International Journal of Agricultural and Environmental Sciences
2021; 6(1): 1-14
http://www.openscienceonline.com/journal/ijaes

Climate Changes and Dynamics of the Ecological Niche of Threatened Woody Species in the Dahomey Gap Corridor in Benin

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To cite this article

Chabi Romeo Brice Kolawole, Dossou Etienne, Yabi Biaou Francis, Yabi Ibouraima, Tente Agossou Brice Hugues. Climate Changes and Dynamics of the Ecological Niche of Threatened Woody Species in the Dahomey Gap Corridor in Benin. *International Journal of Agricultural and Environmental Sciences.* Vol. 6, No. 1, 2021, pp. 1-14.

Received: June 29, 2021; **Accepted**: August 5, 2021; **Published**: August 30, 2021

Abstract

In Benin, the southern part is devoid of continuous dense humid forest like the Ivory Coast or Nigeria due to the presence of Dahomey Gap or Dahomey gap or aridness corridor. But the meager natural resources of this already fragile environment are affected by the effects of environmental changes, particularly climatic ones. The present research aims to analyze the dynamics of the distribution areas of endangered woody species under the effect of climate change in the part affected by Dahomey-Gap in Benin. The methodology employed two approaches including phytosociological inventories and modeling based on the Maximum Entropy (MaxEnt) model on exposed woody species appearing in the IUCN international red list. Floristic inventories were carried out in 570 plots over an area of 30 m x 30 m according to the Braun-Blanquet method within the different land use units that made it possible to analyze the floristic composition of the woody plants in the area of study. In total, 186 woody species have been identified in the Dahomey-gap in the southern part of Benin. Of these woody species, 17 are endangered. The endangered woody species (EN) are grouped in three (03) classes: Aphania senegalensis, Dalbergia setifera and Pterocarpus erinaceus. In addition, 10 woody species are vulnerable (VU) (Afzelia africana, Albizia ferruginea, Khaya senegalensis, Millettia warneckei, Nesogordonia papaverifera, Pierreodendron kerstingii, Pseudospondias microcarpa, Pterygota macrocarpa, Ricinodendron heudelotii and Vitellaria paradoxa). Finally almost 4 threatened woody species (Chrysophyllum albidum, Eucalyptus camaldulensis, Irvingia gabonensis and Milicia excelsa) are identified. Habitats distribution of 17 threatened woody species are found. The future projection by 2050 according to the optimistic RCP4.5 and pessimistic RCP8.5 emission scenarios revealed that these species could lose up to 35% of habitat area. Currently, the conditions are very favorable. These results should guide the management and conservation policies of woody resources in the area of study.

Keywords

Dahomey Gap (Benin), Woody Species, Conservation Status, Maximum Entropy (MaxEnt), Climatic Scenario

1. Introduction

African forest resources are among the most important and richest in terms of abundance and diversity of species [1]. However, over the past three decades, African countries have experienced a decline in these resources. The factors potentially involved in this worsening were attributed to: both loss of habitats and destruction [2, 3], deforestation [4-6] and climate change [7]. Thus, despite the great utility of genetic resources for local communities, they are threatened in their natural habitats by deforestation, vegetation fires, extensive cattle grazing, charcoal production, abundant use of firewood, shifting cultivation on slash and burn, illegal logging [8, 9]. This tendency is accentuated particularly in Benin and we are witnessing deforestation as well as the degradation of forest resources. Indeed, Benin is already handicapped by its inadequate forest resources, due to its location in the dry corridor called Dahomey Gap or Dahomey Gap [10]. The Dahomey Gap is considered to be an important ecological and geographical barrier to the exchange of plant species between the two blocks of the Guinean-Congolese CRE [11, 12]. It is characterized by a decrease in annual rainfall (from 2000 mm at the level of the two blocks to 1300-900 mm). Thus, it has experienced a reduction in its forest cover of 55.6% in less than a quarter of a century. Certainly, on average, Benin loses 6,000 ha of forest each year [13]. The degradation would be more accelerated in meridional Benin, which does not have large protected areas however, where more than half of the country's population is concentrated, in a surface area equivalent to one-tenth of the national territory [14]. Thus, dense deciduous and semi-deciduous forests are rapidly disappearing due to their irrational uses [10].

