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How far can climate changes help to conserve and restore *Garcinia kola* Heckel, an extinct species in the wild in Benin (West Africa)

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A study was conducted to assess how well climate changes can help to conserve and restore *Garcinia kola* Heckel in the Protected Area Network (PAN) and in urban areas in Benin. To achieve this, occurrence data from GBIF was used and the environmental data from AfriClim was used in order to model the species' potential habitat under current and future climates. The maximum entropy modeling approach of MaxEnt was used with scenarios RCP4.5 and RCP8.5 for future predictions. Geographic information systems were used to establish the high confidence prediction areas (HCPA) for *G. kola*. Gap analysis was performed throughout PAN and municipalities with regard to the HCPA. Considering the climate envelop, results revealed that climate change prooved to have only positive consequences on the distribution of the species. Moreover, considering the HCPA, the percentage of municipalities that were suitable for the species is far above the percentage of PAN that was predicted as suitable (7.44% versus 0.93%). RCP4.5 and RCP8.5 indicated respectively 3.00 and 6.27% of PAN as positive climate change impact zones. As for the municipalities, it was respectively 13.60 and 17.60% of the total municipalities areas. Therefore, it is not worth relying only on PAN to conserve and restore the species, rather urban forestry and reforestation in PAN may be key actions to save this genetic resource. Further studies with regard to introduction of *G. kola* in urban areas and its use for reforestation are compulsory.

Key words: *Garcinia kola*, Urbanization, climate change, medicinal woody plants, biodiversity conservation.

INTRODUCTION

Human activities threaten highly tropical forests (Htun et al., 2011; Bargali et al., 2015; Baboo et al., 2017). Clearing the half of the world's residual forests would remove 85% of all the species that inhabit them (Pimm

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and Raven, 2000). In tropical forests, natural and biotic disturbances as well as habitat alterations cause continuous loss of more than one higher plant species per day (Myers, 1990), a disappearance of 20 ha forests and destruction of more than 1800 populations per hour (Hughes et al., 1997), and loss of species populations at a percentage rate of 3 to 8 times than the rate of species extinction (Costanza et al., 1997).

Garcinia kola (Heckel) also known as “bitter kola” is one of multiple non-timber forest products that is of socio-economic importance in Benin (Akoegninou et al., 2006; Assogbadjo et al., 2017) and in the sub region (Yakubu et al., 2014). The species belongs to the top ten priority non-timber forest products in Benin (Assogbadjo et al., 2017). *G. kola* is also a medicinal tree species that provides active compounds for the treatment of many diseases (Esimone et al., 2002; Farombi et al., 2005). It occupies the third rank of medicinal plants in Benin in terms of number of recipes in which the species is incorporated (Souza de, 2001). Some of its medicinal uses include the treatment of cough, of imminent abortion, diabetes, palpitations, colic, of dysmenorrheas, jaundice, anaemias, etc. (Akoegninou et al., 2006).

G. kola belongs to the Benin red list of IUCN and has been listed since 2011 as extinct in the wild (Neuenschwander et al., 2011). The use of the species for vegetable toothbrush and the trade of its nuts constitute the main threats (Neuenschwander et al., 2011). In fact, the species’ high interest because of its multipurpose character (Rai, 2003) results in its overexploitation leading to extinction in several African countries (Tchatat, 1999). Moreover, climate changes and relatives consequences (McClean et al., 2005), population growth and urban planning (Clergeau, 2010; Beninde et al., 2015; Scapino, 2016), and deforestation (Babalola and Agbeja, 2010) constitute some other impactful threats for forest species like *G. kola*.

Plants are known to be part of the mankind’s healthcare system worldwide (Parihaar et al., 2014; Padalia et al., 2015); and all parts of a plant, even the whole plant, could be used in the treatment of illness in Africa (Falodoun, 2010). The use of herbal medicines in Africa has greatly elevated and enhanced the primary healthcare system in Africa (Falodoun, 2010). It was therefore found important to align our investigations with those of previous researches, including their implications and their recommendations to contribute to the sustainable management and conservation of forest resources. More precisely, this study is intended to inform natural resource managers and decision makers so that they can incorporate the impacts of global changes to reforestation policies and strategies of valorization of *G. kola* in urban planning in Benin and the management of protected areas in the country.

In line with this aim, the following research questions were addressed: (1) Will the climate change impact positively the potentially suitable areas for the growth of *G. kola* either in municipalities or in protected areas network? (2) Would it stand only in protected areas network for actions toward the conservation of *G. kola*? (3) Which municipalities would likely host the urban forestry actions, and which protected areas to reforest with the species?

