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SPATIAL DISTRIBUTION AND BIOCLIMATIC FACTORS OF SUDANO-SAHELIAN AGROFORESTRY TREE SPECIES: THE CASE OF AFRICAN LOCUST BEAN (*PARKIA BIGLOBOSA*) AND SHEA (*VITELLARIA PARADOXA*) IN THE PROVINCE OF BOULKIEMDÉ, BURKINA FASO

Abstract: African locust bean (*Parkia biglobosa*) and shea (*Vitellaria paradoxa*) are emblematic species of West African agroforestry parklands. They play a major role in food security, rural livelihoods and the structuring of agricultural landscapes. However, their spatial distribution is insufficiently documented at the local level, particularly in a context of climate change and increasing pressure on natural resources. This study analyses the spatial distribution and bioclimatic determinants of African locust bean in the province of Boulkiemdé, in central-western Burkina Faso, combining an integrated approach that combines field inventories, spatial analyses and modelling of potential distribution. Data on presence and abundance were collected between November and December 2024 using systematic sampling based on a 3 km grid. The potential distribution of the species was modelled using the MaxEnt model, and the relationships between the probability of presence and bioclimatic variables were analysed using Pearson's correlation. The results highlight a heterogeneous distribution of African locust bean and shea trees, structured by a marked south-north gradient. The southern areas have the highest probabilities of occurrence and densities. The seasonality of rainfall and quarterly precipitation explain the spatial distribution of the species. Conversely, climate variability and temperature extremes appear to be limiting factors. This study highlights the importance of combining ecological modelling and abundance data to inform land use planning and sustainable management of agroforestry parks in the context of climate change.

Keywords: *Parkia biglobosa, Vitellaria paradoxa*, spatial distribution, climate change, Burkina Faso

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Introduction

Agroforestry parklands are one of the foundations of rural landscapes in the Sudano-Sahelian region of West Africa. They are the result of long-standing interactions between rural societies and the natural environment, during which certain useful tree species are voluntarily conserved and managed within agricultural areas (Boffa, 1999; Nair, 1993). Among these species, the African locust bean (néré) (*Parkia biglobosa*) and shea (Karité) (*Vitellaria paradoxa*) occupy a special place due to their multiple food, economic, cultural and ecological functions (Odounharo et al., 2022). Its seeds are used to make widely consumed fermented products, while the tree helps to improve soil fertility, regulate the microclimate and maintain biodiversity (Ouédraogo et al., 2014; Teklehaimanot, 2004). In Burkina Faso, these two species are recognised as being strategic for rural livelihoods and for the resilience of agrarian systems in the face of climate hazards (Sanou et al., 2012). However, several studies highlight a gradual decline in certain agroforestry species due to land pressure, agricultural intensification and the effects of climate change (Garrity et al., 2010; Lykke et al., 2013; Faye et al., 2018). However, several studies highlight a gradual deterioration of Karité tree parklands due to agricultural intensification, reduced fallow land and increasing land pressure (Lykke et al., 2013; Garrity et al., 2010).

Added to these dynamics are the effects of climate change, characterised by increased rainfall variability (Yameogo, 2025a, 2025b, Rouamba et al., 2023), a rise in extreme temperatures (Yameogo, 2024, Yameogo and Rouamba, 2023, Yo et al., 2025) and rainfall (Yameogo, 2025c), which directly affect the growth, productivity and regeneration of shea trees (Sanou et al., 2012; Brandt et al., 2017; Yameogo and Yanogo, 2023). Furthermore, climate variability in Burkina Faso is manifested by an intensification of temperature extremes and a shift in rainfall patterns, with increased alternation between wet and dry periods and a seasonal concentration of rainfall (Yanogo et al., 2023, Yaméogo & Sawadogo, 2024, Yo et al., 2025, Yaméogo et al., 2026). This differential dynamic between climatic zones- particularly between the north, which is more exposed to rainfall extremes, and the south-west, which benefits from a more even distribution of rainfall – exacerbates the vulnerabilities of agricultural systems that are heavily dependent on climatic conditions. The spatial distribution of Karité and Néré trees thus appears to be the result of a complex interaction between bioclimatic factors and territorial dynamics. These dynamics raise questions about the capacity of rural areas to sustainably maintain their woody resources, particularly in climate transition zones such as central-western Burkina Faso. Previous studies have shown that precipitation, climatic seasonality and temperature extremes play a decisive role in the distribution of Sahelian tree species such as Combretaceae (Thiombiano et al., 2006), *Vitellaria paradoxa* (Dimobe et al., 2020) in Burkina Faso, *Parkia biglobosa*, *Vitellaria paradoxa* and *Vitex doniana* in Benin (Kakpo et al., 2024), *Vitellaria paradoxa* in Ghana (Nasare et al., 2025) and *Vitellaria paradoxa* (the shea tree) in the Guinean savannah ecosystem in West Africa (Salako et al., 2025). Nevertheless, at the local and regional levels, knowledge remains fragmentary, particularly when it comes to linking the probability of species presence to their actual abundance in space. However, this distinction is essential in order to go beyond a purely ecological interpretation and integrate issues of land use planning and natural resource management (Lambin et al., 2003).

The province of Boulkiemdé is a relevant area for study in this regard. Located in the Sudano-Sahelian zone, it has a wide variety of bioclimatic conditions and land use systems, ranging from heavily transformed areas by human impact around urban centres to agricultural areas dominated by agroforestry parks. Despite the socio-economic importance of these two tree species in this province, few studies have thoroughly analyzed their spatial distribution, density gradients, and the environmental factors that determine their range. The central question of this research can therefore be formulated as follows: how is the spatial distribution of African locust bean (*Parkia biglobosa*) and shea (*Vitellaria paradoxa*) structured in the province of Boulkiemdé, and to what extent do bioclimatic variables explain the contrasts observed in terms of presence and abundance? The underlying hypothesis is that the distribution of African locust bean follows a spatial gradient strongly conditioned by climatic variables, reflecting the increased vulnerability of the species in northern areas, which are more environmentally restrictive. To address this issue, this study combines an environmental geography approach, georeferenced field inventories, spatial analyses and potential distribution modelling using the MaxEnt model. By cross-referencing data on the probability of occurrence and abundance, the goal is to develop an integrated spatial analysis of the dynamics of these two tree species, in order to inform conservation strategies, the development of agroforestry parks, and land-use planning in the context of global climate change.

Materials and methods

Study area

This study was conducted in the province of Boulkiemdé, located in the central-western region of Burkina Faso. The province is part of the Sudano-Sahelian bioclimatic zone (Figure 1), characterised by a short and irregular rainy season and a long dry season marked by significant temperature variations. Average annual rainfall varies overall along a north-south gradient, which strongly influences the structure of the vegetation and the distribution of tree species.

