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What ecological prediction for *Cola nitida*: an indigenous fruit species in Benin?

Quelle prédiction écologique pour *Cola nitida* : une espèce fruitière indigène au Bénin ?

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Abstract

The variation of climatic parameters influences the distribution of several indigenous fruit species in Benin. This research evaluates the spatio-temporal dynamics of favorable habitats to the cultivation of *Cola nitida* under current climatic conditions and by 2085 in Benin. To do this, 230 occurrences of *C. nitida* were combined with the environmental layers using the MaxEnt algorithm in order to highlight its favorable habitats. The AUC (0.969) and SEDI (0.918) results suggest a very good performance of the model. The precipitation of the driest quarter (43.6%) and the maximum temperature of warmest month (41.8%) are the variables that most influenced the geographical distribution of *C. nitida* in Benin. More than 87% of the national territory remains less favorable to the conservation of *C. nitida*. Very favorable habitats went from 5.21% (present climatic conditions) to 1.29% (RCP 4.5) i.e., a loss of 3.92%, and occupy only 0.16% of the national territory (RCP 8.5) either a regression of 5.05%. Furthermore, the priority conservation habitats resilient to climate change occupy only 9.69% of the territory. Thus, it is important to implement reforestation projects in priority natural habitats resilient to climate change (classified forest of Pahou, Ouèdo, Djigbé, Itchèdè-Toffo, Niaouli and the reforestation perimeter of Abomey) which are entirely suitable for the conservation of *C. nitida*. The promotion of *C. nitida* in agroforestry parks should be encouraged for sustainable production and management.

Keywords : *Cola nitida*, climate change, favorable habitats, priority areas, Benin

Résumé

La variation des paramètres climatiques influence la distribution de plusieurs espèces fruitières autochtones au Bénin. Cette recherche évalue la dynamique spatio-temporelle des habitats favorables à la culture de *Cola nitida* sous les conditions climatiques actuelles et à l'horizon 2085 au Bénin. Pour ce faire, 230 données occurrences de *C.*

nitida ont été combinées avec les couches environnementales à l'aide de l'algorithme MaxEnt afin de ressortir ses habitats favorables. Les résultats de AUC (0,969) et SEDI (0,918) suggèrent une très bonne performance du modèle. Les précipitations du trimestre le plus sec (43,6 %) et la température maximale du mois le plus chaud (41,8 %) sont les variables qui ont le plus influencé la distribution géographique de *C. nitida* au Bénin. Plus de 87 % du territoire national reste moins favorable à la conservation de *C. nitida*. Les habitats très favorables sont passés de 5,21 % (conditions climatiques actuelles) à 1,29 % (RCP 4.5) soit une perte de 3,92 % et n'occupent plus que 0,16 % du territoire national (RCP 8.5) soit une régression de 5,05 %. De plus, les habitats prioritaires de conservation résilients au changement climatique n'occupent que 9,69 % du territoire. Ainsi, il est important de mettre en œuvre des projets de reboisement dans les habitats naturels prioritaires résilients aux changements climatiques (forêt classée de Pahou, Ouèdo, Djigbé, Itchèdè-Toffo, Niaouli et périmètre de reboisement d'Abomey) qui sont entièrement favorables à la conservation de *C. nitida*. La promotion de *C. nitida* dans les parcs agroforestiers doit être encouragée pour une production et une gestion durable.

Mots clés : *Cola nitida*, changement climatique, habitats favorables, aires prioritaires, Bénin

1. Introduction

The combined actions of climate change and human activities on natural resources no longer need to be demonstrated, because they have increased in recent decades to the point where they hold the attention of researchers and many organizations both national than international. Indeed, the climatic variations caused or not threaten the biological resources (Delvaux *et al*., 2010; Sinadouwirou *et al.*, 2022). The impact of these on biodiversity has remained a central concern for biomanagers for decades (Lebourgeois *et al*., 2010; Zakari *et al*., 2017; Ali and Kpatinnon, 2022).

