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Impact of Climate Change on the Extent of Favorable Areas for the Future Distribution of Multipurpose Agro Forestry Species in Niger: The Case of Vitellaria Paradoxa C.F. Gaertn

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Abstract:- The combined effects of climate change and increasing anthropogenic activities (deforestation, intensification of agriculture, overgrazing, timber exploitation, urbanization, etc.), threaten the existence of biodiversity on earth. Indeed, several climate projections predict scenarios that foresee the combined adverse effects of these scourges on the existence of habitats favorable to the distribution of several woody agroforestry species (ELA), of socio-economic importance, on earth. The objective of this study is to determine the impact of climate change on the extent of favorable areas for the future distribution of Vitellaria paradoxa C.F. Gaertn. In Niger. This distribution was modeled using the maximum entropy approach.

Environmental data, such as bioclimatic variables, as well as geo-referenced occurrence data of the species were used in MaxEnt 3.3.3k software to produce a distribution model. For future climate projections, two emission scenarios (Representative Concentration Pathways (RCP)) were used. These are the optimistic scenario (RCP 4.5) and the pessimistic scenario (RCP 8.5) which are the most appropriate for Africa by 2050.

The results reveal that the habitats favorable for future tamarind conservation are located in the Sahelo-Sudanian zone of the country. Annual rainfall and temperature are the environmental variables that influence the distribution of the species. According to the scenarios, global warming will negatively affect the area of the habitat very favorable for the future distribution of Vitellara paradoxa, which will decrease by - 2.28% and -7.14% for RCP45 and RCP85, respectively. These results obtained are essential for future conservation programs for this species in Niger. To this end, any project or program to restore the density of the populations of this species must take into account this result.

Keywords:- *Agroforestry species* **-** *Vitellaria paradoxa* **-** *climate change – Niger.*

I. INTRODUCTION

In West Africa, particularly in the Sahel region, people are placing increasing value on multi-purpose agroforestry species. This is due not only to the use of these species in many areas of life (food, health, handicrafts, etc.), but also to people's awareness and belief in their beneficial effects. One example is Vitellaria paradoxa. This species, known for its many virtues by both rural (farmers and herders) and urban populations, is increasingly sought-after in West African Sahelo-Sudan zones [1], [2]. Non-timber forest products from this species, notably butter, play an important role in the lives of rural households and in the economies of many developing countries [3], [4[, [5]. The kernels from the seeds harvested by women are processed into butter or sold dried. They generate enormous income for local populations and play an important role in the economies of producing countries. The results of recent studies on the ranking of agricultural export products show that in Benin, Vitellaria paradoxa or shea ranks third after cotton and cashew nuts [6]. Its production contributes 0.3% to the country's national wealth [7]. Between 1999 and 2006, Burkina Faso exported shea seeds worth over thirteen billion CFA francs [8], [9]. In Mali, shea is protected under the forestry code because of its social, economic and ecological values [9]. According to [10], cited by Nouvellet et al. (2006) [4], its density varies according to the country's agro-ecological zones. It varies from four trees per hectare to eight (08) trees in the more heavily irrigated southern part of the country. Despite its important role in the food security of rural populations in sub-Saharan Africa,the populations of this species are subject to abusive logging practices that do not respect any standards. Despite these multiple threats, in agroforestry parks, natural regeneration is the only process that ensures the renewal of this species [11]. Today, the combined effect of anthropogenic pressures (fruit harvesting, excessive pruning, abusive felling, etc.) and climate change (repetitive droughts, high temperatures and sunshine, etc.) are having a major impact on natural regeneration in vitellaria paradoxa parks. At present, the shea tree is experiencing difficulties in maintaining and increasing production due to its limited presence in the field.. It is therefore necessary to study the population dynamics of this species in a context of high climatic variability and demographic pressure. A study to determine the impact of climate change on the extent of favorable areas for the future distribution of Vitellaria paradoxa C.F. Gaertn.in Niger is urgently needed.