MATERIALS AND METHODS

Study species and presence data

G. kola Heckel (Clusiaceae) is a medium-sized and shade-tolerant tree with a cylindrical trunk that is slightly buttressed to the ground. It is endemic to the humid lowland rainforest vegetation of the West and Central African sub regions, and is found in coastal areas and lowland plains up to 300 m above sea level with an average of 2000 to 2500 mm of annual rainfall, with temperatures ranging from 21.4 to 32.15°C (Ntamag, 1997). Its geographical distribution area extends from Congo to Sierra Leone (Vivien and Faure, 1985). Figure 1 shows the spatial distribution of the species downloaded occurrences in the landscape of interest. The area of interest for the present work is Benin. However, modeling on the countries within the sub-region was made for best results applicable in Benin (Fitzpatrick et al., 2009). A total of 67 occurrence points of the species (Figure 1) have been collected on the site of GBIF (http://doi.org/10.15468/dl.obgpne).

Environmental data

Present and future data were collected for modeling potential suitable areas of *G. kola*. These environmental data were obtained on the website of AfriClim (https://webfiles.york.ac.uk/KITE/AfriClim/GeoTIFF_150s/baseline_worldclim/; Platts et al., 2015) at the resolution of 2.5 min (150 s); format GeoTIFF at the extent of Africa. Those layers belong to the climate timescale 1950 to 2000 (Hijmans, 2005), representing data for modeling currently suitable areas for a given species or a set of living forms. As for projection in the future, bioclimatic variables built under realistic representative concentration pathways were also downloaded from AfriClim (https://webfiles.york.ac.uk/KITE/AfriClim/GeoTIFF_150s/africlim_ensemble_v3_worldclim/; Platts et al., 2015). The file set used was the ensemble v3 worldclim. The scenarios used were the Representative Concentration Pathways 4.5 that is realistic and optimistic (Meinshausen et al., 2011), and the Representative Concentration Pathways 8.5 that is realistic and pessimistic (Meinshausen et al., 2011), at the horizon 2055. AfriClim website was used because climate experts had set up data with regard to the climate specificity and ecological realities in Africa (Platts et al., 2015), so that the use of those data lead to meaningful results on the continent.

Model fitting and evaluation

The MaxEnt model has been used to model the potentially favorable areas for the species under present and future climates (Philips et al., 2006; Pearson et al., 2007). Future predictions were done using the optimistic scenario (RCP 4.5) and pessimistic scenario (RCP 8.5) (Meinshausen et al., 2011) at horizon 2055. For each scenario, the ensemble mean v3 model (Platts et al., 2015)