In West Africa as in Benin, the impacts of climate change are observed on native species. Thus, niche models were developed very quickly in Benin on species such as *Tamarindus indica, Prosopis africana, Garcinia kola, Milicia excelsa, Triplochiton scleroxylon*, etc. (Fandohan *et al*., 2013; Houetchegnon, 2016; Djotan *et al*., 2018; Kakpo *et al*., 2019; Toko Imorou, 2020), to assess the impact of climate change on the habitats of these species.

Several species used in ethnobotany in Benin are threatened (*Mansonia altissima*, *Khaya senegalensis*) and two are already extinct in the wild (*Caesalpinia bonduc* and *Garcinia kola*). Furthermore, some are vulnerable (*Vitellaria paradoxa*, *Borassus aethiopum*, *Chrysophyllum albidum*) and others are not assessed, such as *C. nitida*. However, *C. nitida* is a species highly prized by the populations of Benin in particular and the whole world in general because of these many virtues and constitutes a source of Non-Timber Forest Products (NTFPs). What are the current and future impacts of climate change on habitats favorable to the cultivation of *C. nitida* in Benin? It is in the face of this central question that this research tends to estimate the spatio-temporal dynamics of habitats favorable to the cultivation of *C. nitida*. Thus, at the end of this research, the favorable habitats to the cultivation of *C. nitida* in Benin under current and future climatic conditions will be known for its rational use and the implementation of priority conservation action.

2. Material and methods

2.1 Study environment

The Republic of Benin is between 6°15' and 12°25' north latitude then between 0°48' and 3°50' east longitude. It is subdivided into three biogeographical regions (Guineo-Congolese, Sudanian and Sudano-Guinean) and 10 phytodistricts (Adomou *et al*., 2007; Neuenschwander *et al*., 2011). Three types of climates are distinguished. These are the Guinean-Congolese climate, the Sudanian climate and the Sudano-Guinean transitional climate. The Guineo-Congolese climate is found from the coast to the latitude of Dan (Commune of Djidja) and is characterized by a low annual thermal amplitude (< 5°C). The presence of the Atlantic Ocean affects the relative humidity which varies between 70% and 90%. The first rainy season concentrates 40% to 60% of precipitation and the second concentrates 18% to 30%. In addition, the Sudano-Guinean climate concerns middle Benin up to the latitude of the Commune of Bembèrèkè, characterized by a high temperature and a thermal amplitude going beyond 10°C. The small rainy season in this region is very short. The Sudanese climate, from the Commune of Bembèrèkè to the latitude of the Commune of Malanville, is characterized by a well-defined dry season and a rainy season. Figure 1 presents the biogeographic zones of Benin.