II. METHODOLOGIE

A. *STUDY AREA*

The present study was carried out across the country, following the north-south climatic gradient. On this agro-ecological trajectory, four (04) agro- ecological zones can be distinguished from north to south (figure 1):

- The Saharan Zone (100 to 300 mm);
- The Sahelo-Saharan Zone (300 and 500 mm);
- The Sahelian zone (500-700 mm);
- and the Sudanian zone (700 mm and over).

This methodology was adopted to better understand the distribution of the species, as well as the environmental variables that influence the distribution along this climatic gradient.

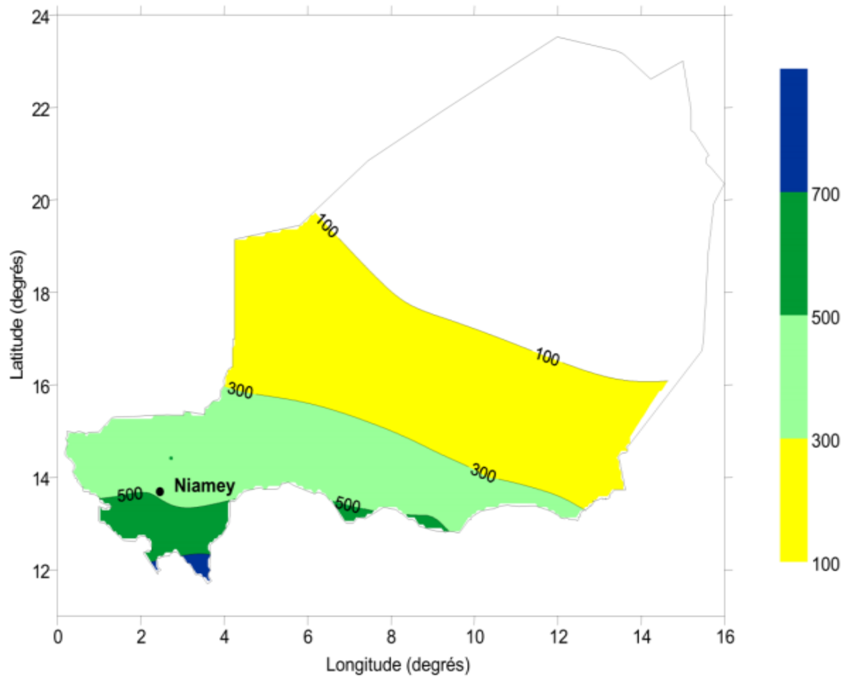

Fig. 1: Distribution of average annual rainfall in Niger by agro-ecological zone Source: base map: Direction générale de la Méthéorologie du Niger (DMN))

B. *COLLECTING POINTS OF OCCURRENCE*

From the north to the south of the country, the coordinates of the points of presence of the species were recorded through floristic surveys during field data collection campaigns. These coordinates were completed using those downloaded from the G.B.I.F. (Global Biodiversity Information Facility) website. All these coordinates were used to reconstitute a database of Vitellaria paradoxa presence points in Niger.

C. *BIOCLIMATIC VARIABLES*

The 19 bioclimatic variables (Table 1) used were extracted from the WORLDCLIM database (http://www.worldclim.org). They are collected at a grid resolution of 2.5 arc-minutes at ground level [12], [13].

Table 1: Bioclimatic variables used to model Vitellaria paradoxa distribution

BIO1Mean annual temperature	BIO2 Average daily temperature variation [monthly average (max temperature-mini temperature)].
BIO3 Ratio of daily temperature variation to annual temperature variation	BIO4 Temperature seasonality (standard deviation*100)
BIO5 Maximum temperature in the warmest month	BIO6 Maximum temperature in the coldest month
BIO7 Annual temperature variation	BIO8 Average temperature in wettest quarter
BIO9 Average temperature in the driest quarter	BIO10 Average temperature in the warmest quarter
BIO 11 Average temperature in the coldest quarter	BIO12 Annual precipitation
Bio13 Precipitation in the wettest month	BIO14 Precipitation in the driest month
BIO15 Precipitation seasonality (coefficient of variation)	BIO16 Precipitation in the wettest quarter
BIO17 Precipitation in the driest quarter	BIO18 Warmest quarter precipitation
BIO19 Precipitation in the coldest quarter	