Furthermore, climate change is the other factor that also poses a worrying threat to Benin's forest resources. It is presently among the greatest development challenges facing our planet [15, 16]. These phenomena have direct consequences on forest resources and the first effects such as the advancement of the phenological stages of plant species and loss of habitat are already noticeable more acutely in African countries [17].

In Benin, several authors have concluded that the climatic feature has undergone multifaceted disturbances over the past decades [12, 18, 19, 21, 23]. These mutations are manifested by a pronounced irregularity in the annual rainfall totals associated with a strong intra-seasonal instability without ignoring the thermal warming [24] and the advent of extreme weather-climatic events.

In addition, most projections predict harder climatic conditions in the future, particularly over the tropics where significant fluctuations in the rainfall system are anticipated. In West Africa for example, among other things [14], it is anticipated between 2050 and 2100, an increase in the intensity of extreme climatic events such as droughts and water stress, land aridity, and so forth. In Benin, [21, 25, 26] reached similar conclusions, namely that in the different regions of Benin (including the Dahomey-Gap area) the future climate will be characterized by a variation of the rainfall patterns associated with an increase in temperatures.

Such a future climatic context will have consequences on forest resources, in particular woody species and their habitats with regard to the dependence of forest ecosystems on climatic conditions [27]. Indeed, climate change will affect the distribution of plant species and their habitats [17]. In this context, it is necessary to anticipate the dynamics of the ecological niche of endangered woody species in the Dahomey-Gap area of Benin to orient decision-making towards the sustainable management of natural resources in the era of climate change in this particular part of Benin.