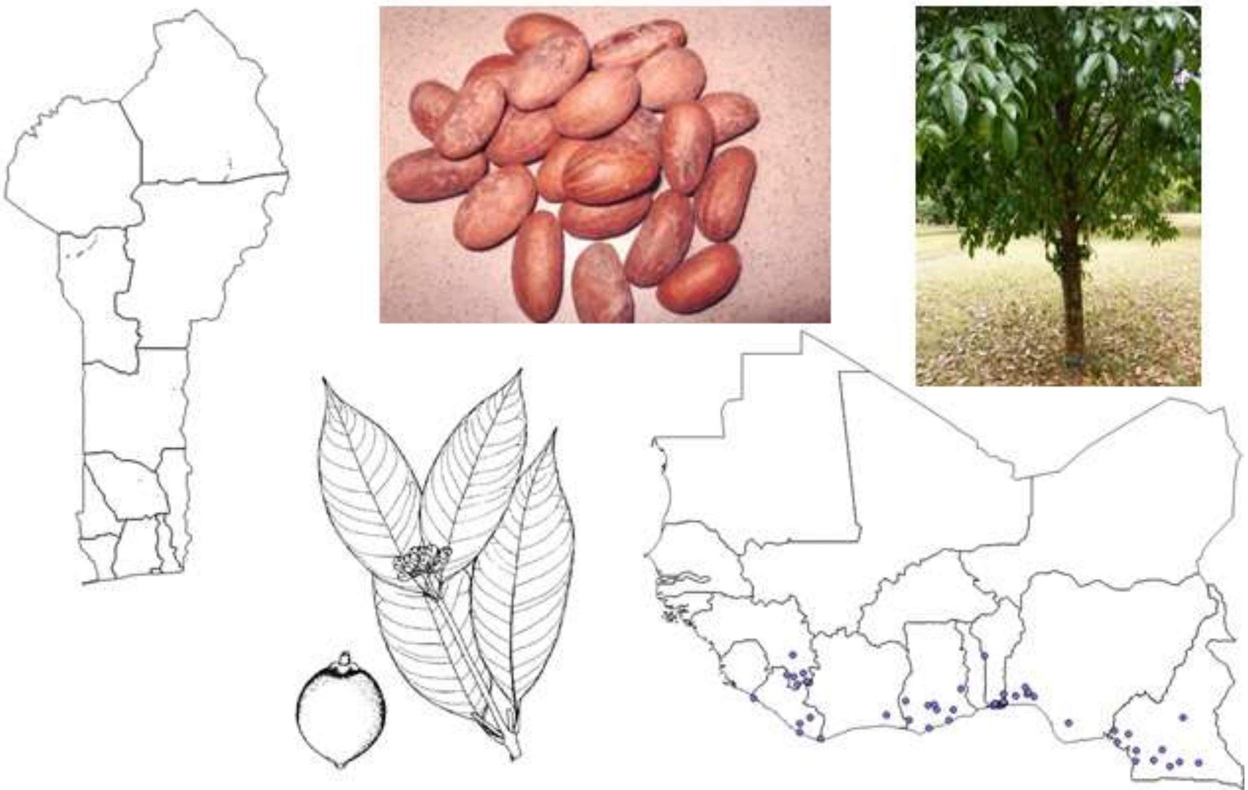

Figure 1. Study areas, species parts, and distribution of occurrences.

was used. As for the MaxEnt parameters, default values were used as recommended by Dossou et al. (2016). But in addition to default parameters of MaxEnt, we set randomly 25% of the present points as test points. The model was run step by step and selected the variables to exclude at each run based on cross-validation sampling. In these ways, the five most explanatory variables in the distribution of the species were selected while giving each variable a reasonable chance to show its importance in the species' distribution model building. For the variable selection, the correlations between variables (Warren et al., 2010), the statistics computed by MaxEnt itself such as Jackknife chart, the Area Under the Curve (AUC) value, the response curves, and the contribution table were taken into account (Elith et al., 2006). The species ecology was also considered in the process of selection. The models were evaluated on three bases. Those bases were AUC (Elith et al., 2006), TSS (Allouche et al., 2006), and the Partial ROC (Peterson et al., 2008). With the five most representative variables, the model was run again using bootstrap as sampling method with 10 replications.

Spatial analysis and decision

The logistic probability corresponding to the threshold "10 percentile training presence" was chosen from the last step MaxEnt model outputs that had been run on a cross validation sampling method to classify using Geographical Information Systems (GIS), the areas as suitable or unsuitable. In addition, the suitable areas are subdivided into two classes: highly suitable when the probability of the presence is higher than or equal to 0.5 and suitable when the probability is between the threshold and 0.5. The "10 percentile training presence" corresponds to the logistic probability above which, when sampled to grid values, the 10% least suitable presence points cannot fall. This threshold classified fairly the continuous maps for our studied species, and it also was used by Fandohan et al. (2015). The model used for the classification was the average of the ones that came from the bootstrapping sampling with 10 replications. The high confidence prediction areas (HCPA) was defined, and corresponded to areas where a model for current climate, and both models (RCP 4.5 and RCP 8.5) for future climate, revealed favorable conditions for our species. The HCPA was used to recommend restoration and conservation actions in favor of *G. kola*. Quantum GIS was used to perform gap analysis across Benin's protected areas network and municipalities. The proportion of protected areas and the proportion of municipalities that were shown to be in the HCPA were calculated and compared. The same computations were done to assess the climate change impact on the species' potentially suitable areas.

RESULTS

Model validation

The Area Under the Curve (AUC) associated to the model was 0.941 while the one associated to its test was 0.936 (Figure 3). The "10th percentile training presence" threshold gave a value of 0.275, 0.000 for test omission

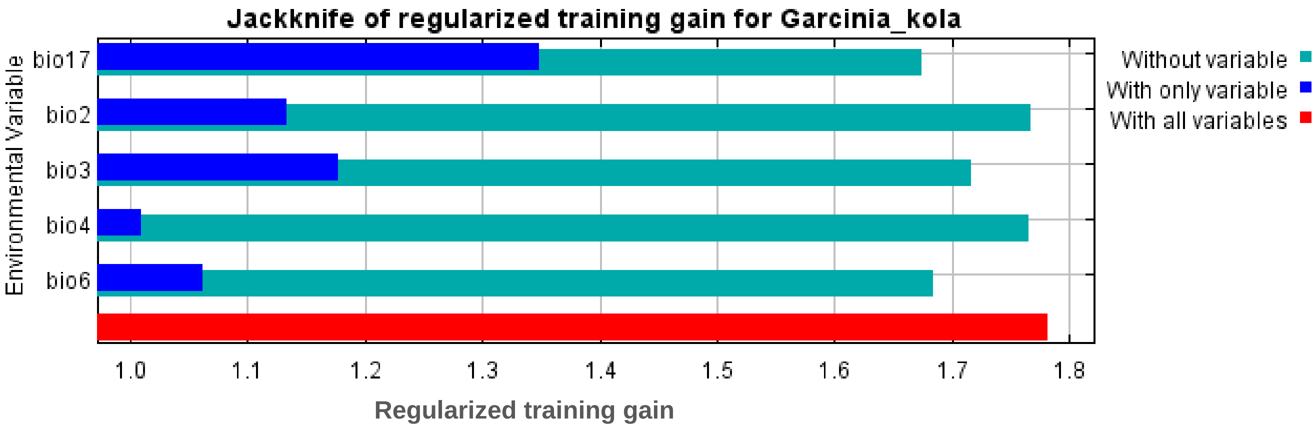

Figure 2. Jackknife of regularized training gain (*Garcinia kola*).