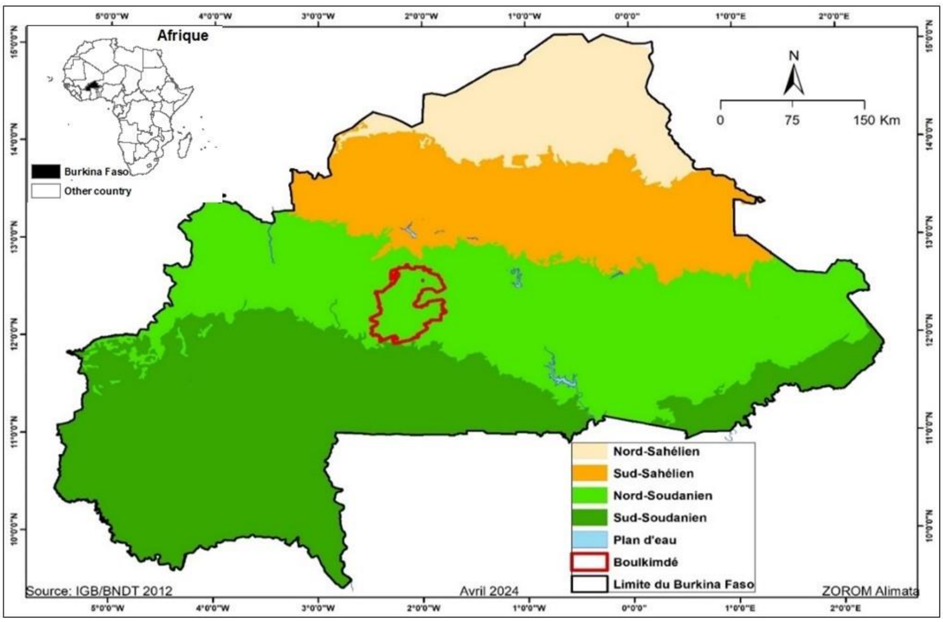

Fig. 1. Biogeographical division of Burkina Faso

The landscape is dominated by agroforestry systems in which Néré (*Parkia biglobosa*) and Karité (*Vitellaria paradoxa*) groves are major elements of land use (see photo plate). Anthropogenic pressure is increasing, particularly around urban centres and transport routes. This province is therefore particularly relevant for analysing the interactions between bioclimatic factors, spatial dynamics and land use planning.

Sampling strategy and field data collection

- ❖ Spatial sampling device

Data on the presence and abundance of African locust bean were collected using systematic sampling, a method widely recommended for spatial distribution studies in order to ensure uniform coverage of the territory and limit biases related to accessibility (Guisan & Zimmermann, 2000). A regular grid of 3 km square network was generated across the entire province using ArcGIS software. The intersections of the grid lines were selected as theoretical sampling points, resulting in the identification of 2,364 points distributed evenly across the entire provincial territory.

- ❖ Collection of occurrence data

The data was collected in the field between November and December 2024, using a GPS receiver to precisely locate each sampling point. At each point, the presence or absence of African locust bean (Néré) (*Parkia biglobosa*) and shea (Karité) (*Vitellaria paradoxa*) was recorded according to a binary protocol (presence/absence), commonly used in species distribution models (Phillips et al., 2006). A total of 99 points where African locust bean was present were identified and entered into a georeferenced database to serve as a reference for the year 2024. A total of 108 points where shea was present were identified and entered into a georeferenced database to serve as a reference for the year 2024.

- ❖ Abundance data collection

In order to go beyond a simple presence analysis, abundance data was collected to characterise the actual spatial structure of African locust bean populations. At each point of presence, an inventory was carried out in a circular plot with a radius of 250 metres, centred on the GPS point. In each plot, the total number of African locust bean trees was counted. This approach makes it possible to link the probability of presence to the actual density of the species and thus provides essential information for the development of agroforestry parks and the sustainable management of wood resources (Kindt et al., 2008).

- ❖ Environmental data and bioclimatic variables

The environmental variables used in this study were taken from the WorldClim database, which is widely used in species distribution analyses (Hijmans et al., 2005). Nineteen bioclimatic variables (Table 1) describing temperature and precipitation regimes were initially considered, to which altitude was added.

Table 1. Variables used in the modelling process

Code	Environmental variables	Unité
Bio1	Average annual temperature	°C
Bio2	Average daily range (monthly average (max temp—min temp))	°C
Bio3	Isothermality (BIO2/BIO7) (× 100)	%
Bio4	Seasonality of temperature	°C
Bio5	Maximum temperature of the warmest month	°C
Bio6	Minimum temperature of the coldest month	°C
Bio7	Annual temperature range (BIO5-BIO6)	°C
Bio8	Average temperature of the wettest quarter	°C
Bio9	Average temperature of the driest quarter	°C
Bio10	Average temperature of the warmest quarter	°C
Bio11	Average temperature of the coldest quarter	°C
Bio12	Annual precipitation	mm
Bio13	Precipitation of the wettest month	mm
Bio14	Precipitation of the driest month	mm
Bio15	Seasonality of precipitation	%
Bio16	Precipitation of the wettest quarter	mm
Bio17	Precipitation in the driest quarter	mm
Bio18	Precipitation in the warmest quarter	mm
Bio19	Precipitation in the coldest quarter	mm
Altitude	Slope ° Altitude	m

Source: Worldclim

In order to limit the effects of collinearity between explanatory variables, a Pearson correlation analysis was performed using SPSS software. Correlation coefficients (r) and associated significance levels (p-values) were used to assess the individual influence of each variable on the probability of néré presence and to identify the most decisive climatic variables. The correlation coefficient (r) is defined as follows:

$$r = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i-\bar{y})^2}} \quad (1)$$

With,
r : Pearson's correlation coefficient
x_i; y_i : observed values of the two variables X and Y
$\bar{x}, \bar{y}$: averages of variables X and Y
n : total number of observations

Modelling potential distribution

- ❖ MaxEnt model

The potential distribution of néré and karité was modelled using the MaxEnt (Maximum Entropy) model, which is particularly suited to presence-only data and widely used in biogeography and spatial ecology (Phillips et al., 2006; Elith et al., 2011; Smith et al., 2012; Daï et al., 2023; Zenebe et al., 2024; Yahaya et al., 2025). This model is based on the principle of maximum entropy and estimates the most uniform possible distribution of the species while respecting the constraints imposed by the environmental variables observed at the presence points.

- Model performance evaluation

Model performance was evaluated using the area under the ROC curve (AUC), a standard indicator for measuring the discriminatory power of a species distribution model. An AUC value between 0.7 and 0.8 is generally considered to indicate moderate to satisfactory performance (Swets, 1988). The probabilities of occurrence derived from the model were classified into four categories (very low, low, moderate or high) to facilitate spatial interpretation and mapping.