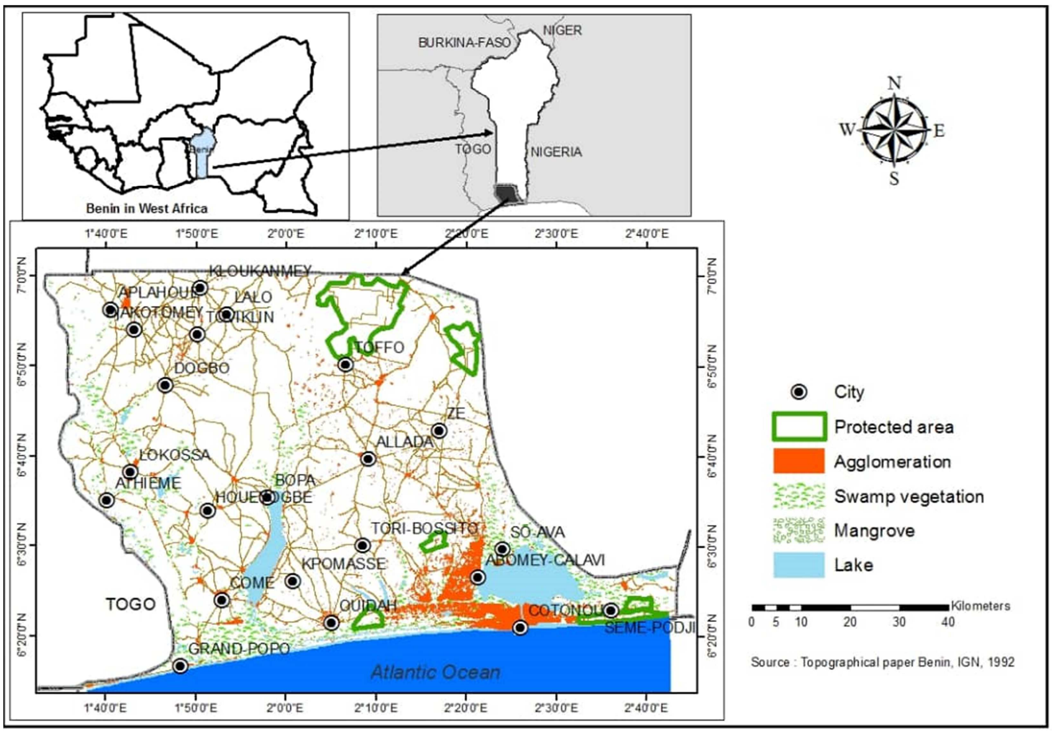

Figure 1. *Geographical location of the study area.*

2. Materials and Methods

2.1. Study Area

The present research was carried out in the domain of Benin's Dahomey-Gap. It is located in the South of Benin between the geographical coordinates of 1°37'45' and 2°42'35' East in longitude and between 6°12'37' and 7°1' North in latitude and covers an area of 6702.807673 km² (Figure 1).

A subequatorial climate type is encountered in this zone. It is characterized by two rainy seasons and two dry seasons. The long rainy season covers the months from April to July while the short one from September to October. The long dry season covers the months from December to March and the short one from August to September [28] cited by [29]. The average of annual rainfall oscillates around 1300 mm.

Hydrographically, the study area has several streams, the most important of which are the Oueme River in the Center and the South (510 km), the Couffo River in the South-East (170 km) and finally, the Mono river in the West (400 km) [30].

In addition, the study sector has in the shoreline part an important lagoon-lacustrine network of about 270 km^2. The main lakes and bays of South Benin are the Toho, Lake Togbadji, Lake Aheme (78 km^2), Lake Nokoue (135 km^2) and the Porto-Novo inlet (30 km²) [31].

Three types of vegetation are identified over the study area namely, the plant formations of the sandy shores of the coast, swampy depressions and plateaus [32]. We found several sociolinguistic groups such as: Fon, Adja, Mina, Kotafon, Houedah, Pedah, Aizo, Sahoue, Xwla, Goun, Tori, Tofin, Yorouba, Holly and Ouemenou. Currently, inhabitants in this zone exceed 5,894,168 [14] and they carry out several economic activities, the main ones being: agriculture, fishing, animal husbandry, crafts and to a lesser extent quarrying.

2.2. Data Collection Method

2.2.1. Method for Collecting Data on the Woody Flora of Dahomey-gap in Southern Benin

To identify woody species in the study environment, phytosociological surveys were employed. On the basis of a land use map from the study region, major occupancy components were identified. Following the identification of the occupation components, field surveys were carried out within these land occupation pieces of plant formations to determine the woody species. The inventory of the elements are visually determined in the field on the basis of physiognomic, floristic and ecological homogeneity as well as the importance of each of these areas. The size of the surveys is determined by taking into account the work carried out by several authors ([33, 36]) in a tropical environment and who used variant surfaces between 100 m² and 900 m² depending on the training vegetation and strata. Therefore, the vegetation surveys were worked out within facies floristically and ecologically homogeneous from plots of 30m x 30 m. This is the reason that justifies the irregularity of plots number of plants surface areas plants. A total of 570 plots were installed in the large land of units' occupation (Figure 2 and Table 1).