Source : *http://www.wordclim.org* [14]

For future climate projections, two emission scenarios were used, one optimistic (RCP 4.5 or Representative Concentration Pathways) and the other pessimistic (RCP 8.5). These two scenarios are the most appropriate for Africa. Indeed, these two greenhouse gas emission scenarios predict a decrease in rainfall in West Africa by 2050. The consequences of this precipitation could therefore lead to the drying-up of wetland ecosystems recognized as favorable habitats for these species. These scenarios were used to get an idea of what would happen in 2050 in the best and worst case scenarios. Table 2 summarizes the different characteristics of each scenario.

Table 2: Characteristics of the optimistic scenario (RCP 4.5) and the pessimistic scenario (RCP 8.5)

Scena-rios	Characteristics	Predictions
RCP4.5	- Radiative forcing rate (~4.5W/m2) in 2100 - GHG concentration (ppm) (~650 eq-CO2) in 2100 - Stabilization of forcing rate and GHG concentration after 2100	- Very low energy intensity. Strong reforestation programs. - Less frequent use of cultivated land. Rigorous climate policies. - Methane emissions stable - CO2 emissions increase only slightly before the onset of decline around 2040.
RCP8.5	- Radiative forcing rate (>8.5 W/m2) in 2100 - GHG concentration (ppm) (~1370 eq CO) in 2100 - No change in emissions reduction strategy.	- Very high concentration of CO2 emitted into the atmosphere (three times current levels) by 2100. - Rapid growth in methane emissions. - Growing use of cropland and grassland due to population growth. - World population estimated at 12 billion by 2100. - High energy intensity. No implementation of climate policies.

D. DATA PROCESSING AND ANALYSIS

➢ *Modeling future distribution of Vitellaria paradoxa*

Bioclimatic variables downloaded in tif* format were converted to ASCII(ascii) format using ArcGIS 10.5 software in order to obtain environmental rasters that could be handled by the MAXENT modeling program. These rasters are made up of 19 environmental variables, some of which were discarded after a Pearson correlation test. In this study, five (5) bioclimatic variables were retained (Table 3), given their low correlation (r < 0.80) [15]. A high correlation between variables would introduce bias into the model [16], [17], [18], [19], [20]. To realize the model, the Maximum Entropy approach was used, via an independent Java artificial intelligence program called MaxEnt (Maximum Entropy Modeling), version 3.3.3k [21].

This program has been widely used to model the distribution of ecological niches, with consistently good results [22], [23]. To determine which variables contributed most to the modeling, a Jackknife test was performed [24].

Table 3: Bioclimatic variables selected for future modelling of Vitellaria paradoxa

Codes	environmental variables
BIO3	Isothermality
BIO9	Average temperature for the driest quarter
BIO10	Average temperature for the warmest quarter
BIO12	Annual rainfall
BIO18	Precipitation in the warmest quarter

To evaluate the model, 25% of the species' contact points were used, and the remaining points were used to calibrate the model. Model performance was assessed using the AUC statistic (area under the curve) [25]. A model is said to be of good quality if the AUC value is greater than 0.90.

➢ *Mapping the current and future distribution of Vitellaria paradoxa*

The modelling results were imported into ArcGIS 10.5 software to map the current and future geographical distributions of the tamarind tree and the habitats favourable to its conservation

III. RESULTS

The results in Figure 2 show the current distribution of Vitellaria paradoxa across the country. These results show that, following the north-south gradient, the density of the species' populations is greater in the Sudanian zone than in the country's other agro-ecological zones.

