in ecological studies. Models developed for both *Prosopis africana* and *Caesalpinia bonduc* exhibit high Area Under the Curve (AUC) values, indicating strong predictive accuracy. For *Prosopis africana*, significant portions of Benin are predicted to offer highly suitable climatic conditions (> 80% suitability under current and future scenarios), highlighting areas conducive to species development. Strategic reforestation efforts and mitigation of threats such as human encroachment, invasive species, and agricultural deforestation are recommended to safeguard and enhance populations of this species. Analyzing the distribution map of *Caesalpinia bonduc* reveals that protected areas in Southern and Central Benin predominantly align with suitable habitats for the species. These findings underscore the importance of targeting these protected zones for initiatives focused on species enrichment, reintroduction, and cultivation. In conclusion, integrating MaxEnt modeling with spatial analysis offers valuable insights into habitat suitability and conservation strategies for threatened plant species in Benin, guiding effective management practices aimed at preserving biodiversity and supporting sustainable ecosystem health.

INTRODUCTION

Benin, situated in West Africa, boasts extensive biodiversity found within its diverse forest ecosystems and protected areas. Through rigorous phytosociological surveys, examination of herbarium records, flora databases, and rarity index assessments, researchers have identified 280 threatened plant species in Benin (Adomou et al., 2010). Given their vulnerable status, conserving these species is imperative as they face significant risks of extinction.

However, a critical challenge in biodiversity monitoring and conservation efforts lies in the substantial gaps in spatial distribution data, hindering the development of effective biodiversity indicators and regional conservation strategies. To address this gap, we employed Species Distribution Modeling (SDM) to study two threatened species in Benin, Prosopis africana (G. and Perr.) Taub and Caesalpinia bonduc (L.) Roxb. This approach provides crucial insights into their geographic distributions, enabling targeted conservation planning and management strategies to safeguard their populations and habitats.

Prosopis africana is a perennial leguminous tree and the sole African tropical species within the Prosopis genus, inhabiting the region from Senegal to Ethiopia in the transition zone between the Sahel and savannah forests. This tree holds multifaceted utility: in Benin, its fermented seeds are employed as

a food condiment, while its young leaves and shoots serve as highly sought-after fodder during the late dry season. Additionally, cattle consume its pods. Notably, *Prosopis africana* is extensively utilized as a source of energy (charcoal, firewood) due to its dense wood and slow growth rate (Akossou et al., 2013). Despite its significance to various communities in Benin, this species faces considerable threats and is progressively disappearing from its natural habitat.

Caesalpinia bonduc is a thorny, dioecious, woody scrambling shrub belonging to the Caesalpiniaceae family. Widely distributed in tropical and subtropical regions, it is revered for its medicinal properties across its African range. Leaves, bark, and roots of *C. bonduc* are utilized for treating ailments such as fever, headaches, chest pain, and as an anthelminthic. In West Africa, it serves as a rubefacient and tonic in treatments for jaundice, diarrhea, and skin eruptions. However, the species faces an imminent risk of extinction and is categorized as endangered on the IUCN Red List of Threatened Species. The primary threats to its survival in Benin include extensive root use and challenges associated with natural regeneration.

To investigate the influence and impact of climate change on biodiversity loss, we conducted a study to assess its effects on the development of two threatened species with the objectives of (1) determining the potential geographic distribution of P. africana and C. bonduc in Benin, (2) predicting the impact of climate change on their future distribution (by 2050), and (3) formulating appropriate conservation strategies based on the findings. In our study, we employed MaxEnt as a modeling technique, which is specifically designed for species distribution modeling using presence-only data. MaxEnt minimizes the entropy between two probability densities—presence and background (Philips et al., 2006).

METHODS

Study area

The study area spans from 6°10’ to 12°50’ N latitude and 1° to 3°40’ E longitude, situated within the Dahomey Gap in Benin, a West African nation with an area of 114,763 km². The Dahomey Gap, a dry corridor predominantly covered by savannahs, divides the African rainforest into two separate regions. Benin's climate varies distinctly across three zones from south to north (Houechegnon et al., 2015): (i) Subequatorial Zone (6°30’ N to 7°30’ N): Characterized by two rainy seasons separated by a long dry season; (ii) Sudanian-Guinean Zone (7°30’ N to 9°30’ N): A transitional area where the climate shifts to tropical subhumid, with a tendency towards a single rainy season and a single dry season; (iii) Sudanian Zone (9°30’ N to 12° N): Defined by a tropical climate with a unimodal rainfall pattern.