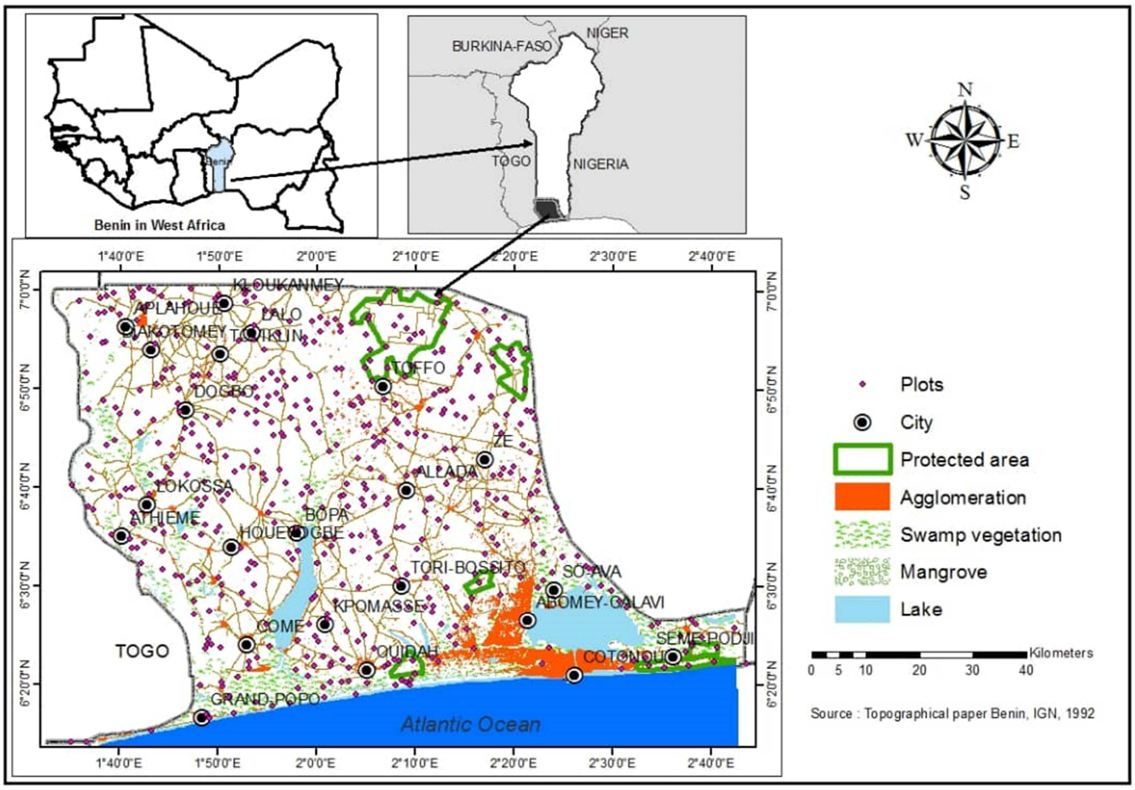

Figure 2. Spatial distribution of the plots over Dahomey Gap.

Table 1. *Distribution of the number of plots per units of occupied lands.*

Units of occupied lands	Surface area (km²)	Number of Plots (30x30m)
Mangroves	6.272533089	35
Urban Vegetation areas	13.08056815	35
Gallery forests	22.49549484	50
Dense forests	57.44652605	45
Open forests and wooded Savannah	156.9576421	70
Swamp formations	660.3570053	55
Tree and shrub savannah	790.5418398	75
Farms and fallows under Palm groves	1195.489383	60
Plantations	1210.483075	50
Farms and fallows	1779.82272	95
Total		570

Source: Field works, December 2020

2.2.2. Phytosociological Surveys

The phytosociological surveys were carried out according to the Braun-Blanquet stigmatic method taken up by [33, 38]. The minimum survey area used is 30 mx 30 m considering the woody stratum. Yet, a similar minimum area has been used successfully by ([39-41]) for the characterization of woody plant groups. The data collected are: (i) - geographical coordinates of each plot, (ii) -percentage of the woody stratum coverage, (iii) - exhaustive list of all the woody species within the plots. The plant species were determined directly in the field using the analytical flora of Benin [42]. Non-identified species in the field are harbored and subsequently will be identified later at the national Herbarium of Benin. In addition to these data taken directly in the field, other complementary bibliographic data relating to the species have been collected according to the IUCN conservation of species. The conservation status of the species was determined from the IUCN International Red List (www.iucnrelist.org) and the National Red List [43].