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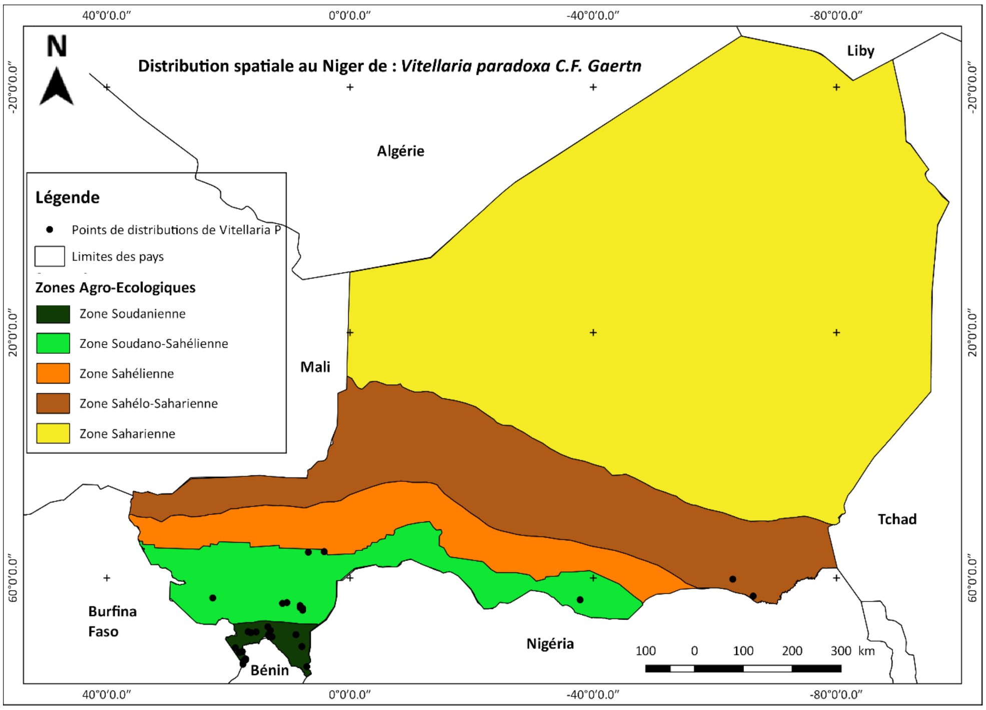

Fig. 2: Current distribution of Vitellaria paradoxa in Niger

A. MODEL VALIDATION

Figure 3 shows that the values of the Area Under the Curve (AUC) for the implementation of the MaxEnt model and for its test are 0.994 and 0.976 respectively. This shows the quality of the model obtained and also attests to the excellent performance of the MaxEnt algorithm in predicting the area favorable to the distribution of the species. The value for the test prediction probability is 0.5. The red curve corresponds to the model training data (AUC =0.994), the blue curve corresponds to the test data (AUC = 0.976) and the black curve represents the random prediction of the model (AUC = 0.5).