Spatial analysis and mapping

The results of the MaxEnt model were integrated into a geographic information system (GIS) to produce maps of the current and potential distribution of Néré and Karité trees across the province. In addition, abundance data were interpolated using the inverse distance weighting (IDW) method to estimate the spatial density of Néré and Karité trees. Although deterministic, this method is suitable for exploratory analysis of the spatial structure of natural resources when regular sampling is available:

$$\hat{Z}(x_0) = \frac{\sum_{i=1}^{n} \frac{Z(x_i)}{d(x_0, x_i)^p}}{\sum_{i=1}^{n} \frac{1}{d(x_0, x_i)^p}} \qquad (2)$$

With,
$\hat{Z}(x_0)$: estimated value at unknown point x_0
$Z(x_i)$: value measured at the known pointx_i
$d(x_0, x_i)$: distance between the point to be estimated $x_0$and the known pointx_i
p : weight power (often $p = 2$),
n : total number of known points used for interpolation

Geostatistical indicators (barycentre, spatial mean and dispersion ellipse) were used to analyse the preferred directions of distribution and territorial gradients. The coordinates of the centroid are calculated using the following formula:

$$x_G = \frac{1}{p}\sum_{p} x_i \ et \ y_G = \frac{1}{p}\sum_{p} y_i \qquad (3)$$

The coordinates of the centroid (G) are calculated using the formula below. It is the weighted average of x and y.

$$G_Z = \min \sum_i n_j d_{ij}^2 \quad \text{with} \quad x_G = \frac{1}{N}\sum_i n_i x_i, \quad \text{and} \quad y_G = \frac{1}{N}\sum_i n_i y_i \tag{4}$$

The standard deviation ellipse is a circle around the centre of gravity (Zaninetti 2005). It is calculated as follows:

$$\theta = \arctan\left[\sum_i ni(x_i - \bar{x})^2 - \sum_i n_i(y_i - \bar{y})^2) + \frac{\sqrt{(\sum_i n_i(x_i-\bar{x})^2 - \sum_i n_i(y_i-\bar{y})^2)^2 + 4(\sum_i (x_i-\bar{x})y_i-\bar{y}))^2}}{2x\sum_i (x_i-\bar{x})y_i-\bar{y})}\right] \tag{5}$$

These calculations are performed using ArcGIS 10.3 software.

Analysis at the administrative level

Finally, an analysis of the distribution of the number of African locust bean and shea trees was carried out at the municipal level in the province of Boulkiemdé. This approach makes it possible to link ecological results to administrative units, thus facilitating their consideration in local land use planning and natural resource management policies.

Projected future distribution of Parkia biglobosa and Vitellaria paradoxa by 2080: climate projection framework

The projection of the future distribution of African locust bean (*Parkia biglobosa*) and shea (*Vitellaria paradoxa*) by 2080 was carried out using the IPSL-CM6A-LR climate model, derived from the CMIP6 programme, and incorporating two contrasting scenarios:

- SSP1-2.6 (optimistic scenario), corresponding to a low level of warming,
- SSP5-8.5 (pessimistic scenario), characterised by a sharp increase in temperatures and a significant decrease in precipitation.

In the province of Boulkiemdé, projections indicate an increase in average annual temperature of up to 33°C under SSP1-2.6 and 37°C under SSP5-8.5 by 2080, compared to more moderate current values. At the same time, annual precipitation could remain close to current values under SSP1-2.6 (≈ 810 mm), but fall to 650 mm under SSP5-8.5, exacerbating arid conditions.

Results

Distribution of Néré and Karité in Boulkiemdé

Modelling the potential distribution of Néré and Karité using the MaxEnt model produced an area under the ROC curve (AUC) of 0.743 for Néré and 0.738 for Karité, based on the training data (see Figure 2). This value indicates that the model has a moderate ability to discriminate between areas favourable to the presence of the species and areas unfavourable to it, and that it performs significantly better than a random prediction.

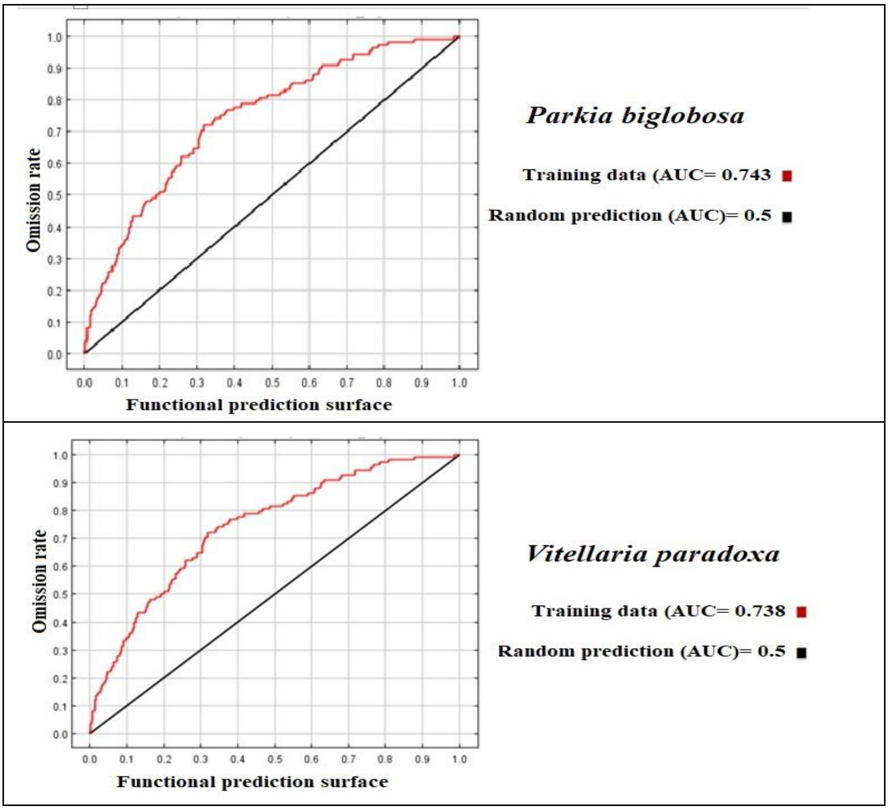

Fig. 2. Performance of the classification model for the presence of Parkia biglobosa and Vitellaria paradoxa in Boulkiemdé
Source: Processing of data from Maxent, 2025

Furthermore, the distribution of the two tree species is shown in Figure 3 in 2024. The probabilities of occurrence generated by the model range from 0.06 to 1, reflecting a wide range of environmental conditions that are more or less favourable to the species (Figure 3). These probabilities have been grouped into four classes to facilitate spatial interpretation.

Figure 3 shows a spatial distribution by probability classes of presence. Areas with very low probability (between 0.06 and 0.3) are mainly located in the north and north-central parts of the province, particularly in the municipalities of Nanoro, Pella, Siglé and Soa. These areas correspond to climatic conditions that are less favourable to the species. Areas with low probability (between 0.3 and 0.5) occupy a large part of the centre of the province, reflecting intermediate environmental conditions that are insufficient for optimal development of the Néré tree but still allow for its occasional presence. Areas with moderate probability (between 0.5 and 0.7) appear to be transitional areas, where bioclimatic conditions are gradually becoming more favourable.