The conservation statuses defined by the IUCN are:

1. EX (Extinct): Extinct species
2. EW (Extinct in Wild): Extinct species in the wild
3. CR (Critical Endangered): Critically Endangered Species
4. EN (Endangered): Endangered species
5. VU (Vulnerable): Vulnerable species
6. NT (Near Threatened): Near Threatened
7. LC (Least Concern): Species of Least Concern
8. DD (Data deficiency): Species of Data deficiency

2. Analysis of the effects of climate change on the ecological niche of woody species

The MaxEnt model was used for the analysis of the effect of climate change on threatened wood resources. It required the collection of occurrence data for threatened woody species and bioclimatic variables.

2.2.3. Collection of Occurrence Data of Threatened Woody Species

The geographic coordinates of all woody species recorded during the inventory were used and supplemented by the geographic coordinates of the species available on the Global Biodiversity Information Facility (GBIF) website.

Choice of bioclimatic variables

For current and future climate projections, the regional circulation ensemble model "AFRICLIM 3.0: high resolution ensemble climate projections for Africa" was used.

A total of 22 bioclimatic variables were downloaded from the website: http://www.york.ac.uk/environment/research/kite/resources/. However, it is advisable to reduce the list to a minimum of variables that are weakly correlated (r <0.70) and important for studying the species. In the study zone, it was shown that the distribution of forest resources is essentially dependent of rainfall and annual mean temperature [42]. On this basis, the 13 weakly correlated variables (Pearson's correlation test) and better reflecting the aridity gradient were selected as presented in Table 2 (the 13 bioclimatic variables finally selected in the present study).

Table 2. *List of the 13 environmental variables used for the modeling.*

No	Codes	Environmental Variables
1	BIO2	Mean temperature of the wettest quarter (C x10, Int16)
2	BIO4	Mean temperature of the hottest quarter (C x10, Int16)
3	PET	Potential Evapotranspiration (mm, UInt16)
4	BIO12	Annual mean precipitation (mm, UInt16)
5	BIO13	Precipitation of the Wettest month (mm, UInt16)
6	BIO14	Precipitation of the hottest month (mm, UInt16)
7	BIO15	Seasonal precipitation (mm, UInt16)
8	MI	Annual humidity Index (x100, UInt16)
9	MIMQ	Precipitations of ¼ of the wettest (x 100, UInt16)
10	MIAQ	Precipitations of ¼ of the driest (x100, UInt16)
11	DM	Number of dry months (months, Byte)
12	LLMD	Length of the longest dry season (months, Byte)
13	SOIL	The nature of the soil

For the future climate projections, two scenarios of emission (representative concentration pathways) have been utilized, namely: the optimist scenario (RCP 4.5) and the pessimist scenario (RCP 8.5) that are more likely to be appropriate for Africa (Table 3).

Table 3. *Characteristics of the optimist (RCP4.5) and pessimist (RCP8.5) scenarios.*

Scenario	Predictions	Sources
RCP4.5	Very weak energizing intensity. Strong reforestation programs. Declining in frequency of cultivated lands utilization. Strict climate policy. Emissions of stable methane. Emissions of CO_2 increase slightly following by a declining to around 2040	[44, 45]
RCP8.5	Very high concentration rate of CO_2 emitted into the atmosphere (three times the current rate of CO_2) by 2100. A rapide increase of emission rate of methane. Increase of cultvited and prairies areas due to the growth of the demography. World population estimated at 12 billion by 2100. High energizing intensity. No implementation of climate policy.	[47]

2.2.4. Analysis of the Collected Data

The Maxent model is used to assess the effect of climate change on favorable habitats for endangered species in the area of research. The equation of probability distribution is defined as follows:

$$H(\overline{\pi}) = -\sum_{x \in X} \overline{\pi}(x) \ln \overline{\pi}(x)$$

Where π is the probability distribution function of the environmental variables, x represents the location of each sample and X the ensemble of the samples that are interpreted then as pixels game covering the study region. The value of $''H''$ is maximum for a uniform distribution, i.e., when the studied specie has an equal probability to appear on each studied surface pixel.