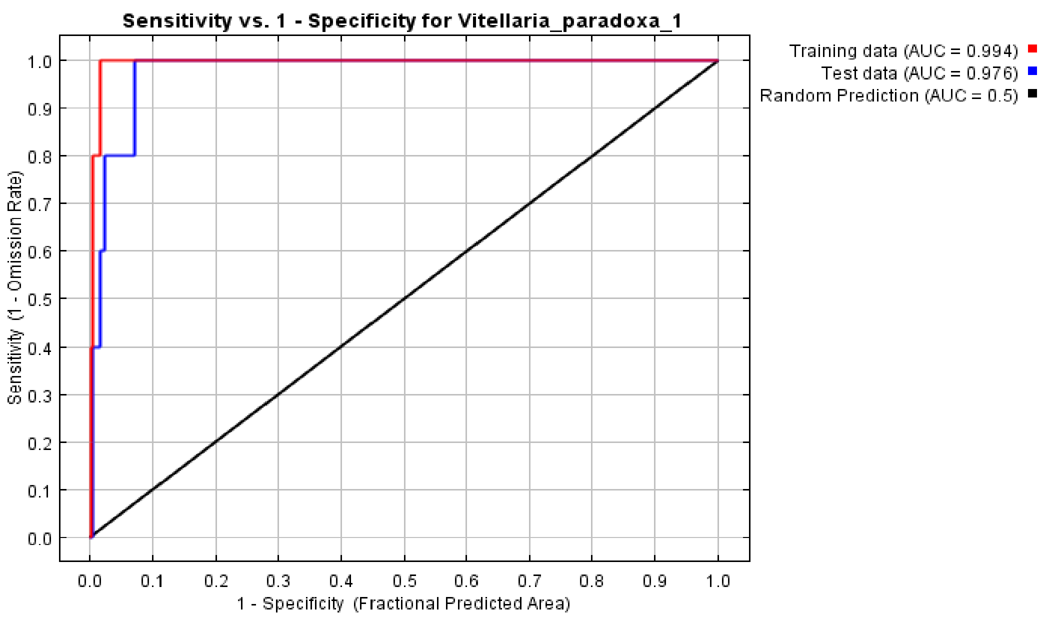

Fig. 3: Calculation of the Area under the Curve (AUC) value, which measures the model's predictive accuracy

B. CONTRIBUTION OF BIOCLIMATIC VARIABLES TO THE MODEL

The analysis of the contribution percentages of the various variables to the model shows that annual precipitation (BIO12), the Ratio of daily thermal amplitude to annual thermal amplitude (BIO3) and the mean temperature in the warmest quarter (BiO10) are the variables that have contributed most to the model (figure 4). Their contribution percentages are 51.8%, 34.5% and 6.5% respectively. %. The Jackknife test (figure 5), also shows that BIO12 is the environmental predictor with the best gain and gives the most useful information when used in isolation in the model. The blue curve corresponds to the percentage contribution of each variable, the light green curve is without the variables, while the red curve is associated with the variables+.

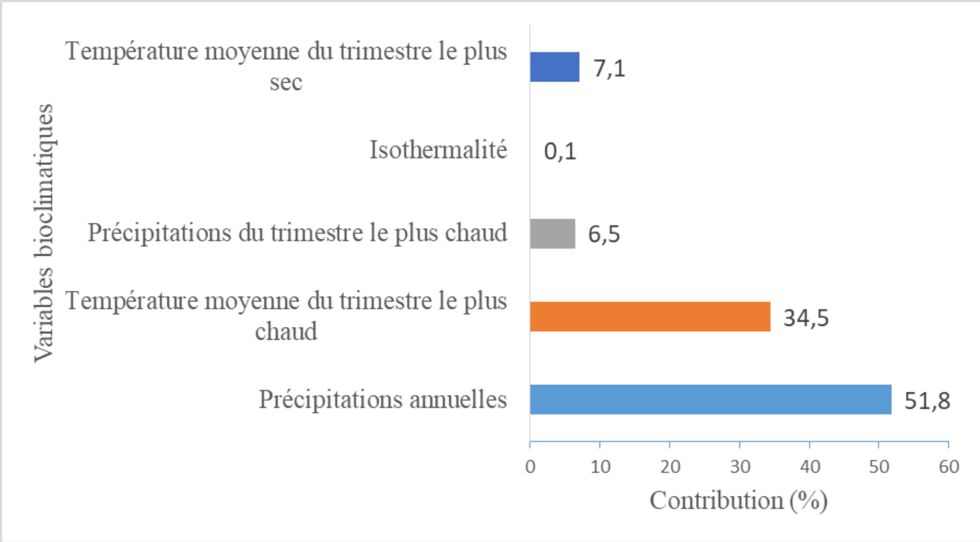

Fig. 4: Contribution of variables to the current distribution of Vitellaria Paradoxa

- VARIABLES BIOCLIMATIQUES: bioclimatic variables
- Température moyenne du trimestre le plus sec: average temperature in the driest quarter
- Isothermalité : isothermality
- Précipitations du trimestre le plus chaud : rainfalls in the hottest quarter
- Température moyenne du trimestre le plus chaud : average temperature in the hottest quarter
- Précipitations annuelles : yearly rainfalls