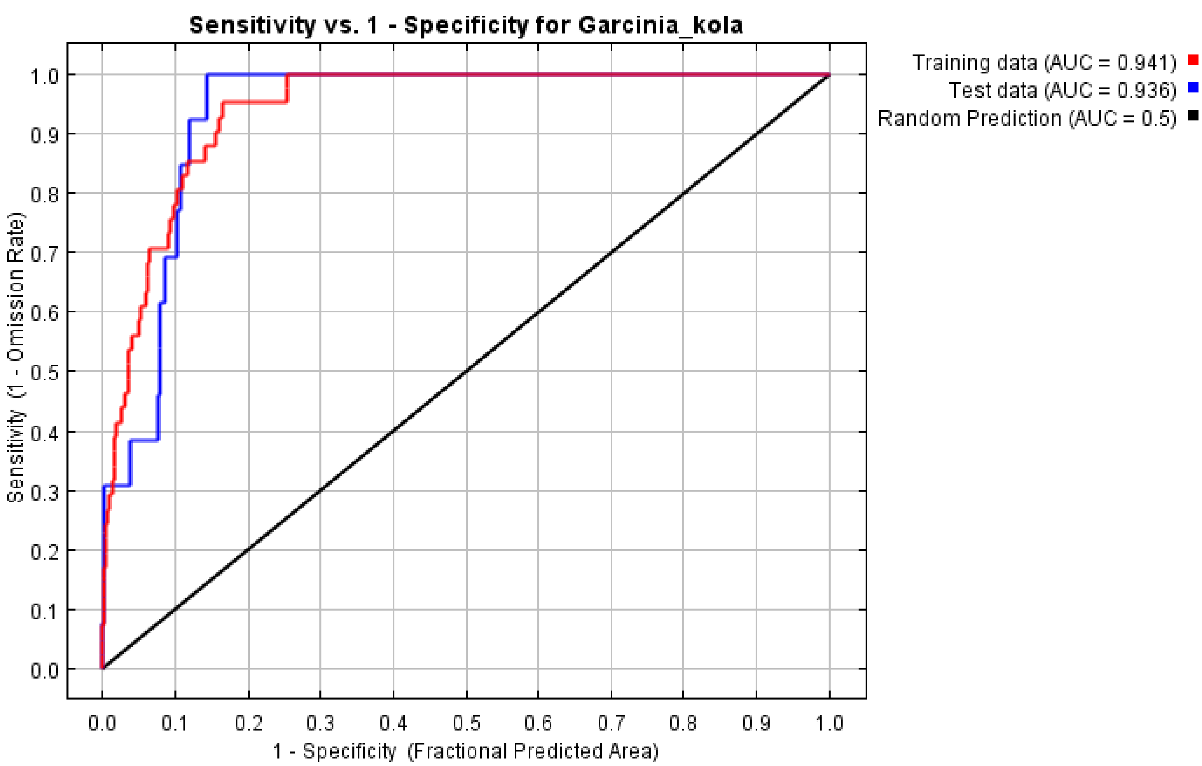

Figure 3. Receiver operating characteristic.

rate and 0.098 for the training omission rate. The True Skill Statistic (TSS) calculated with that threshold gave a value of 0.790. As for the Partial ROC, the minimal ratio was 1.01 and the maximal one was 1.15. All ratios on 1000 iterations were well above 1. These statistics indicated that our models were very good, predictive and performed better than random. The value of the standard deviation among runs was 0.032 for the AUC test, showing that the model is stable and did not fluctuate randomly. Variables bio 17, 6, 2, 3, and bio 4 were the most significant among bioclimatic variables were inputted in the algorithm MaxEnt (Figure 2). Bio 17 is the rainfall of the driest quarter (mm); Bio 6 is the minimal temperature of the coolest month (°C ×10); Bio 2 is the

Table 1. Variables contribution.

Variable	Percent contribution	Permutation importance
Rainfall of the driest quarter (mm)	74.3	63
Minimal temperature of the coolest month (°C ×10)	18.5	1.6
Mean diurnal range in temperature (°C ×10)	3.6	2.8
Isothermality (°C ×10)	2.9	29.5
Temperature seasonality (°C ×10)	0.8	3.1

Values are in percentages.