To validate the model used, the initial data game is divided into two sub-groups: a sub-group is composed of 80% of the data counted is used for model calibration, another constituted of 20% of the data counted allow evaluating the predictive capability of the model.

Another criteria used for evaluating the model is the index named "Receiver Operating Characteristics Curve" (ROC) by calculating the area under the curve "area under the curve" (AUC). The AUC's values are interpreted as suggested by [46]:

AUC > 0.90: the model is good; 0.75 ≤ AUC ≤ 0.90: the model is acceptable; AUC < 0.75: the model is bad. The probability distribution data are generated by a cartographical model utilizing GIS under ArcGIS.

3. Results

3.1. Status of Woody Conservation in the Dahomey-gap in the South Benin on the International Red List (IUCN)

Among the flowering woody of Dahomey-Gap in South Benin, seventeen endangered species have been identified. It is notably the endangered (EN) species class represented by three woody (Aphania senegalensis, Dalbergia setifera and Pterocarpus erinaceus), that of vulnerable species (VU) with 10 woody (Afzelia africana, Albizia ferruginea, Khaya senegalensis, Millettia warneckei, Nesogordonia papaverifera, Pierreodendron kerstingii, Pseudospondias microcarpa, Pterygota macrocarpa, Ricinodendron heudelotii and Vitellaria paradoxa) and lastly, 4 woody species, which are near endangered (Chrysophyllum albidum, Eucalyptus camaldulensis, Irvingia gabonensis and Milicia excelsa) (Figure 4). The presence of woody species with less attention are many over the study region. These woody species with less attention (LC) are very important for the study area (52.69% of the total of 186 surveyed species), as well as non-evaluated (NE) species in the IUCN international red list (Figure 3).

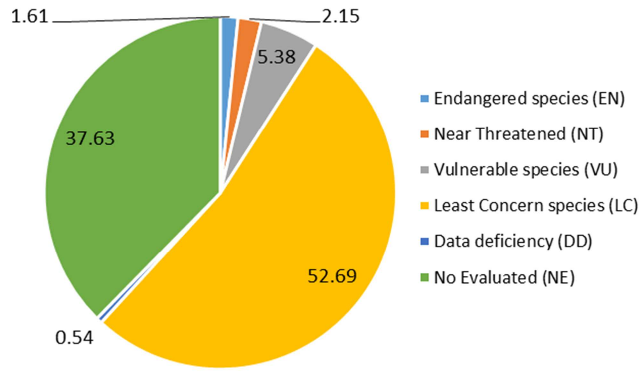

Figure 3. *Distribution of species according to IUCN conservation status.*

3.2. Effect of Climate Change on Area Distribution of Classified Endangered Woody Species in South of Benin

3.2.1. Models Validation

Figure 4 indicates the variation of the AUC along with conservation status of species studied. The analysis of Figure 4 showed that for all categories of species (Vulnerable species, endangered species and near-endangered species), Maxent models have a good discrimination capability of potential habitats (0.8 <AUC<0.95).

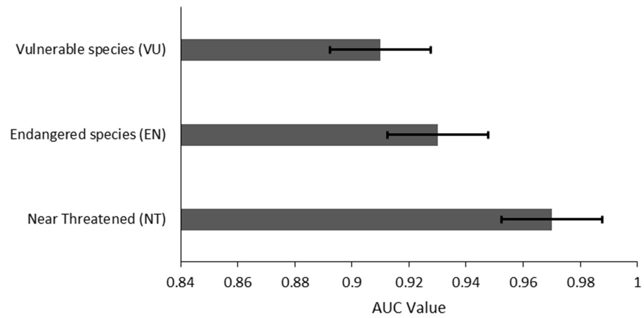

Figure 4. *Mean values of the AUC of different models.*

3.2.2. Bioclimatic Variables Contribution

The table 4 presents the contribution of bioclimatic variables to the model following the conservation status of species. The analysis of that table shows that mean temperature of the trimester of the wettest (bio2 along with a contribution greater than 30% for each of the three models), annual mean precipitation (bio12 along with a contribution of 23.7%, 28% and 31.1%, respectively for endangered, vulnerable and near-vulnerable species) and lastly, the soil type with a contribution of 25.9% for endangered, 26.5% for vulnerable and 16.2% for endangered woody species.