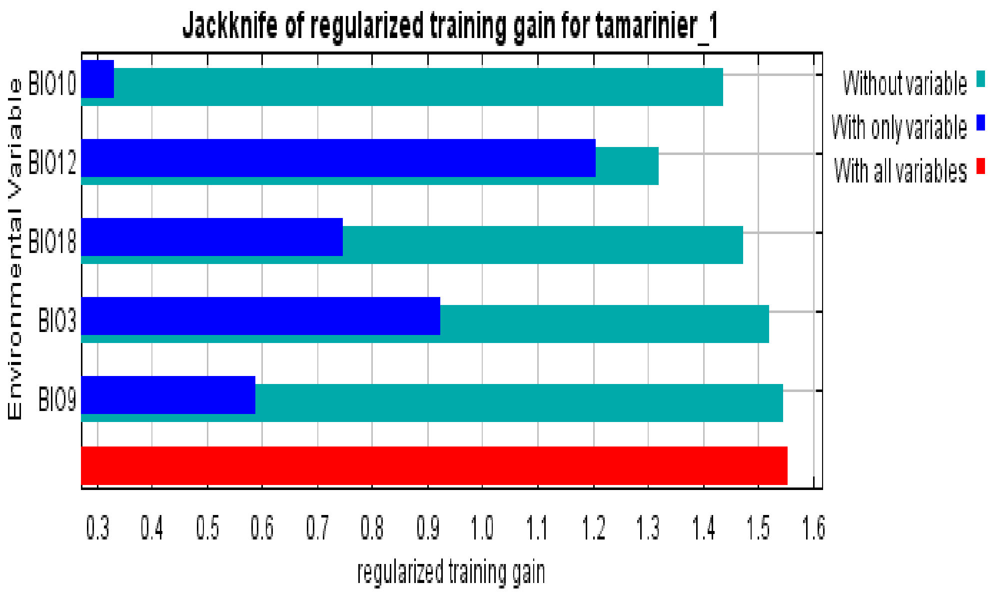

Fig. 5: Calculation of the Area Under the Curve (AUC) value, which measures the model's predictive accuracy

- *Impact of climate change and changes in the areas of future tamarind distribution in Niger according to the RCP4.5 and RCP 8.5 scenarios at horizon 2055.*

Table 2 shows the variation in future range sizes predicted by the RCP45 (optimistic) and RCP85 (pessimistic) scenarios. Figure 6 shows the map of Vitellaria paradoxa distribution areas by 2050. Using the bioclimatic projections of the MIROC 5 model to 2050, the two scenarios RCP 45 and RCP 85 predict an increase in the areas of less favorable and moderately favorable habitats for the future distribution of Vitellaria Paradoxa to 2050. Less favorable habitat increases by 26.64% and 36.09% for RCP 4.5 and RCP 8.5 respectively, while moderately favorable habitat increases by 56.38% and 80.17% for both scenarios. On the other hand, both scenarios predict a decrease in the area of highly favorable habitat by 2050. This regression would be -2.28% and 7.14%, respectively, for the RCP 4.5 and RCP 8.5 scenarios.

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Table 4: Changes in the area of Vitellaria paradoxa's future distribution zones according to RCP 4 5 and RCP 8.5 scenarios by 2050

Scena-rios	**unsuitable habitat**		**Moderately favorable habitat**		**Very favourable habitat**	
	surface (Km^2)	**Trend (%)**	**Surface (Km^2)**	**Trend (%)**	**surface (Km^2)**	**Trend (%)**
Present	54 524	-	44 812	-	29 176	-
RCP45	39 997	+26,64	19 549	+56,38	29 840	-2,28
RCP85	52 556	+36,09	8 885	+80,17	31 260	-7,14