They are distributed discontinuously in the central and southern parts of the province. Finally, areas with high to very high probability (between 0.7 and 1) are heavily concentrated in the south of the province, particularly in the municipalities of Thiou and Sabou.

These areas correspond to the habitats most favourable to the presence of the Néré. Analysis of spatial indicators shows that the centre of gravity of the potential distribution is slightly shifted southwards compared to the spatial average, reflecting the greater attractiveness of southern environmental conditions. The dispersion ellipse highlights a north-east to south-west orientation of the species' distribution.

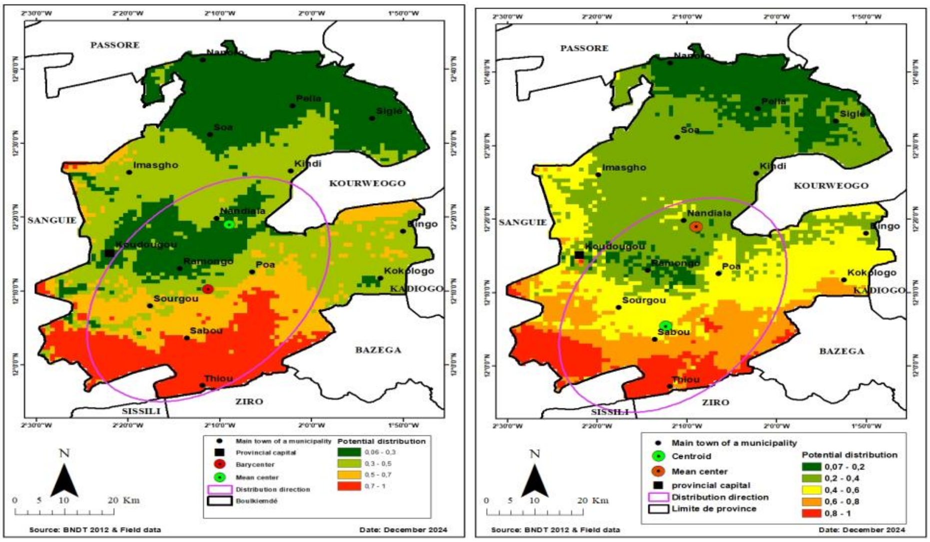

Fig. 3. Current distribution (2024) of Parkia biglobosa (a) and Vitellaria paradoxa (b) in the province of Boulkiemde

Spatial distribution of abundance

Interpolation using the IDW method reveals a variation in the number of African locust bean trees ranging from 0 to 52 at the provincial level (Figure 4). The values were grouped into five density classes. Areas with very low density (0–10 trees) are mainly located in the north of the province. Areas with low density (11–20 trees) are more widely distributed but remain mainly confined to the northern and central regions. Areas with moderate density (21–30 trees) correspond to intermediate regions, where ecological conditions become more favourable. High-density (31–40 feet) and very high-density (41–52 feet) areas are clearly concentrated in the southern part of the province.

Figure 4 shows that the centre of gravity of the abundance distribution is located in the municipality of Ramongo, while the spatial average is located in Nandiala, indicating an asymmetrical distribution dominated by areas of high density in the south. The dispersion ellipse extends broadly from southwest to northeast and encompasses the main areas of moderate to high density.

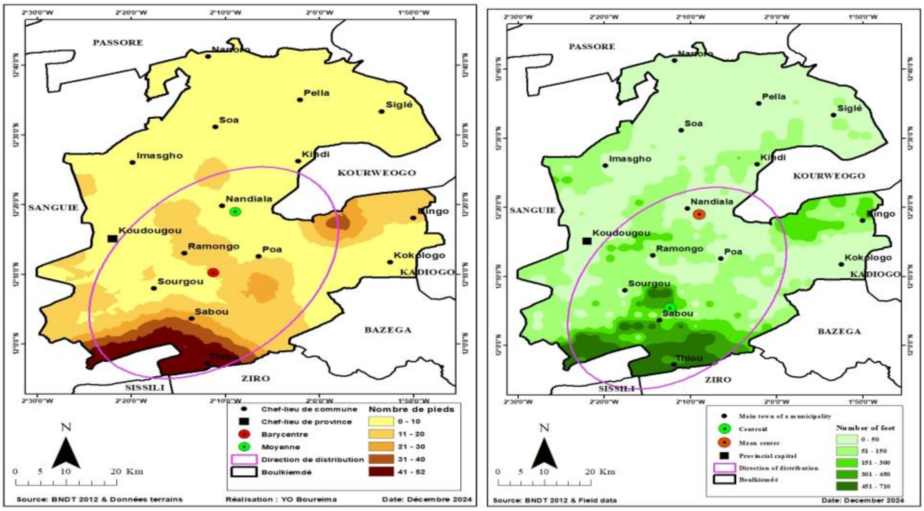

Fig. 4. Density of Parkia biglobosa in the province of Boulkiemdé

Distribution of Néré and Karité trees by municipality

At the administrative level, 334,061 Néré trees were recorded throughout the province of Boulkiemdé (see Figure 5). The distribution by municipality highlights strong territorial contrasts.

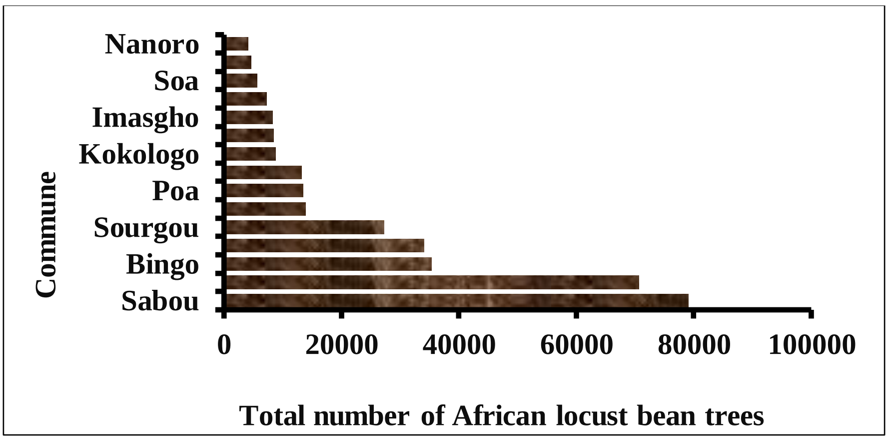

Fig. 5. Distribution of Parkia biglobosa trees by municipality

The southern zone (Sabou, Thiou and Sourgou) accounts for 177,036 trees, or 53.0% of the provincial total. The municipalities of Sabou (79,077 trees) and Thiou (70,685 trees) alone account for nearly 45% of this total. The central zone (Koudougou, Ramongo, Poa and Nandiala) has a total of 74,670 trees (22.4%), with a marked predominance in the municipality of Koudougou. The centre-east (Bingo and Kokologho) has 44,111 trees (13.2%), mainly concentrated in Bingo. Finally, the northern and north-central municipalities have the lowest numbers, with 21,493 trees (6.4%) and 16,751 trees (5.0%) respectively.