Table 4. *Contribution of bioclimatic variables to the distribution of woody.*

endangered species (EN)		Vulnerable species (VU)		near-endangered species (NT)	
Variable	Percent contribution	Variable	Percent contribution	Variable	Percent contribution
bio2	31.9	bio2	33.4	bio2	32.4
soil	25.9	bio12	28	bio12	31.1
bio12	23.7	soil	26.5	soil	16.2
bio15	4.7	bio15	3.5	bio13	6.3
bio13	4.7	bio13	2.8	miaq	6.1
mi	2.9	bio4	2.7	bio15	4.4
bio4	2.4	pet	1	bio4	1.6
bio14	1.6	bio14	0.9	bio14	0.7
pet	1.2	miaq	0.7	mimq	0.5
miaq	0.7	mimq	0.5	pet	0.5
mimq	0.4	llds	0	llds	0.1
llds	0.1	mi	0	dm	0
dm	0	dm	0	mi	0

3.2.3. Current and Future Habitats Favorable to Woody Species Classified as Endangered (EN) on the IUCN Red List

Figures 5, 6 and 7 show the evolution of surface areas distribution of endangered species and the prediction of their distribution under the climatic scenarios RCP4.5 and RCP8.5 by the horizon 2055.

The major part of the studied area is weakly favorable for endangered ligneous conservation (82.17% of the total surface area). A surface area of 560 km^2 (roughly 8.35% of the total surface area) are moderately favorable for those species and solely a surface area of 635km^2 approximately 9.47% of the total surface area of the study region, which are currently very favorable for endangered species conservation (Figure 7). The surface areas very favorable are located in the classified forest of Lama and the compounds of different water beds.

The future projection of surface areas conservation under the pessimist scenario RCP8.5 by the horizon of 2055 (Figure 6) shows that 0.79% of very favorable surface areas conservation will disappear in favor of moderately favorable surface areas. Similar tendency of very favorable habitats loss is observed at the level of the optimist scenario RCP4.5 (Figure 7).