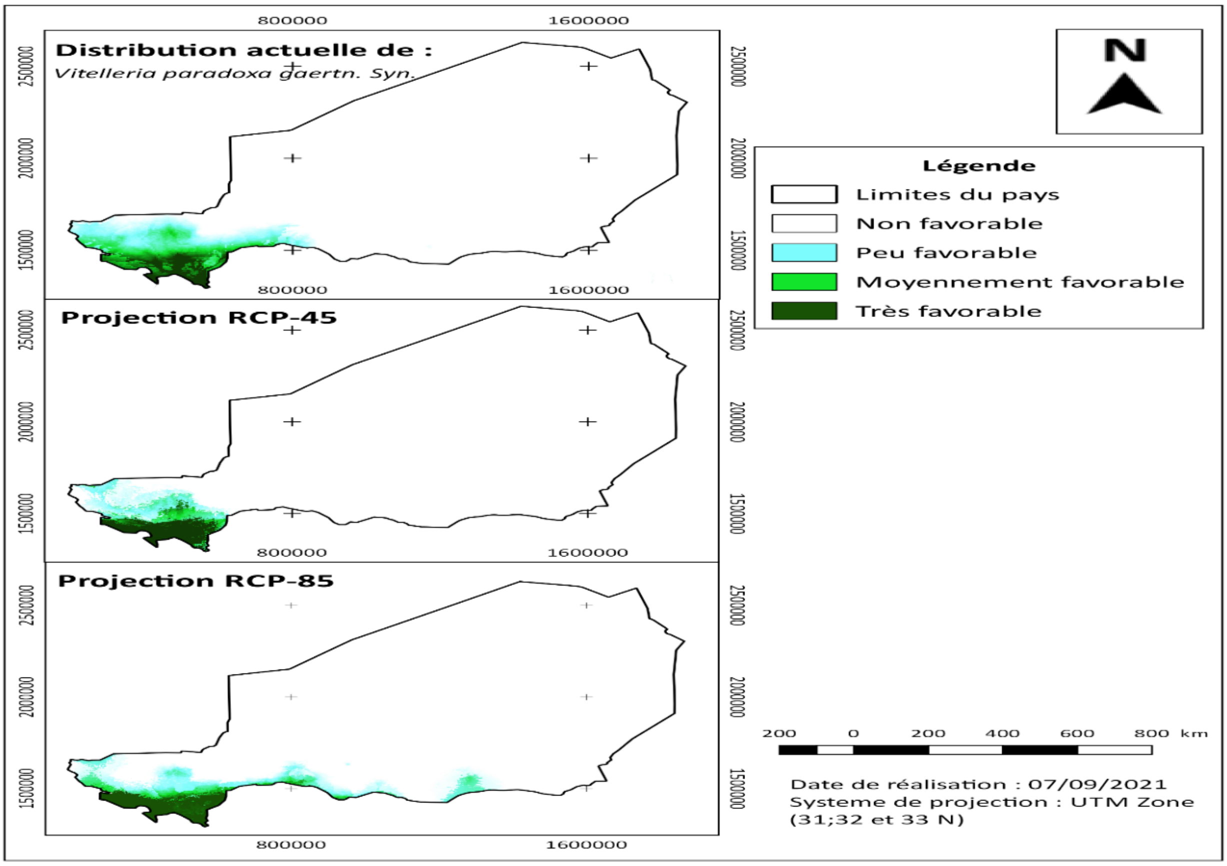

Fig. 6: Map of Vitellaria paradoxa distribution areas by 2050

- *<u>Distribution actuelle de vitelleria parodoxa</u>: current distribution of vitellaria paradoxa*
- *<u>Projection</u> : projection*
- *<u>Peu favorable</u> : less favorable*
- *<u>Moyennement favorable</u> : averagely favorable*
- *<u>Date de réalisation</u> : completion date*
- *<u>Système de projection</u> : projection system*