In total, the number of Karité trees recorded throughout the province is estimated at approximately 4,240,561 (see Figure 6). This figure highlights the importance of Karité as a major component of the agroforestry landscape of Boulkiemdé.

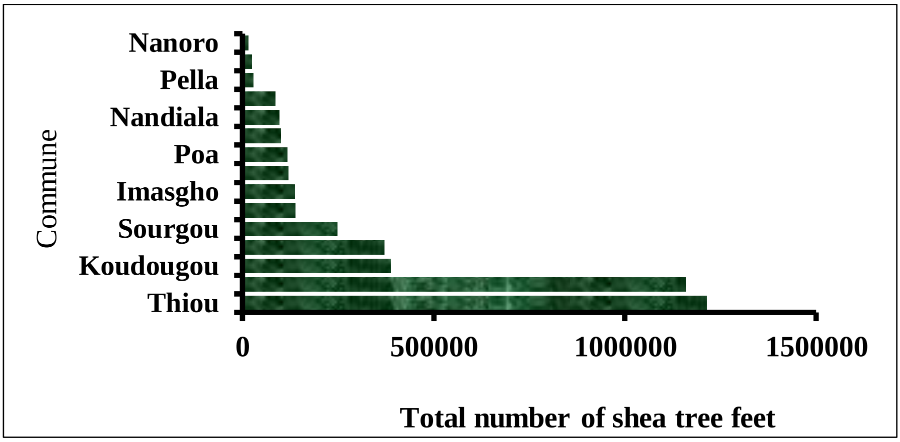

Fig. 6. Distribution of Vitellaria paradoxa by municipality

The spatial distribution shows a high concentration of Karité trees in the south and centre of the province, particularly around the municipalities of Koudougou, Nandiala, Ramongo and Poa. This central area appears to be a high-density core, reflecting both more favourable bioclimatic conditions and a structuring role in agricultural and administrative terms. Conversely, the northern municipalities, such as Nanoro, Soa, Siglé and Pella, as well as certain peripheral areas, have significantly lower densities. This situation could be linked to more pronounced climatic constraints, increased land pressure or farming practices that are less favourable to Karité conservation. Taken together, these results highlight a north-south spatial gradient, characterised by a gradual increase in the number of Karité trees towards the south of the province. This gradient underscore the combined influence of climatic and territorial factors on the structure of Karité.

Influence of bioclimatic variables on the distribution of African locust bean and shea

Pearson's correlation analysis highlights statistically significant relationships between the probability of Néré presence and several bioclimatic variables (Figure 7). The p-values associated with these correlations are significant (between 0.0001 and 0.05), indicating that the correlations observed are statistically significant and unlikely to be due to chance.

Figure 7 shows strong positive correlations between precipitation variables, particularly precipitation in the wettest quarter (Bio16), annual precipitation (Bio12) and precipitation in the wettest month (Bio13). These variables appear to be the most favourable for the presence of nereis. Moderate positive correlations are also observed with certain temperature variables, such as the minimum temperature of the coldest month (Bio6) or the average temperature of the coldest quarter (Bio11).

Conversely, several variables show moderate to strong negative correlations, notably the seasonality of precipitation (Bio 15), the diurnal temperature range (Bio 2) and the average temperature of the wettest quarter (Bio 8), reflecting the sensitivity of the African locust bean to high climatic variability and temperature extremes. Altitude shows a weak and non-determinative correlation, suggesting that this factor plays a secondary role in the study area.

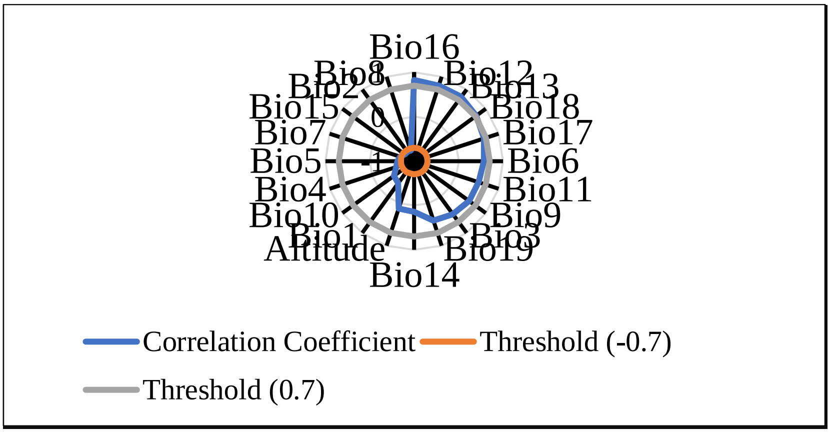

Fig. 7. Significant correlations between bioclimatic variables and the distribution of Néré

The analysis of the influence of bioclimatic variables on the distribution of shea trees is also based on Pearson's correlation coefficient (r), calculated between the probability of occurrence derived from the MaxEnt model and the selected environmental variables (see Figure 8). The p-values associated with these correlations are significant (between 0.0001 and 0.05), indicating that the correlations observed are statistically significant.

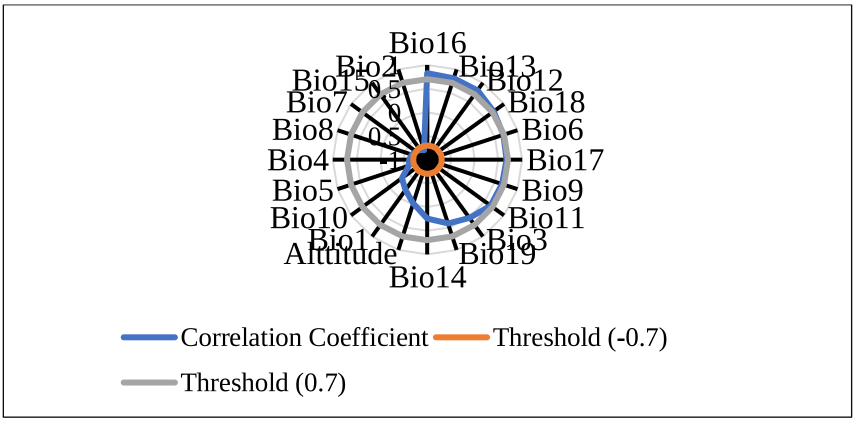

Fig. 8. Significant correlations between bioclimatic variables and shea distribution

This figure reveals strong positive correlations (r > 0.7) between the distribution of Shea trees and certain rainfall variables. The Bio16 variable (rainfall during the wettest quarter) appears to be the most strongly correlated with the presence of the species, indicating that conditions of high-water availability during the wet season are crucial for the growth and reproduction of shea trees. Moderate positive correlations (between 0.4 and 0.7) are also observed with the Bio6 variable (minimum temperature in the coldest month), suggesting that relatively mild minimum temperatures favour the presence of the tree, without however being the main explanatory factor.