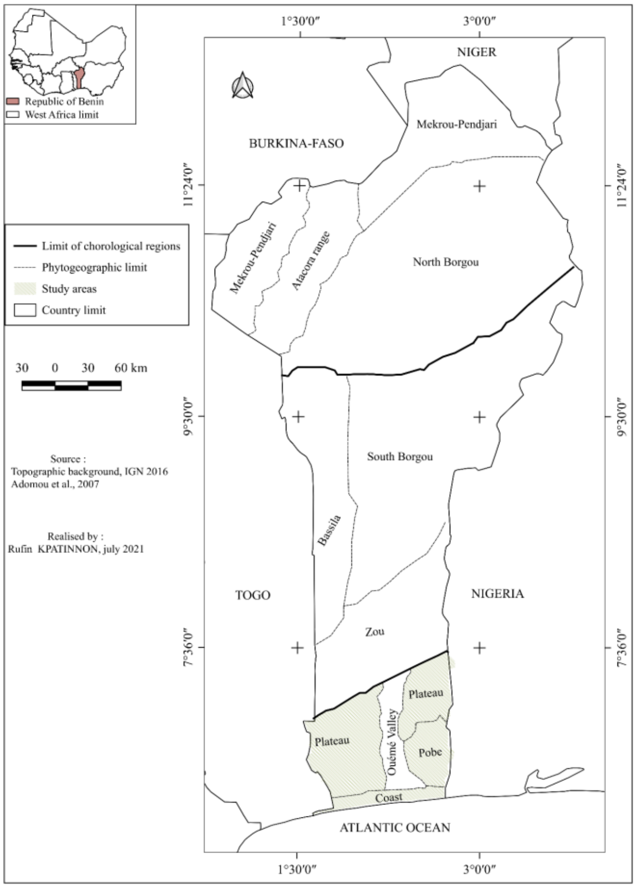

Figure 1. Study area

2.2. Occurrences and environmental data collection

The occurrences of *C. nitida* (135) have been georeferenced from September to October 2021 and supplemented by those downloaded (191) from the GBIF website (http://www.gbif.org/). In addition, bioclimatic variables were downloaded from AfriClim site (https://webfiles.york.ac.uk/KITE/AfriClim/) at the resolution of 30 seconds. The future scenarios RCP 4.5 (optimistic scenario) and RCP 8.5 (pessimistic scenario) were chosen for the 2085 horizon. Variables slope and distance from human habitations (settlement_dis) were integrated into the model in order to consider anthropogenic actions on the species and limit possible predictions of favorable habitats in high altitude regions that are biologically unrealistic to *C. nitida*.

2.3. Data analysis

Data cleaning and model calibration

The occurrences data have been cleaned by the ENMTools 1.3 algorithm. Then the duplicates were removed. These operations made it possible to have a total of 230 occurrencs of *C. nitida*. Moreover, the environmental layers were cut according to the administrative boundaries of Benin with the ArcGis 10.7 software and put in ASCII format (American Standard Code for Information Interchange). Not being an aquatic species, a mask was created to exclude water bodies from the extent of Benin in order to avoid any favorable habitat predictions on these inadequate environments.

These occurrence and environmental data were integrated into the Maxent 4.1 algorithm. To produce performing estimates, the model with the Logistic link was repeated five (05) times with replacement following Bootstrap type and using 10,000 as the maximum number of background points. Model performance was evaluated using AUC (Area Under the Curve) statistics (Phillips *et al*., 2006) and the SEDI (Symmetric Extremal Dependence Index) test of Wunderlich *et al*. (2019). A model is said to be very efficient if AUC ≥ 0.75 (Elith et al., 2006). SEDI has a fixed range of [-1; 1], but is only maximized when sensitivity tends to 1 and specificity tends to 0.

Dynamics of habitats and priority areas resilient to climate change of C. nitida

The pixels of the Maxent output models having values below the Minimum training presence were considered less favorable habitats for *C. nitida* and those between this threshold (minimum training presence) and the 10th percentile training presence constituted relatively favorable habitats. Pixels with values greater than the 10th percentile training presence are qualified as very favorable habitats. The proportions of habitats currently very favorable and likely to become relatively favorable or less favorable in the future and vice versa were also estimated for the climate models according to the following protocol:

$$\Delta\alpha = P1 - P0 \quad \text{with :}$$

$\Delta\alpha$: variation of the proportions of a type of habitat between **P1** and **P0**; **P1**: proportion of a type of habitat in the future (RCP 4.5 or 8.5) and **P0**: proportion of the same type of habitat in the present. For this type of habitat, three cases can be observed: $\Delta\alpha = 0$: habitat stability; $\Delta\alpha < 0$: habitat regression; and $\Delta\alpha > 0$: habitat progression.

The Zonation program was used to establish connectivity between the present and future distributions (RCP 8.5) of *C. nitida* by integrating ecological interactions into the model (positive interaction in this work) (Moilanen *et al*., 2011) to identify priority areas resilient to climate change. Distribution smoothing was used as a zoning option since it allows species-specific connectivity requirements to be included in conservation prioritization. This functionality of ecological interactions has already been tested by Rayfield *et al*., (2009). Based on the map resulting from the classification carried out, the grids with a probability below the threshold of 0.9 were considered as non-priority habitat for *C. nitida* while those with a probability above this threshold were considered as priority habitats for *C. nitida*. In addition, a gap analysis was carried out by overlaying the layer of the national network of protected areas of Benin with the priority habitats for *C. nitida* (Adjahossou *et al*., 2016; Fandohan *et al*., 2013).