Species records

To conduct species distribution modeling, we compiled occurrence data for each species within the study area. The presence data were sourced from literature, museum records, and field observations. In total, 958 occurrence records were used for *Prosopis africana* and 40 for *Caesalpinia bonduc*. To enhance the model’s accuracy, the presence points for *P. africana* were extended beyond Benin's

administrative borders (Abdou et al., 2016). Based on the distribution of these records, we delineated a polygon (M) on the map to represent the probable distribution range of the species. This polygon encompasses areas in Benin, Togo, Ghana, and Ivory Coast. By considering this broader range of occurrence points, the models more accurately reflect the species' distribution.

Environmental input variables

The environmental layers utilized for modeling were bioclimatic variables obtained from WorldClim (www.worldclim.org/bioclim) at a 2.5-minute resolution, representing current conditions from 1950 to 2000. After downloading, the bioclimatic data were processed in QGIS to prepare them for use in Maxent. For future projections, we used AfriClim's climate models for the year 2050, considering two scenarios: RCP 4.5 and RCP 8.5. These models are particularly well-suited for species modeling in Africa, making them appropriate for the climatic conditions present in our study area (Fandohan et al., 2015).

MaxEnt modeling and model evaluation

To model the geographic distribution of the species, we selected the Maximum Entropy (Maxent) method, which is designed for presence-only data. This approach is effective for making predictions and identifying the variables that influence species distribution. We used Maxent version 3.3.3k for our analyses. Model performance was evaluated using AUC values derived from ROC plots, along with the Partial ROC method developed by Peterson et al. (2011). The occurrence data were split into two parts: 80% were used as training data for model development, while the remaining 20% were reserved for evaluating model performance.

RESULTS

The AUC statistic, that represents the predictive power of the model, are very high for the species' models respectively 0.884 for *Ceasalpinia bonduc* and 0.918 for *Prosopis africana*.

- Assessment of Environmental Variables

Table 1 gives an overview of the relative contributions of environmental variables in each species model distribution. The variables Bio2 (thermal climatic factor) and Bio14 (hydrological factor) are respectively the most important predictors in the model of *P. africana* and *C. bonduc* due to their high level of contribution.

Table 1
Relative contributions of the environmental variables to the model of each species (percent contribution)

Environmental variables	Species	
	P. africana	*C. bonduc*
Bio12 (Annual precipitation)	22.9	-
Bio13 (Precipitation of Wettest Period)	11.2	-
Bio11 (Mean Temperature of Coldest Quarter)	11.1	-
Bio3 (Isothermality)	5.9	-
Bio2 (Mean diurnal range)	49	0.5
Bio5 (Max Temperature of Warmest Period)	-	1.5
Bio6 (Min Temperature of Coldest Period)	-	7.4
Bio17 (Precipitation of Driest Quarter)	-	39.2
Bio14 (Temperature Seasonality)	-	51.4

- Present and future predictions of distribution

Distribution map has been drawn based on the outputs of Maxent. We set a threshold to define a continuous probability distribution of different levels: low suitable, medium suitable, highly suitable and unsuitable. We estimate the potential present and future distributions of each species.

• Prosopis africana

Through the result, it has been noticed that the species suitable area, in present condition, is located in the Sudano-Guinean and Sudanian zone where the majority of protected areas of Benin is concentrated. This region still remains suitable in future conditions following the scenarios RCP 4.5 and RCP 8.5 for the models climatic of AfriClim at the level 2050 (Fig. 2b and c). By comparing the unsuitable area and the suitable area we found out that, the last one represents 83% of the total area of Benin. This percentage is also above 83% in both cases of future conditions.