Some variables show weak or almost zero correlations (r close to 0), notably Bio14 (precipitation in the driest month). This result indicates that the amount of precipitation during the driest period plays a limited role in the spatial distribution of shea trees at the provincial level.

Moderate negative correlations (between -0.7 and -0.4) are also observed with variable Bio10 (average temperature of the hottest quarter), reflecting the sensitivity of shea trees to prolonged high temperatures. Furthermore, a strong negative correlation ($r < -0.7$) is associated with Bio7 (annual temperature range), suggesting that large annual temperature variations are a limiting factor for the species.

Projected future distribution of Parkia biglobosa by 2080

Parkia biglobosa is a species known for its relatively high thermal and water tolerance. It grows preferentially in areas where the average annual temperature varies between 25°C and 32°C, and can withstand maximum temperatures of up to 40°C. In terms of water, its ecological optimum is between 700 and 1,300 mm of annual rainfall, thanks in particular to its deep root system, which gives it greater resistance to prolonged water stress. These characteristics explain why, despite more challenging climatic conditions, the African locust bean retains a relatively high potential for spatial maintenance in this province by 2080. Figure 9 shows the evolution, by 2080, of the probabilities of African locust bean's presence in this province. These projections were made according to two scenarios: optimistic (126) and pessimistic (586) (see Figure 9).

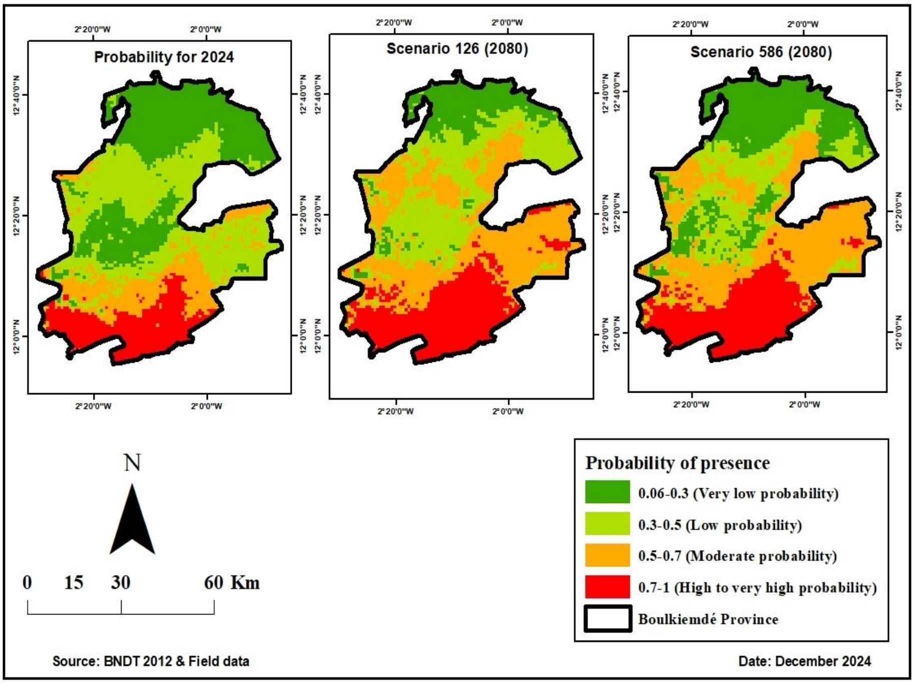

Fig. 9. Future distribution of Parkia biglobosa using Maxent modelling
Source: Processing of data from Maxent, 2025

Figure 9 presents the results of a model of the distribution of a nereid, comparing the current area occupied by the species with the projected areas for two future scenarios (126 and 585).

The results are classified into four categories of probability of presence, ranging from 'very low' to 'high to very high'. Significant changes can be observed in the projected areas for the two future scenarios (126 and 585) compared to the current area. These variations are visible in all probability of occurrence categories. The areas change not only in size but also in probability category. For example, for the 'moderate' probability (0.5-0.7), the area increases significantly in both future scenarios. Scenarios 126 and 585 show different trends. Scenario 126 seems to indicate an overall increase in areas for moderate to high probabilities, while scenario 585 shows a more marked increase for low to moderate probabilities.

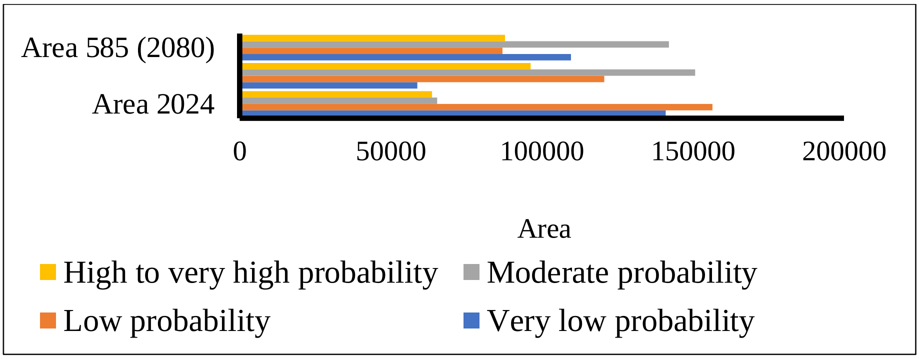

Fig. 10. Changes in the areas of probability of occurrence of Parkia biglobosa in 2080
Source: Processing of data from Maxent, 2025

Projected future distribution of shea (Vitellaria paradoxa) by 2080

Shea (*Vitellaria paradoxa*) is recognised as a species that is more demanding in terms of climate than néré, particularly with regard to rainfall and temperature stability. Its ecological optimum is generally found in areas receiving 800 to 1,200 mm of annual rainfall, with an average annual temperature between 24°C and 30°C. High maximum temperatures and an increase in annual temperature range are limiting factors for its growth and regeneration. Climate projections for 2080, based on the IPSL-CM6A-LR (CMIP6) model, indicate that in the province of Boulkiemdé :

- an increase in average annual temperature of up to +2.1 °C under SSP1-2.6 and +4.3 °C under SSP5-8.5;
- an estimated decrease in annual precipitation of between –5% (SSP1-2.6) and –20% (SSP5-8.5).

These climatic changes pose major constraints for the future survival of shea tree populations. Figure 11 summarises the changes in the probability of shea tree presence in the province of Boulkiemdé by 2080. These projections were made according to two scenarios (optimistic (126) and pessimistic (586)).