IV. DISCUSSION

The exploitation of forest ecosystem services is the basis of the rural economy. The degradation of populations of species of socio-economic importance, the cause of the decline in ecosystem services, continue to affect the well-being of these populations. Accelerating environmental degradation is eroding rural people's natural assets. The integration of the ecological niche modeling approach into the plant genetic resources conservation program is a decision-support tool. In this study, the Maxent tool was used to model the distribution of Vitellaria paradoxa in Niger. The results show that, following a north-south gradient, Vitellaria paradoxa densities are now mainly concentrated in the southern strip of the country. In other agro-ecological zones, the distribution of the species is gregarious, with very low densities. The reasons for the degradation of this species' populations stem from the impact of the multiple uses made of its products by local populations. In addition to these anthropogenic causes, there are climatic factors such as recurrent droughts and high temperatures. In the northern part of the country, the average temperatures exceed 45°C in April. These results are similar to those obtained by Garba and al. in 2020 [25] on Tamarindus indica L in Niger. Anthropogenic activities such as deforestation to supply large cities with wood for energy, and land clearing for agriculture, are the main causes of the degradation of plant formation. In Niger, deforestation and desertification are progressing inexorably, reaching 75% of the national territory. Natural forest cover fell from around 16 million hectares in 1982 to around 5 million hectares in 2006, due to agricultural clearing, timber harvesting and climate change. Also, over the period 1975- 2013, rainfed crop areas increased from 12.6% in 1975 to 18.1% in 2000 and 24.5% in 2013 [26], [27].

The occupation of forest formations and the destruction of plant resources to satisfy the needs of populations continues to metamorphose the agrarian landscape. The ecosystems and biodiversity on which they depend are becoming increasingly degraded, access to and quality of arable land are declining, and forest resources are becoming increasingly limited and degraded. The results of the model predict that the current habitats favorable to the conservation of the species are located in the Sahelo-Sudanian zone of Niger, situated in the southern band. These zones are characterized by mean annual rainfall of between 500-700mm and over 700mm respectively, which demonstrates the significant contribution of the bioclimatic variable annual rainfall (BIO 12) to the predicted model, at 51.8% (BIO12 = 51.8%). This shows that the distribution of Vitellaria paradoxa populations is influenced by both annual rainfall and high temperatures. Soil type and topography are also edaphic factors likely to influence this distribution. This information is in line with that obtained by Fandohan et al. [22] on tamarind in Benin and Laouali and al. [20] on Prosopis africana (G. et Perr.) Taub.. in Niger.

Both RCP 4.5 and RCP 8.5 scenarios predict a reduction in the area of highly favorable habitat by 2050. V. paradoxa is a forest species whose phenological parameters are correlated with climatic parameters. As the distribution of Vitellaria paradoxa is influenced by climatic parameters, it can be expected that any future climate change will have an impact on the dynamics of this species. With this in mind, climate change projections predict that 20-30% of animal species in Africa will face a greater risk of extinction if global warming exceeds 1.5°C to 2.5°C in Africa [22, 28, 29]. In Africa, 25 to 42% of plant species could be threatened with extinction due to a loss of 81 to 97% of favorable habitats by 2085 [30]. These results are in line with those obtained by Hadonou-yovo and al [31] on Ficus trichopoda, Mitragyna inermis, Sorindeia grandifolia and Pterocarpus santalinoides, three socio-economically important forest species in Benin. It has been shown that these two greenhouse gas emission scenarios predict a decrease in rainfall in West Africa by 2050. These climatic constraints could lead to the drying out of wetland ecosystems, which are favorable areas for the conservation of these species. With this in mind, it has been demonstrated that fluctuations in climatic variables such as precipitation and temperature will have an impact on biological diversity and on the geographical distribution of habitats favorable to the future distribution of forest species [28]. These climatic fluctuations will also have an impact on production systems, leading to chronic food deficits.

V. CONCLUSION

Using the MaxEnt algorithm, this study has mapped the current distribution of V. paradoxa and predicted the impact of climate change on the extent of its favorable areas in Niger. Through modeling, our research has also digitized the future conservation and distribution of V. paradoxa under the RCP 4.5 and RCP 8.5 emission scenarios. This vital information will serve as a database for the future in situ restoration and conservation program for this species in Niger. It will help park managers of this species to establish a sustainable restoration and conservation program in the face of the consequences of climate change. Such an ambition cannot be achieved without political support.

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