3. Results

3.1. Model validation and contribution of variables

The AUC value of the model is 0.969 (AUC > 0.90). This translates that the executed model has an excellent power of discrimination. Moreover, the Symmetric Extreme Dependence Index (SEDI) is equal to 0.918. This value close to 1 implies that the forecasting system is better than random. Thus, these two tests suggest a very good performance of the model. Indeed, six environmental variables contributed to the dispersal of *C. nitida* in Benin. These are the seasonality of precipitation or coefficient of variation (bio15), the precipitation of driest quarter (bio17), the geomorphological variation (slope), the maximum temperature of warmest month (bio5), the proximity to human habitations (settlement_dis) and the annual mean diurnal range of temperature (bio2) (table 1).

Table *1.* Contribution of variables to the distribution of *Cola nitida* in Benin

Variables	Contribution (%)	Permutation (%)
bio17 (precipitation of driest quarter)	43.6	87.6
bio5 (maximum temperature of warmest month)	41.8	3.4
settlement_dis (proximity to human habitations)	4.4	1
slope (geomorphological variation)	3.6	1.6
bio15 (seasonality of precipitation)	3.4	4.6

The environmental variable with the highest gain when used in isolation is bio17 (Figure 2), which therefore appears to have the most useful information on its own. Similarly, the environmental variable that decreases the gain the most when omitted is bio17, which therefore seems to have the most information missing in the other variables.

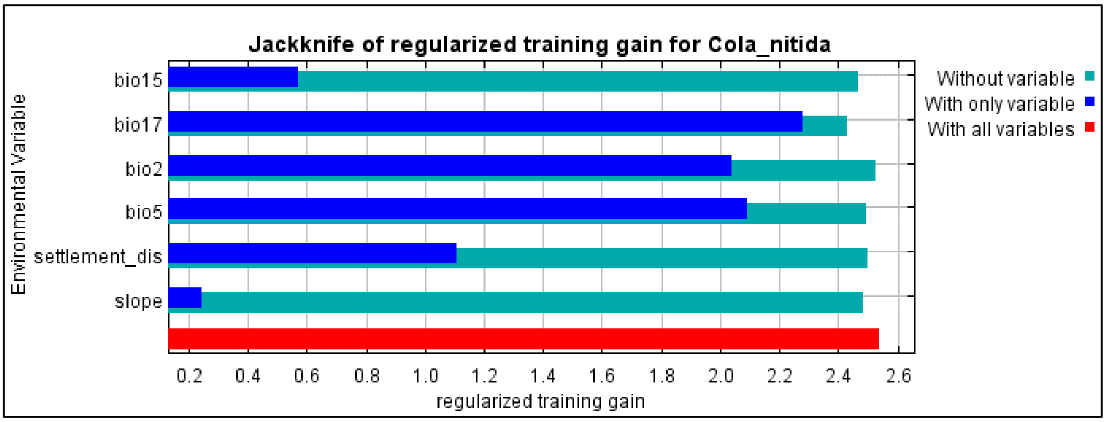

Figure 2. Jackknife test of the importance of the variables of *Cola nitida*

3.2. Favorable areas for the cultivation of *Cola nitida* under current and future conditions

Modeling results show that favorable habitats for *C. nitida* in Benin are located in the Guinea-Congolese region and the Sudano-Guinean transition zone. The phytodistricts of Coast, Pobè, Plateau, Ouémé Valley and Zou (up to 7°45' north latitude) are mainly favorable to *C. nitida* in the present and in the future. On the other hand, the territory of northern Benin (phytodistrict of Borgou north, Atacora range and Mekrou-Pendjari) is entirely less favorable to it in the present and in the future. In the Bassila and Borgou South phytodistricts, imprints of relatively favorable habitats (circled in purple on the map) are observed in the present, but absent from future predictions. In addition, very favorable habitats experienced a drop according to the RCP 4 scenario (figure 3).