Figure 11 presents the modelling results, which compare the current area occupied by the species with the projected areas for two future scenarios (126 and 585). The results are classified into six categories of probability of occurrence, ranging from 'very low' to 'very very high'. Significant changes can be observed in the projected areas for the two future scenarios compared to the current area. These variations are visible in all probability of occurrence categories.

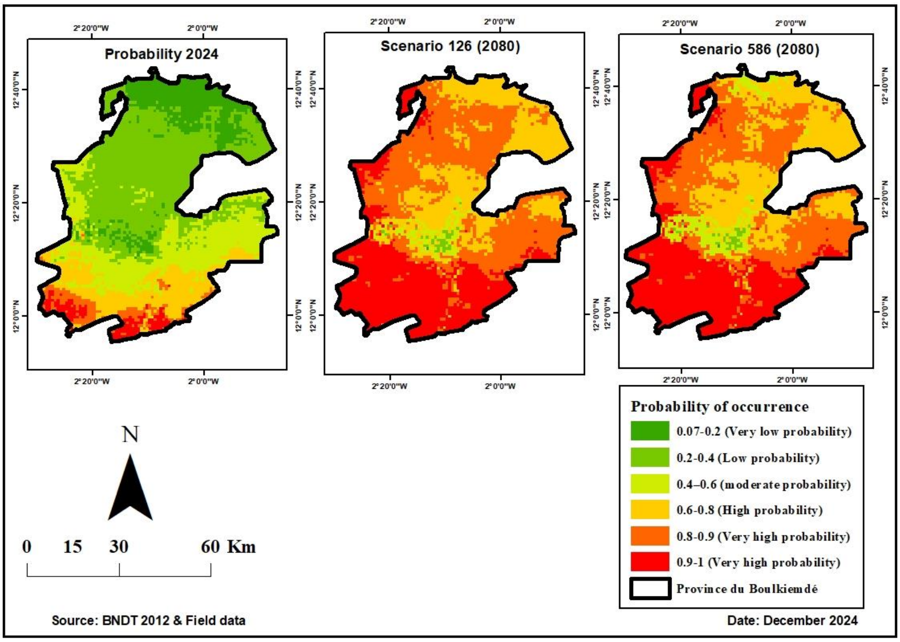

Fig. 11. Future distribution of Vitellaria paradoxa based on Maxent modelling
Source: Processing of data from Maxent, 2025

The areas change not only in size but also in probability category. For example, for the 'moderate' probability (0.4-0.6), the area increases significantly in both future scenarios. Scenarios 126 and 585 show different trends. Scenario 126 seems to indicate an overall increase in areas for moderate to high probabilities, while scenario 585 shows a more marked increase for low to moderate probabilities. There is a drastic decrease in area for very low and low probabilities in the future scenarios. This suggests a possible disappearance of the species in areas where the probability of occurrence is currently low.

There is also a significant increase in the areas with high and very high probabilities in future scenarios. This suggests a possible concentration of the species in areas where the probability of occurrence is currently high. Scenarios 126 and 585 show similar results for very low and low probabilities, but differences for moderate to high probabilities. This suggests that the scenarios have different impacts on areas where the probability of occurrence is higher. The modelling results suggest a significant change in the distribution of the plant species studied. Areas with a low probability of occurrence could disappear, while areas with a high probability of occurrence could expand. Future scenarios 126 and 585 show similar trends for low probabilities, but differences for high probabilities, suggesting different impacts on areas with higher probability of occurrence.

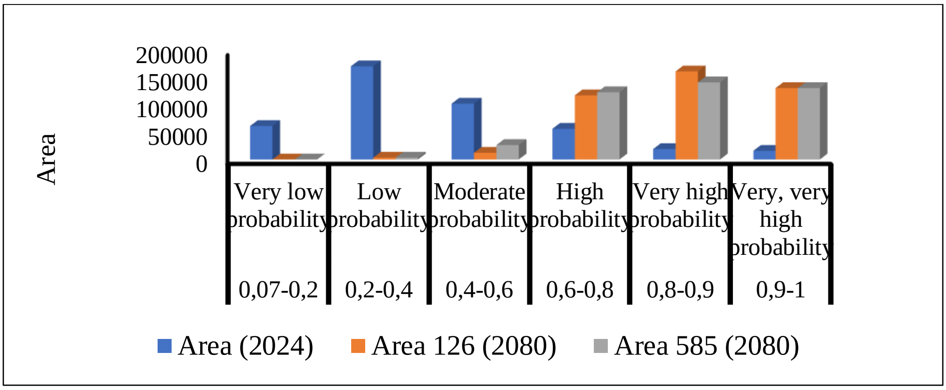

Fig. 12. Change in areas of probability of occurrence of Vitellaria paradoxa in 2080
Source: Processing of data from Maxent, 2025

Discussion

Climate-related distribution patterns of Parkia biglobosa and Vitellaria paradoxa: confirmation and nuances

The results of this study confirm the central role of climatic factors, particularly rainfall, in the spatial structure of *Parkia biglobosa* and *Vitellaria paradoxa*. The strong positive correlation observed between annual rainfall and rainfall during the wettest quarter and the distribution of néré confirms this. The spatial distribution of Karité trees in the province of Boulkiemdé is also strongly structured by a north-south climatic gradient, characterised by a concentration of stands in the southern and central areas. This highlights the fact that *Vitellaria paradoxa* is a species preferentially associated with Sudanian zones, where rainfall patterns are more regular and thermal constraints less pronounced. The conclusions of this study are consistent with those of several studies conducted in West Africa, which identify water as the main limiting factor for the growth and regeneration of Sudano-Sahelian agroforestry species (Teklehaimanot, 2004; Faye et al., 2018). However, our results add an important nuance by showing that it is not only rainfall volumes that influence the presence of African locust bean and shea trees, but above all their seasonal regularity.

The strong negative correlation with rainfall seasonality (Bio15) suggests that sudden alternations between very dry and very wet periods are a major stress factor for the species. This observation corroborates the work of Sanou et al. (2012), who highlight the sensitivity of néré to intra-annual climate variations, particularly during the flowering and fruiting phases. The same authors also note that water availability during the rainy season is a determining factor for the flowering and fruiting of the shea tree.

The negative relationship between the presence of African locust bean, shea trees and several thermal variables, notably the maximum temperature of the hottest month and the diurnal temperature range, highlights a limiting effect of thermal stress. Although African locust bean is often described as a relatively heat-tolerant species, these results suggest that excessive temperatures, particularly when combined with water deficits, can compromise its development. These observations are consistent with those of Ouédraogo et al. (2014) in Burkina Faso and Yabi et al. (2025) in Benin, which show that high temperature ranges and humidity reduce the survival of young *Parkia biglobosa* and *Vitellaria paradoxa* plants. Similarly, the work of Boffa (1999) indicates that the natural regeneration of African locust bean is particularly sensitive to microclimatic conditions, which are often modified by agricultural practices and the degradation of tree cover. Thus, the low influence of altitude observed in this study confirms that it is not topographical gradients that structure the distribution of African locust bean in Boulkiemdé, but rather combined climatic constraints at the local level.