• Ceasalpinia bonduc

Modeling results have reported that the areas of south and center Benin are currently favorable to the species. It represents the Guinean-Congolese and Sudanian-Guinean regions with the following phytogeographical districts: Coast, Pobè, Plateau, Oueme-Valley, Zou, Borgou – Sud and Bassila. The most favorable habitats cover the entire region of southern Benin (the Guinean-Congolese region) represented by the coast, Pobè, Plateau and Oueme-Valley phytogeographical district. When we compare the result of Maxent with the known distribution of the species, we found out that there are some new

areas that need to be inspected to census the new natural population of the species. Those areas are situated in the phytogeographical district of Zou and Pobè.

Under the effect of future climate change (2050), the Guinean-Congolese and Sudanian-Guinean geographical zones are predicted by Africlim-MIROC5 (Figs. 1b and 1c) as a favorable range of occurrence of the species. We also noticed an extension of the suitable areas to certain regions of the Sudanian region according to the scenarios RCP4.5 (Localities of Boukoumbe, Bemebereke) and RCP8.5 (localities of Cobli, Tanguieta, and Sinende).

DISCUSSION

Maximum entropy (Maxent) modeling has great potential for identifying distributions and habitat suitability for species given its reliance on only presence locations (Baldwin, 2009). This is an advantage as long as it is not easy to obtain or be sure of absence data. The fact that Maxent works well with small sample size is a great advantage compared to other modeling program (Phillips *et al.*, 2006).

The evaluation of the different model established shows that they performed better than random prediction with an average test area under the curve (AUC) value superior to 0.80.

Many environmental factors influence the distribution of *P. africana*, but in our model, the thermal climatic factors (Bio2 and Bio3) are predominant in the definition of its geographical distribution in this study. By comparing habitat suitability of both present and future conditions (at the level of 2050 for RCP 4.5 and RCP 8.5), the result shows a small decrease, respectively 5% and 3% on the study area. However, the proportion of suitable area in Benin, that is above 80% (current and future conditions), ensure climatic conditions favorable for the development of the species. Then, managers must encourage reforestation actions with this species and prevent all other threats that destroy its population like human pressure, invasive species actions, deforestation for agriculture. The natural forest that should be a priority for in situ conservation of this species are the ones of the transition zone and Sudanian zones and firstly the protected areas that are also suitable in the future such as: Classified forest of “Trois Rivieres”, “N’dali”, “Alibori Superieur”, “Oueme Superieur” and “TTK”.

In the case of *C. bonduc*, precipitation of driest period (BIO14), precipitation of driest quarter (BIO17), min temperature of coldest period (BIO6), max temperature of warmest period (BIO5) and mean diurnal range (max temp – min temp) (monthly average) (BIO2) are identified as dominant variables which explain the variability of the geographical distribution of in Benin. By analyzing the distribution map and comparing the suitable habitat of the species with the Benin map of protected areas, we found out that most protected areas in the South and Central Benin are favorable habitats to the species and should be targeted for enrichment, reintroduction, and cultivation of the species: it is the case of Lama natural Forest and those of Pobè, Bonou, Niaouli; the reserve forest of Pahou (Ahozon), Dan – Atcheribé, Logozohè (Dassa-Zoumè), Dogo-Ketou, Ouémé-Boukou, Savalou, Djidja. It is important to consider also the natural and sacred forests of south and center departments of Benin (case of the natural forest of

Bahazoun in Abomey-Calavi, Domesezoun natural forest in Zè…) and the agroforestry and garden systems of Atlantic – Littoral and Mono - Couffo departments.

The species distribution modeling (SDM) allows us to predict environmental factors that influence the distribution of species. It is a useful tool that guides strategies in terms of conservation in climate change context that is a real threat and challenge for species according to the adaptation aspect. SDM also assists in identifying remote natural areas where a species is not certain to exist but, based on the climatic characteristics, presents suitable conditions for species. In our case, these tools have been used to model threatened species distribution using predictive modeling approach. We got a good result in terms of how and where to conduct effective conservation actions to manage the restoration of those species that population is disappearing from natural habitat.

Declarations

Competing interests

The authors declare that they have no conflict of interest.

Data availability.