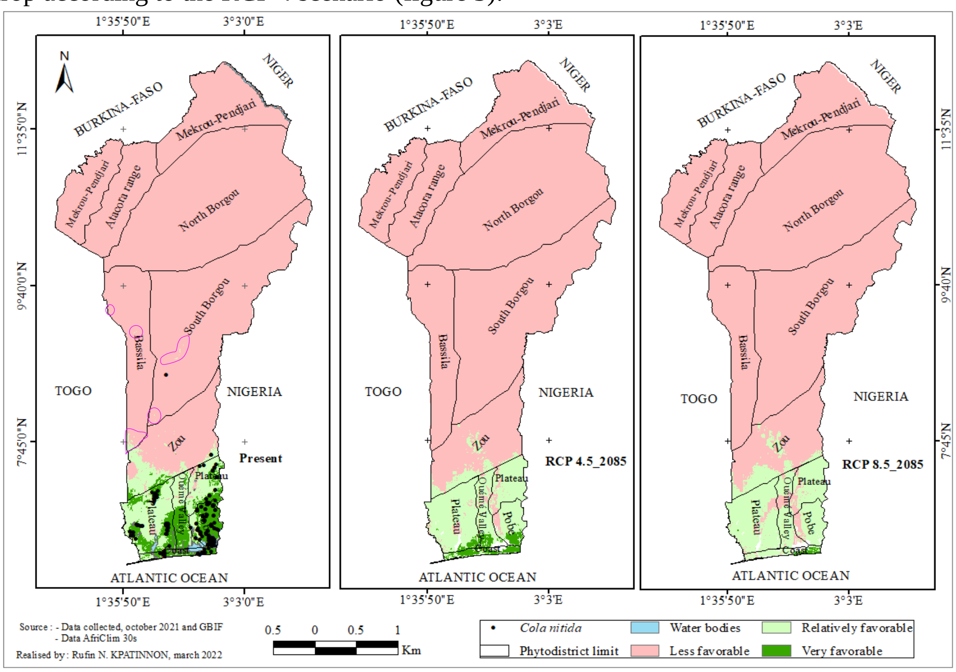

Figure 1. Potential habitats of *Cola nitida* under current and future climatic conditions in Benin

3.3. Dynamics of *C. nitida* habitats

The habitats less favorable to *C. nitida* are estimated at 87.38% in the present (2022) and reach 88.79% under scenario 4.5 (i.e., a gain of 1.42%) and 88.80% under scenario 8.5 (an increase of 1.42%). Those relatively favorable experience an increase of 2.51% in proportion going from 7.41% at present to 9.92% under scenario 4.5 and to 11.04% under scenario 8.5, a gain of 3.63%. On the other hand, habitats very favorable to *C. nitida* went from 5.21% in the present to 1.29% under RCP 4.5, i.e., a net loss of 3.92% and occupy only 0.16% scenario 8.5 i.e., a regression estimated at 5.05% (table II).

Table 2. Dynamics of the habitats of *C. nitida* under climatic conditions

Habitats quality	Present (%)	RCP 4.5 (%)	Balance present - RCP 4.5 (%)	RCP 8.5 (%)	Balance present - RCP 8.5 (%)
Less favorable	87.38	88.79	1.42	88.80	1.42
Relatively favorable	7.41	9.92	2.51	11.04	3.63
Very favorable	5.21	1.29	-3.92	0.16	-5.05
Total	100	100		100	

From the conversions observed, it emerges that very favorable habitats experience a regressive dynamic to the detriment of relatively favorable habitats and those less favorable in the future, under the RCP 4.5 and RCP 8.5 scenarios. Climate change therefore has a negative impact on the distribution of *C. nitida* in Benin by 2085; which leads to the determination of priority areas for its conservation.

3.4. Distribution of priority habitats of *C. nitida* resilient to climate change

Habitat connectivity reveals a concentration of priority areas resilient to climate change for the conservation of *C. nitida* in southern Benin (from the coast to 7°45' north latitude). However, imprints of non-priority habitats stand out in this same region of the country. Indeed, the priority habitats occupy only 9.69% of the national coverage. The superposition of the national layer of protected areas shows that the classified forest of Pahou, Ouèdo, Djigbé, Itchèdè-Toffo, Niaouli and the reforestation perimeter of Abomey are ecosystems that are entirely priorities for the conservation of *C. nitida* in Benin. In addition to these protected areas, the classified forests of Lama, Dan, Dassa-Zoumè, Dogo-Kétou and Savalou constitute partial priority ecosystems (figure 4).