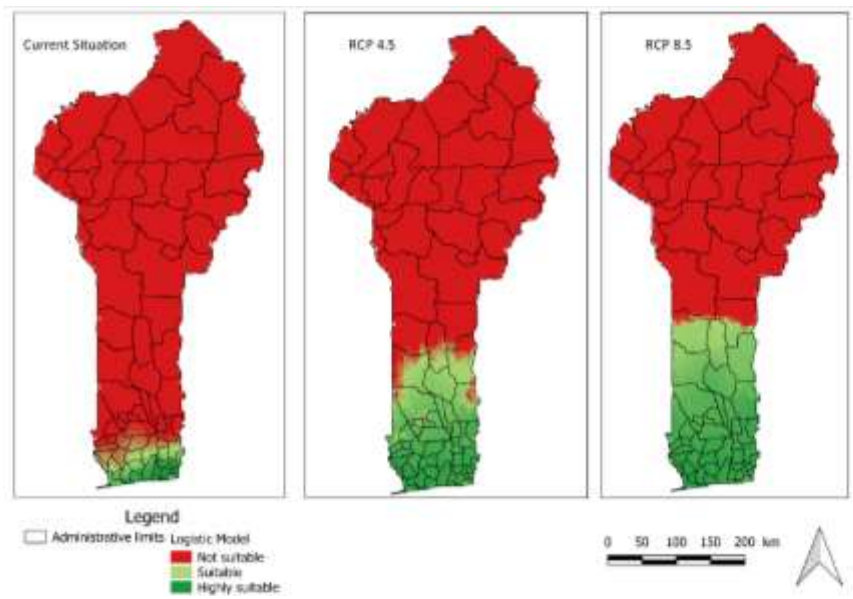

Figure 4. Distribution of predicted suitable areas for *Garcinia kola* from current scenario to scenarios of 2055s.

mean diurnal range in temperature (°C ×10); Bio 3 is the isothermality (°C ×10); and Bio 4 is the temperature seasonality (°C ×10). Table 1 shows the contribution of the retained variables.

Suitable areas for the species

Considering the results that were obtained from the models, the evolution of the climate is in favor of the extension of the climate envelop-based potential ecological niche of *G. kola*. In fact, it was found from the present scenario that the favorable areas range from the coastal areas of Benin (South) to the latitude of Zogbodomè (6.95^{o}N). Meanwhile, a projection in future at 2055 using the RCP4.5, the optimistic one, revealed that the species can enlarge its potentially suitable areas from the coastal areas to the latitude of center Glazoué (8.19°N). It was found that it was much better according to the projection done with the RCP8.5, a pessimistic scenario. This latter showed us that the species can have its favorable areas extended beyond the latitude at the center of Glazoué, it is projected to reach the latitude at the end of Glazoué and the beginning of the municipality of Bassila (8.56°N). So, estimate can be retained in that the climate change is in favor of the species *G. kola* in Benin, whether we consider either the optimistic or the pessimistic scenario. Moreover, whether a scenario is pessimistic or optimistic depends on the species that we consider. Figure 4 shows more details on the maps.

Climate change impacts and conservation of *G. kola*

Protected areas network

Areas that were projected to belong to the HCPA encompass four protected areas (Table 2). But the

Table 2. Distribution of suitable areas and climate change impacts across protected areas (areas in Km²)

Protected areas	Suitable areas/Climate change impacts		
	All scenarios	RCP4.5	RCP8.5
FC Agoua	0	44.46	691.19
FC Atcherigbe	0	31.13	31.13
FC Dassa-Zoume	0	32.57	32.57
FC Dogo	0	319.88	319.88
FC Ketou	0	129.95	129.95
FC Logozohe	0	26.1	26.1
FC Monts Kouffe	0	0	221.45
FC Oueme Boukou	0	0	231.88
FC Oueme-Boukou	0	231.88	0
FC Savalou	0	14.35	14.35
FC Setto	0	13.03	13.03
FC Toui-Kilibo	0	0	51.94
FC Pahou	8.59	-	-
FC Agrime	27.59	-	-
FC Djigbe	47.22	-	-
FC Lama	178.39	-	-
Total	261.79	843.35	1763.47
Percentage of total PAN	0.931486514	3,000760731	6,274680176

projection using the RCP 4.5 at 2055s gave suitable areas that cover eleven more protected areas as results of positive climate change impacts (Table 2). As for the one using the RCP 8.5 at 2055, twelve more protected areas were found in addition to the stable one, as results of positive climate change impacts (Table 2). It was also remarked that there were no areas with negative climate change impacts. Figures 5 and 6 show more details of the climate change impacts on the distribution of suitable areas for *G. kola* across municipalities and across protected areas network (PAN).