The occurrence data of each species can be downloaded respectively from: *Prosopis africana*: https://doi.org/10.15468/dl.etmzz (GBIF.org, 2017); *Caesalpinia bonduc*: http://doi.org/10.15468/dl.vpbrk9 (GBIF.org, 2016). The dataset from Hesse is not publicly accessible. The environmental layers used for the modeling are bioclimatic variables downloaded on WorldClim (www.worldclim.org/bioclim) at the resolution of 2.5 min.

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Figures



Figure 1

Occurrence data of *P. africana* (yellow point) and *C. bonduc*(red star) in the study area

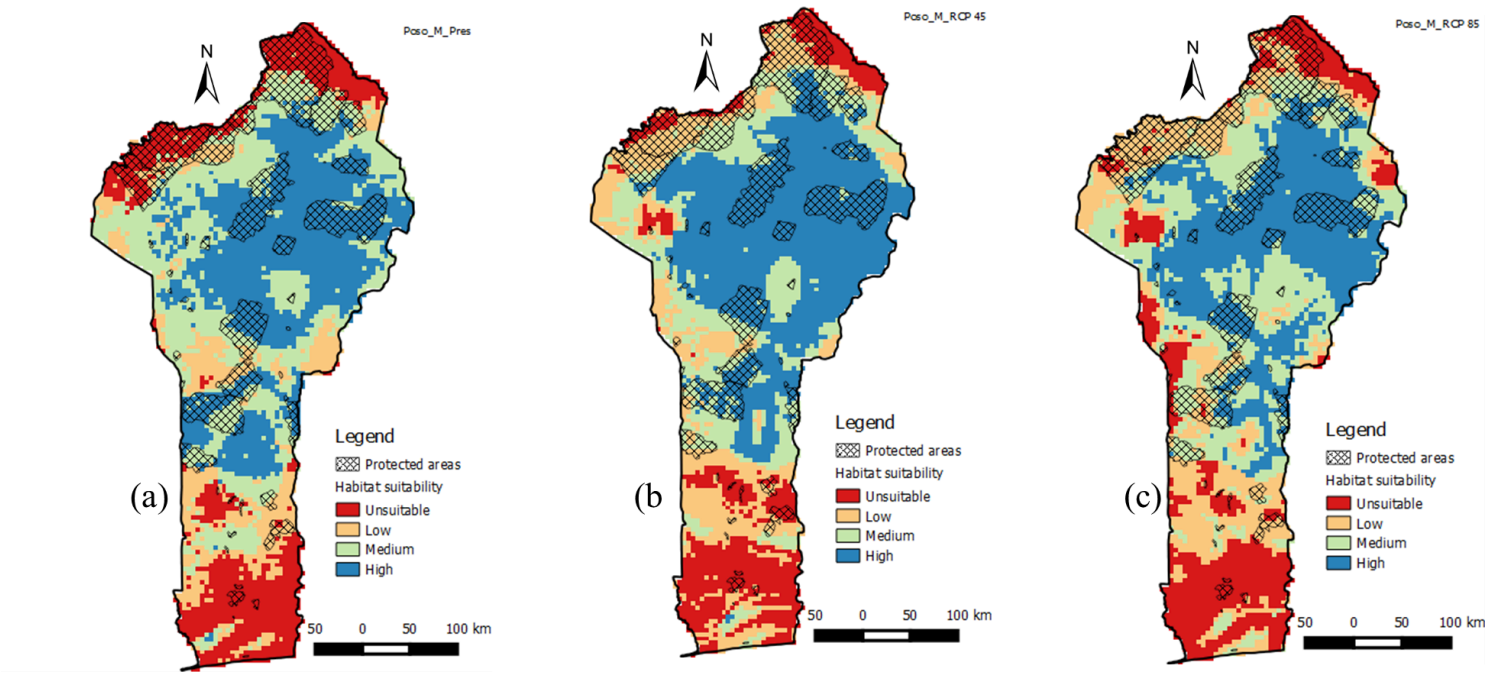


Figure 2

Map showing the suitability area of *P. africana* in Benin: (a) current, (b) Africlim MIROC5 RCP4.5, (c) Africlim MIROC5 RCP8.5