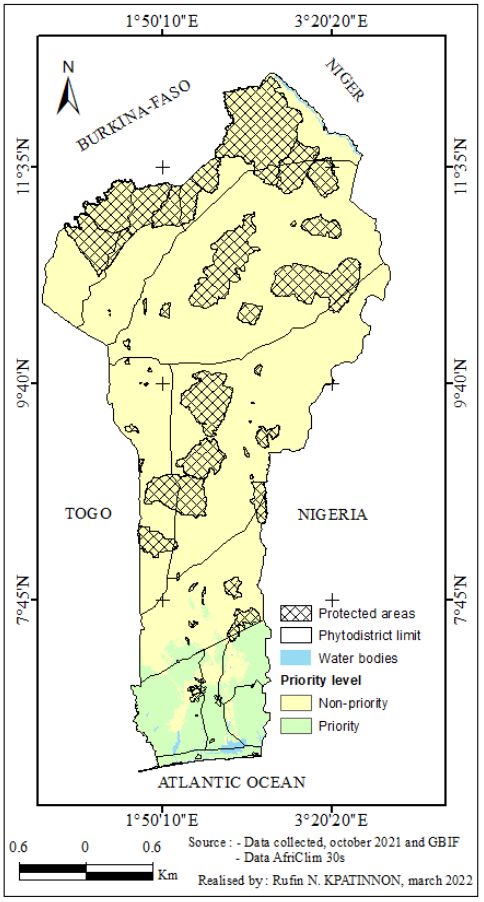

Figure 2. Habitats of *C. nitida* resilient to climate change in Benin

4. Discussion

4.1 Model AUC Validation

The results of the model give an average value of the AUC equal to 0.969; indicating a very good performance of the distribution of *C. nitida* habitats in Benin. Similar performance values have already been obtained in African countries in species distribution prediction (Gbesso et al., 2013; Laouali et al., 2020). On the other hand, the distribution models realized by (Fandohan et al., 2015; Ganglo et al., 2017) are of good quality across the AUC value. One of the reasons for this variation of the AUC can be the source of variables (WordClim, Chelsa, Africlim, etc.), the extent of the area considered for the models, the mode of selection of the variables, the resolution of the environmental data, etc.

4.2 Contribution of variables to the distribution of *Cola nitida* in Benin

The environmental layers used for this research have a resolution of 30 seconds of arc (about 0.87 km per side) for a fineness of the outputs. The latter reveal that the variables that best characterize the distribution of *C. nitida* in Benin are climatic: bio17 (precipitation of driest quarter), bio5 (maximum temperature of warmest month), bio15 (seasonality of precipitation) and bio2 (annual mean diurnal range of temperature); and on the other topographic: settlement_dis (proximity to human habitations) and slope (geomorphological variation). But those that have contributed the most to the model are the climatic variables bio17 and bio5. *Cola nitida* is therefore a species of hot and humid ecosystems. In effect, it supports an average annual precipitation ranging from 1,200 to 1,800 mm and an average annual temperature varying between 26-35°C with a marked dry season that can exceed 3 months. The variable bio17 has already been reported in the construction of the models of *C. albidum* and *Garcinia kola* (Gbesso et al., 2013; Djotan et al., 2018). As for bio5, it contributed to the model of *Capparis spinosai* (Ashraf et al., 2018). Moreover, the proximity to human habitations of this species is linked to its presence in houses as a symbol of protection and above all constitutes an idol to the populations of the Thron cult.

4.3 Distribution areas and habitat dynamics of *Cola nitida* in Benin

The output models show that the areas favorable to *C. nitida* in Benin are mainly found in the south, particularly in the phytodistricts of Coast, Pobè, Plateau, Ouémé Valley and Zou. It therefore emerges that *C. nitida* is a lowland forest species (low altitude). Its ecological range is quite limited in Benin; which can constitute a weakness in its conservation. Like it, the areas favorable to *C. albidum* are also limited to southern Benin (Gbesso *et al.*, 2013) unlike *Tamarindus indica* and *Dialium guineense* which have a wider distribution (Fandohan et al., 2013; Ganglo et al., 2017). This variation in distributions is mainly dependent on the ecological requirements of the species.