Municipalities

Numerous municipalities fell into the potentially suitable areas for *G. kola*, equally well under current climate as under the future's one with both RCPs. The trend was the same as the one observed in the distribution of the suitable areas across PAN over time and space. Overall, forty municipalities belonged to the HCPA (Table 3). The changes in the climate borne by the RCP 4.5 showed twenty-four more suitable municipalities for the species as positive impacts of climate change (Table 3). As for the information obtained by the RCP 8.5 at 2055, 26 more municipalities were added to those that were suitable with all scenarios together (Table 3). No negative climate change impacts were indicated. The percentage of municipalities that were suitable for the species far above the percentage of protected areas network that were predicted as suitable (7.44% versus 0.93%) when considering the domain of maximal prediction confidence (HCPA) (Figures 5, 6 and 7). The trend remains similar with the RCPs individually (Tables 2 and 3).

DISCUSSION

Some previous studies including those of Assogbadjo et al. (2017) recommended appropriate incentives for the valuation of priority species such as *G. kola*. The present results led to some recommendations that may be a useful guide to be used by resource managers and decision makers in implementing the incentives. In fact, Cuni-Sanchez et al. (2010) stated that fundamental niche and potential distributions are convenient when the purpose of the modeling is the introduction of a species in a geographic region. Moreover, it is worth knowing the environmental requirement of a species, its potentially suitable areas, and its potential response to climate change for conservation and management purposes (Bowe and Haq, 2010). Therefore, Blach-Overgaad et al. (2010) and Bowe and Haq (2010) recognized that Ecological Niche Modeling of threatened species, agroforestry species, pests, and invasive species is useful to recommend policy and decision makers on their management. Other studies from Gbètoho et al. (2017) indicated that Ecological Niche Modeling could also be

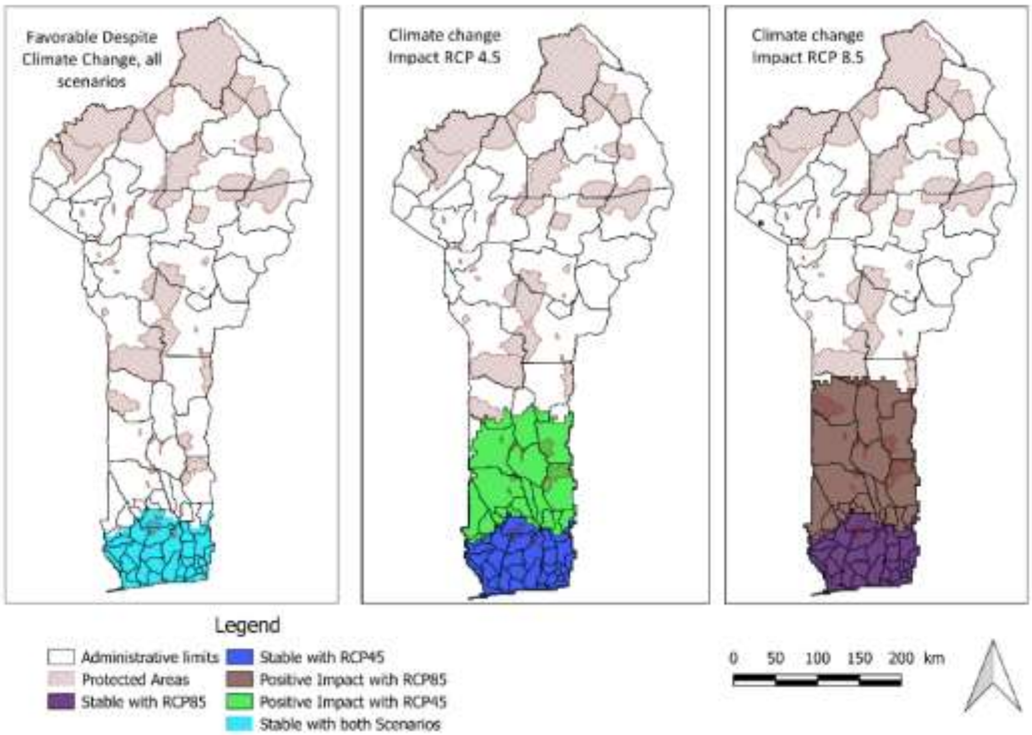

Figure 5. Climate change impacts on the distribution of suitable areas for *Garcinia kola* across municipalities and across protected areas network.