The south-north gradient of the two agroforestry species observed in the province of Boulkiemdé is part of a broader dynamic observed at the regional level. Several authors have highlighted a gradual concentration of useful agroforestry species in wetter areas, reflecting a spatial adaptation to recent climate change (Garrity et al., 2010; Brandt et al., 2017). From this perspective, the current distribution of African locust bean in Boulkiemdé can be interpreted as an ecological retreat towards more favourable climatic niches. This phenomenon, already observed for shea (*Vitellaria paradoxa*), raises the question of the sustainability of agroforestry parks in climate transition zones and reinforces the idea of a gradual recomposition of Sahelian rural landscapes (Lykke et al., 2013).

Current and future ecological differentiation of Parkia biglobosa and Vitellaria paradoxa in agroforestry parklands

The results confirm that *Parkia biglobosa* currently has a relatively diffuse and continuous spatial distribution in the province of Boulkiemdé, reflecting greater ecological plasticity than shea. This observation is consistent with previous studies describing African locust bean as a species capable of adapting to a wide range of edaphic and climatic conditions in the Sudano-Sahelian zone (Teklehaimanot, 2004; Ouédraogo et al., 2014). Climate projections for 2080 reinforce this interpretation. Unlike many agroforestry species that are sensitive to heat and water stress, African locust bean retains a significant spatial maintenance capacity, even in the pessimistic SSP5-8.5 scenario. This projected resilience can be explained by several functional traits: a deep root system, high tolerance to maximum temperatures and the ability to exploit more irregular rainfall patterns (Sanou et al., 2012; Faye et al., 2018). Thus, the future distribution of the African locust bean will not be characterised by a sudden contraction, but rather by a gradual spatial reconfiguration, with a shift from areas of high probability to areas that are more favourable in terms of water availability. This type of response corresponds to what Guisan and Zimmermann (2000) describe as spatial adaptation rather than local extinction, which is common among species that are tolerant to climate stress.

At the current scale, the spatial concentration of shea trees in the southern and central areas of the Boulkiemdé region already shows a marked dependence on relatively stable rainfall patterns, as demonstrated by several studies in West Africa (Sanou et al., 2012; Ouédraogo et al., 2014). Climate projections for 2080 reinforce this analysis. Under the SSP1-2.6 scenario, shea retains some of its favourable areas, but already shows signs of fragility, with a decrease in high probability of occurrence and a gradual migration towards areas of moderate probability. Under the SSP5-8.5 scenario, the contraction is more pronounced, with a significant reduction in the ecological niche, mainly due to higher maximum temperatures and lower rainfall. These results are consistent with the work of Lykke et al. (2013), which highlights the dependence of shea trees on relatively regular water conditions, as well as with that of Brandt et al. (2017), which highlight the limits of the natural adaptation of climate-sensitive woody species in the face of intensifying warming.

The decisive role of local practices and territorial dynamics

While climatic factors largely explain the potential distribution of African locust bean and shea trees, the actual distribution of their abundance reveals the importance of anthropogenic factors. The high densities observed in certain southern municipalities cannot be explained solely by favourable environmental conditions, but also by local tree management and protection practices. Studies conducted in Burkina Faso and Mali, in West Africa, show that the voluntary conservation of useful trees by farmers, particularly in areas where African locust bean has high economic value, is essential for maintaining stands (Kindt et al., 2008; Bayala et al., 2014). Conversely, in areas subject to high land pressure, the reduction of fallow land and the intensification of agriculture are leading to the gradual erosion of agroforestry parklands. The observed dissociation between areas of high probability of occurrence and areas of high density confirms the limitations of purely bioclimatic models and highlights the need to integrate socio-territorial dynamics into the analysis of agroforestry systems.

Contributions and limitations of MaxEnt modeling in an agroforestry context

The moderate performance of the MaxEnt model (AUC = 0.743 for African locust bean and AUC = 0.738 for shea) is comparable to that reported in other studies on the distribution of woody species in anthropized environments (Elith et al., 2011; Merow et al., 2013). This performance reflects both the relevance of climatic variables and the limitations inherent in this type of model. Indeed, Phillips et al., 2006, report that the limitations of MaxEnt are that it only takes presence data into account. Warren and Seifert (2011) note a dependence on statistical criteria (AUC) that can sometimes be misleading. Furthermore, the MaxEnt model does not incorporate socio-economic variables (Tosso & Hambuckers, 2013; Zurell et al., 2020). However, in agroforestry systems, where the presence of trees is as much a result of social choices as ecological constraints, the combined use of presence probability and abundance data appears to be a particularly relevant approach. However, not taking human action into account may underestimate MaxEnt results in the study area.

Conclusion

This study aimed to analyze the spatial distribution of African locust bean (*Parkia biglobosa*) and shea trees (*Vitellaria paradoxa*) in the province of Boulkiemdé, combining an integrated approach involving field inventories, spatial analyses, and modelling of potential distribution. The results highlight a highly heterogeneous distribution of the species, structured by a north-south climate gradient and modulated by territorial dynamics and local agroforestry park management practices. MaxEnt modeling reveals that the presence of African locust bean is mainly conditioned by rainfall variables, in particular annual precipitation and precipitation during the wettest quarter, while climate variability and temperature extremes appear to be major limiting factors. This dependence on relatively stable climatic regimes explains why the highest probabilities of occurrence and densities are concentrated in the southern part of the province, to the detriment of the northern areas, which are more environmentally challenging. However, joint analysis of probability of presence and actual abundance shows that, although decisive, climatic factors alone are not sufficient to explain the structure of African locust bean and shea tree populations.

The contrasts observed at the community level also reflect the influence of agricultural practices, land pressure, and management choices made by local actors. These two tree species thus appear to be central to rural socio-ecosystems, with their distribution resulting from a close interaction between environmental constraints and territorial dynamics. From a methodological perspective, this study highlights the value of combining potential distribution modeling with abundance data collected in the field to better understand the complexity of agroforestry systems.

The combined use of the MaxEnt model and spatial analysis tools makes it possible to go beyond a strictly ecological interpretation and place the results in a land-use planning perspective. At the operational level, the results highlight priority areas for the conservation and enhancement of African locust bean and shea tree parklands, particularly in the south of Boulkiemdé province, and identify more vulnerable areas that require specific adaptation strategies. In a context of climate change and increasing pressure on natural resources, it is essential to take into account climatic gradients and local practices to ensure the sustainability of agroforestry systems. Ultimately, African locust bean appears to be an essential economic and food resource, but also a spatial indicator of the resilience of rural areas. Incorporating these two species into sustainable land management and land-use planning policies is a strategic tool for helping rural communities in West Africa adapt to environmental changes.

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