Future projections made under the RCP 4.5 and RCP 8.5 frames for *C. nitida* indicated remarkable mutations by 2085. Indeed, a temperature increase ranging from 1.1°C to 2.6°C (RCP 4.5) and ranging from 2.6°C to 4.8°C (RCP 8.5) according to the estimates of the GIEC (2013), would respectively lead to a decrease of 3.92% and 5.05% of habitats that are very favorable to *C. nitida* in Benin to the detriment of relatively favorable and less favorable habitats. Some previous work had already announced the negative impact of climate change on biological diversity (Pearson and Dawson, 2003; Thomas et al., 2004). In Benin as in Africa, previous work in fauna and flora led to the reduction of favorable habitats (Kakpo et al., 2019; Asseh et al., 2019). For (Busby et al., 2010), the variation of climatic parameters such as precipitation and temperature will have an impact on biological diversity and on the geographical distribution of suitable habitats. Nevertheless, climate change does not have a negative impact on the distribution patterns of *Chrysophyllum albidum, Garcinia kola, Prosopis africana*, (Gbesso et al., 2013; Djotan et al., 2018; Laouali et al., 2020).

4.4 Priority areas of *Cola nitida* resilient to climate change

In this research, the two scenarios (RCP 4.5 and RCP 8.5) announce a drastic reduction in very favorable habitats. The latter are even almost non-existent with the RCP 8.5 projections. Thus, the species *C. nitida* presents a high threat to climate change by 2085. These results confirm previous work that announced the threat of species extinction due to a loss of favorable habitats by 2085 (IPCC, 2007). The species *Cola nitida* is therefore found in this batch of species threatened with extinction by 2085 given that a loss of 95% of the initial area of priority areas resilient to climate change leads to extinction in the wild. Thus, the policies of decision makers must be oriented towards protected areas hosting priority areas resilient to climate change for appropriate conservation. To these protected areas, we must add the islands of sacred forests which also constitute reservoirs of biodiversity.

4.5 Research weakness

Ecological niche modeling is a powerful tool for mapping the current and future distribution of species and predicting the impact of climate change on their distribution (Van Zonneveld *et al*., 2009). However, the uncertainties related to the model, the idiosyncratic individual responses of species to climate change, the difficulties in parameterizing ecological interactions, etc. are aspects to be taken into account (Schwartz, 2012). Likewise, despite the strengths and efficiency of MaxEnt, other modeling algorithms including GARP, BioClim, BRT, RF, etc. can also be used for comparison of output models. Nevertheless, Thorn *et al.* (2009), recommend the use of MaxEnt in studies of the geographic distribution of species. Thus, this model from MaxEnt carried out on *C. nitida* and having taken into account the most important limiting factors, provides very fundamental and essential information in terms of decision-making for the conservation of the species.

4.6. Implication of this research

The species has not yet really caught the attention of the IUCN. Indeed, *C. nitida* is of least concern globally and has not yet been assessed in Benin by this institution. But with climate predictions, if urgent actions are not taken for its conservation, it risks dying out in silence or presenting difficulties (cost for example). The necessary precautions to be taken for its protection and conservation must therefore focus on limiting anthropogenic pressures through public awareness campaigns. In addition, given its socio-cultural importance, planting operations (reforestation) must be considered in favorable habitats in order to offset the impact of exploitation. Thus, the challenge of conservation of the species is major.

5. Conclusion

MaxEnt model indicates good performance and high predictive power for *C. nitida* habitats. We can therefore rely on the results of this model to develop conservation strategies. Southern Benin, in particular the phytodistricts of Coast, Pobè, Plateau, the Ouémé Valley and Zou, are globally favorable to *Cola nitida*. However, favorable habitats undergo a regressive evolution under future climatic conditions. Indeed, only the Coast phytodistrict remains very favorable under the RCP 8.5 grid by 2085. The two scenarios (RCP 4.5 and RCP 8.5) thus announce an absolute reduction in very favorable habitats in 2085. Anthropogenic causes an exponential loss or even disappearance of priority conservation habitats that are resilient to climate change. Government policies must therefore be directed towards resilient protected areas for adequate conservation.

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