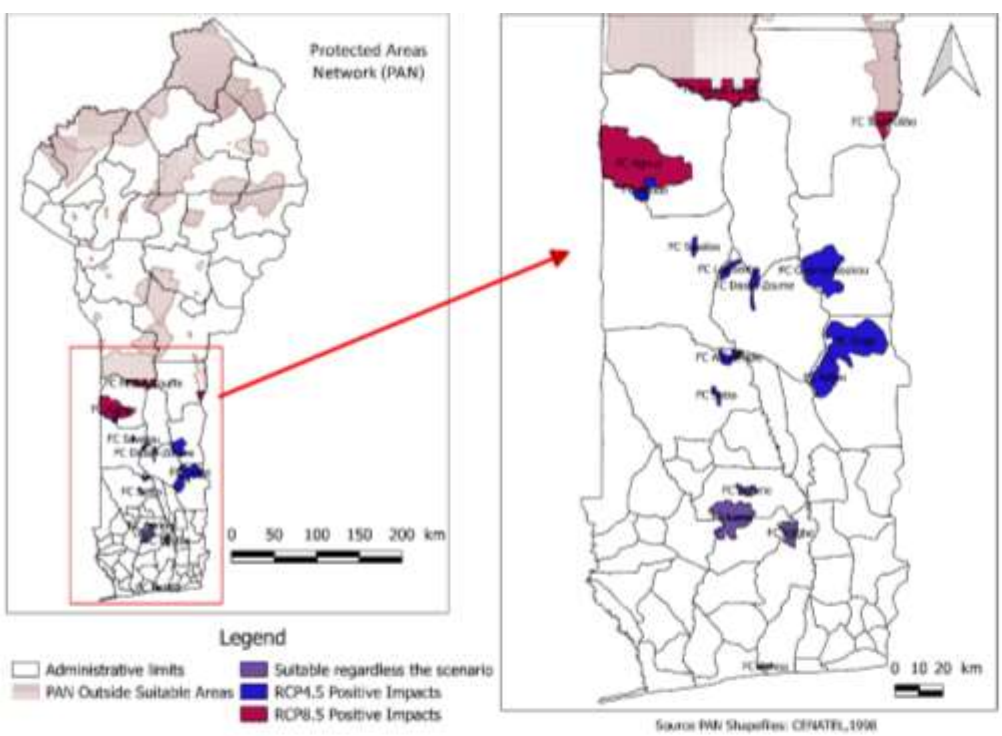

Figure 6. Protected Areas Network along with the climate change impact with regard to suitability areas for *Garcinia kola*.

Table 3. Distribution of suitable areas and climate change impacts across municipalities (areas in Km²).

Municipality	Suitable areas/Climate change impacts		
	All scenarios	RCP4.5	RCP8.5
Bante	0	473.45	2432.01
Bassila	0	0	199.22
Boukounbe	0	0	21.04
Cove	0	443.54	443.54
Dassa	0	1715.84	1715.84
Djidja	0	2181.85	2203.02
Glazoue	0	1111.81	1781.67
Ketou	0	1764.53	1764.53
Savalou	0	2311.23	2688.29
Save	0	1845.39	2236.07
Tchaourou	0	213.96	1260.49
Zangnanado	0	536.04	536.04
Abomey	4.02	146.73	146.73
Za-kpota	4.37	400.29	400.29
Aplahoue	4.43	970.82	970.82
Ouinhi	9.1	287.27	287.27
Bohicon	24.29	132.59	132.59
Klouekanme	25.5	398.89	398.89
Agbangnizoun	46.12	144.84	144.84
Porto-Novo	50.85	-	-
Adjara	61.88	-	-
Cotonou	70.57	-	-
Pobe	73.93	303.09	303.09
Avrankou	85.54	-	-
Toviklin	95.65	38.41	38.41
Akpro-Misserete	95.7	-	-
Djakotome	113.5	96.65	96.65
Seme-Kpodji	137.44	-	-
Aguegue	150.55	-	-
Dangbo	159.27	-	-
Come	162.28	-	-
Athieme	163.79	-	-
Ifangni	170.06	-	-
So-Ava	176.93	-	-
Adja-Ouere	181.36	273.07	273.07
Grand-Popo	220.65	-	-
Dogbo-Tota	262.71	-	-
Ouidah	264.55	-	-
Bonou	267.6	3.91	3.91
Houeyogbe	296.31	-	-
Adjohoun	306.26	-	-
Kpomasse	309.04	-	-
Lokossa	321.27	-	-
Tori-Bossito	334.64	-	-
Bokpa	387.01	-	-
Allada	397.63	-	-
Lalo	422.1	0.92	0.92
Sakete	431.76	-	-

Table 3. Contd.

Abomey-Calavi	488.03	-	-
Toffo	547.35	-	-
Ze	687.04	-	-
Zogbodome	695.52	120.19	120.19
Total	8706.6	15915.31	20599.43
Percentage of total municipalities	7,440585812	13,60108766	17,6040965

used for exploring species that could be used for restoration of secondary forests. The selection of variables to include in the model differs from one scientist to another. It was found that the distribution of a species at large scale depends mainly on climate (Vayreda et al., 2013). However, contrary to Gbètoho et al. (2017) who selected "a priori" four variables that they found to be the most biologically relevant in plant ecology in tropical West Africa and easy to interpret and Adjahossou et al. (2016) who selected variables only on the correlations between them before running the model, gave chance to all variables, even those that are shown to be correlated to reveal how well it contributes to the model building before making a decision to remove it. The present study is in line with all previous sources of information about recommended strategies for the conservation and the restoration of *G. kola* in its potentially suitable areas.