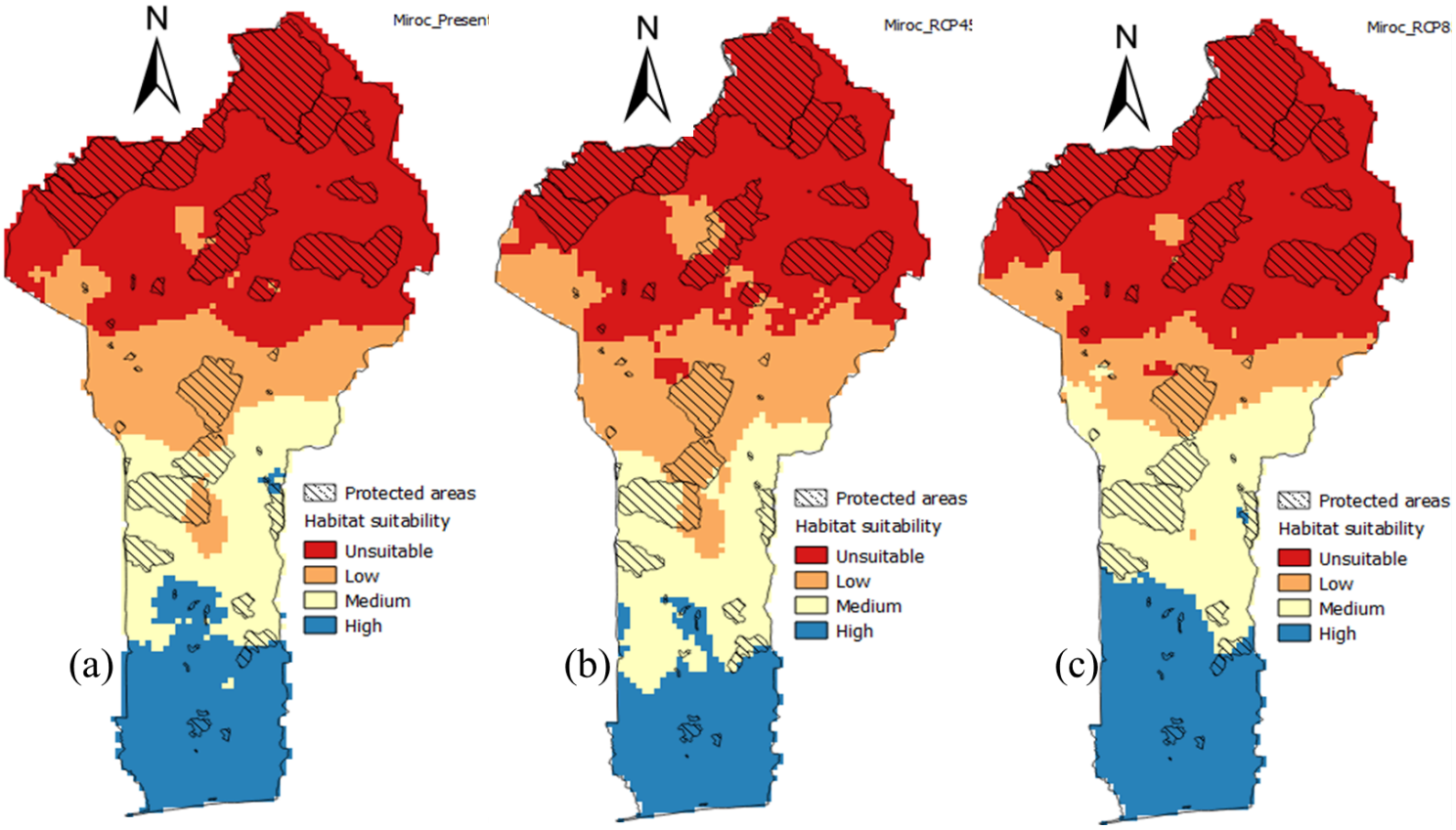


Figure 3

Map showing the suitability area of *C. bonduc* in Benin: (a) current, (b) Africlim MIROC5 RCP4.5, (c) Africlim MIROC5 RCP8.5