Neuenschwander et al. (2011) reported that the species' nut trading and its use for vegetable toothbrush constitute the main threats and that the species occurs in inhabited areas, but may also occur in dense humid forests and riparian forests. Our findings confirm their statement because models showed first that the species may find its climatic preferences in dense forests in Southern Benin, and can be grown in some cities always in Southern Benin. The same authors recommended that conservation efforts should include the restoration of the species in natural occurrence sites, and that further research may profitably focus on the distribution, ecology, regeneration, and silviculture of the species. There are now some advances based on research for vegetative propagation of *G. kola* (Kouakou et al., 2016) and this may ease multiplication and introduction of the species in urban forestry, agroforestry and home garden systems. However, many other parameters may drive the introduction of *G. kola* in urban areas.

The present study focused on the distribution and biogeography of the species, and then gave background on areas where the species can be restored. The suitable areas shown by our models for *G. kola* also conform to the ecological and geographical descriptions made on the species by Vivien and Faure (1985) and Ntamag (1997). The favorable zones according to the present results corresponded to parts of the Guinean zone in Benin and the coastal areas; and this highlights the evidence of the concentration of suitable areas in Southern Benin. The protected forests that may be retained for the conservation of the species are all in the Southern Benin, the part of the country belonged to the high prediction confidence areas. So, just a part of protected areas can conserve a given species. This information is an addition to the conclusions of Houehanou et al. (2013) and Adjahossou et al. (2016), who noted that some protected areas are threatened by unsustainable use of the existing resources. The use of the High Confidence Prediction Areas (HCPA) is a means to keep at the lowest level as possible the prediction error, giving more confidence to the users of the study results. The HCPA represented areas that were shown suitable for *G. kola,* whether under the conditions of the current climate, or regardless of the likely future scenario as used among the RCP4.5, and RCP8.5 at 2055s. The HCPA represented areas that were shown suitable for *G. kola* as well under current climate as under future climates regardless of used scenario among RCP4.5 and RCP8.5 at 2055s.

Positive climate change impacts include some municipalities and some protected areas in the center Benin to be suitable for hosting the species upon 2055s. In contrast to the findings of some authors who modeled other species, for example Ganglo et al. (2017) who modeled *Dialium guineense*, climate change has only positive impacts on the distribution of *G. kola*. But it is worth mentioning that different thresholds had been used for the classification, and this may create a slight difference on the classification results that they observed. It is unfortunate that many protected areas are in the northern parts of the country and those protected areas may not guarantee sustainable conservation sites for *G. kola*. Areas where *G. kola* may find its climatic envelope are medium to high population density areas. So, as remarked on one hand by Sogbohossou and Akpona (2006, 2007), Santini (2013), Idohou et al. (2014), Salako et al. (2014), and Gbedomon et al. (2015, 2016) that home gardens, botanical gardens in cities, urbanization through the green spaces and any other area in urban centers maintain the urban biodiversity and their remark aligns with the present findings. On the other hand, urban biodiversity is essentially influenced by human pressure (Sogbohossou and Akpona, 2006, 2007; Santini, 2013), giving more importance to the results that were obtained emphasizing the importance of the promotion of urban forestry and agroforestry.

CONCLUSION AND PERSPECTIVES

Climate changes were shown to have negative as well as positive consequences on the distribution of species. Modeling the ecological niche of *G. kola* gave background on its environmental envelop. More insights have been found on whether the evolution of climate is in favor of sustaining the species or not. Each research question found an appropriate response at the conclusion of the study. *G. kola* is a valuable tree species, which can benefit from predicted climate changes in Benin, regardless of the scenario. Evidence in response to the second research question revealed that decision makers and resources managers may not rely only on the protected areas network to conserve and restore the species in Benin. Our municipalities can provide a greater chance for *G. kola* (an extinct species in the wild) to extend its favorable areas due to likely climate changes. The percentage of municipalities that were suitable for the species is far above the percentage of PAN that was predicted as suitable habitats. Municipalities and protected areas that would be able to host conservation measures and actions toward enhancing the survival and habitat expansion of the species were identified. Thus, decision makers and resource managers may focus on those identified sites.

Overall, there are suitable natural and human habitable spaces to introduce *G. kola* and expect a success. With regard to the synthesis of suitability areas shown in Tables 2 and 3, it is worth introducing the species in farmland, homeland, cities, streets, public spaces, and home gardens. However, some additional research is needed to focus on some key physiological and horticultural aspects. First, a better understanding of the root system requirement of the species. On the other hand, more documented evidence of the interactions between humans and this species are needed when introduced in cultivation as another important research focus.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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