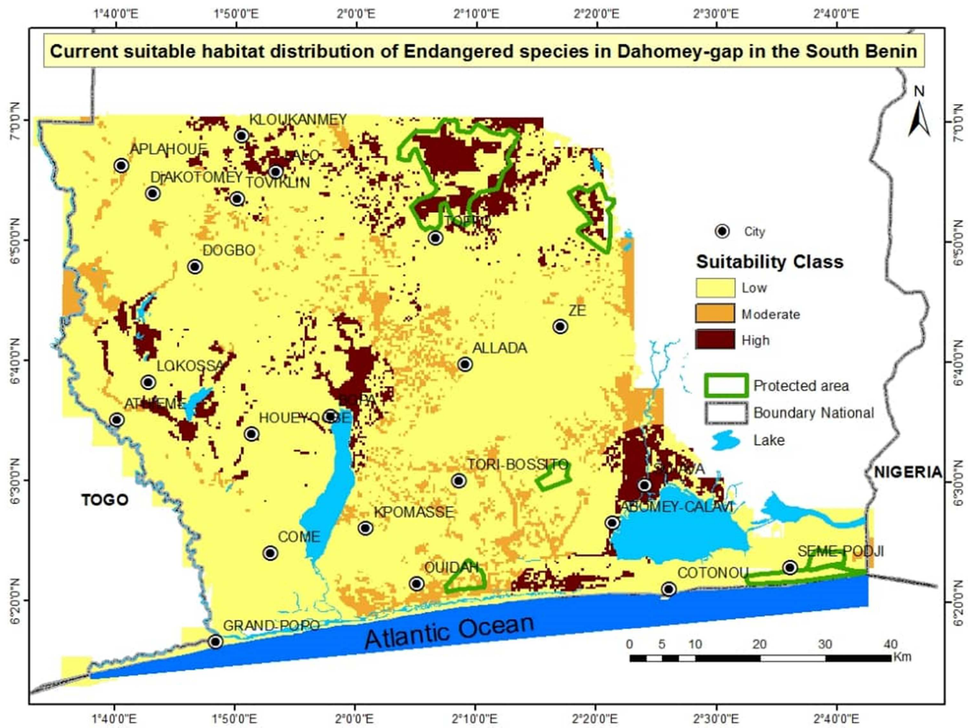

Figure 5. *Prediction of current surface areas distribution of classified endangered woody (EN) on the IUCN red list.*

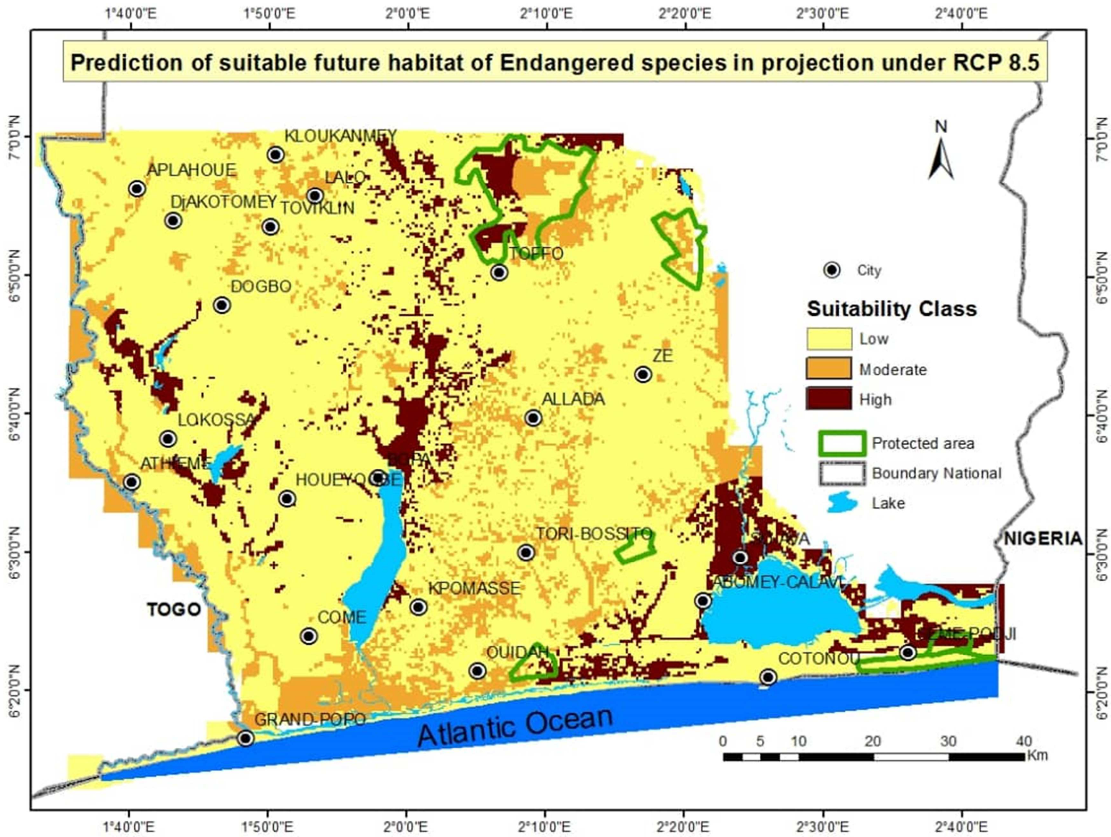

Figure 6. *Prediction of future surface areas distribution of classified endangered ligneous (EN) on the IUCN red list based on RCP8.5 scenario by the horizon of 2055.*

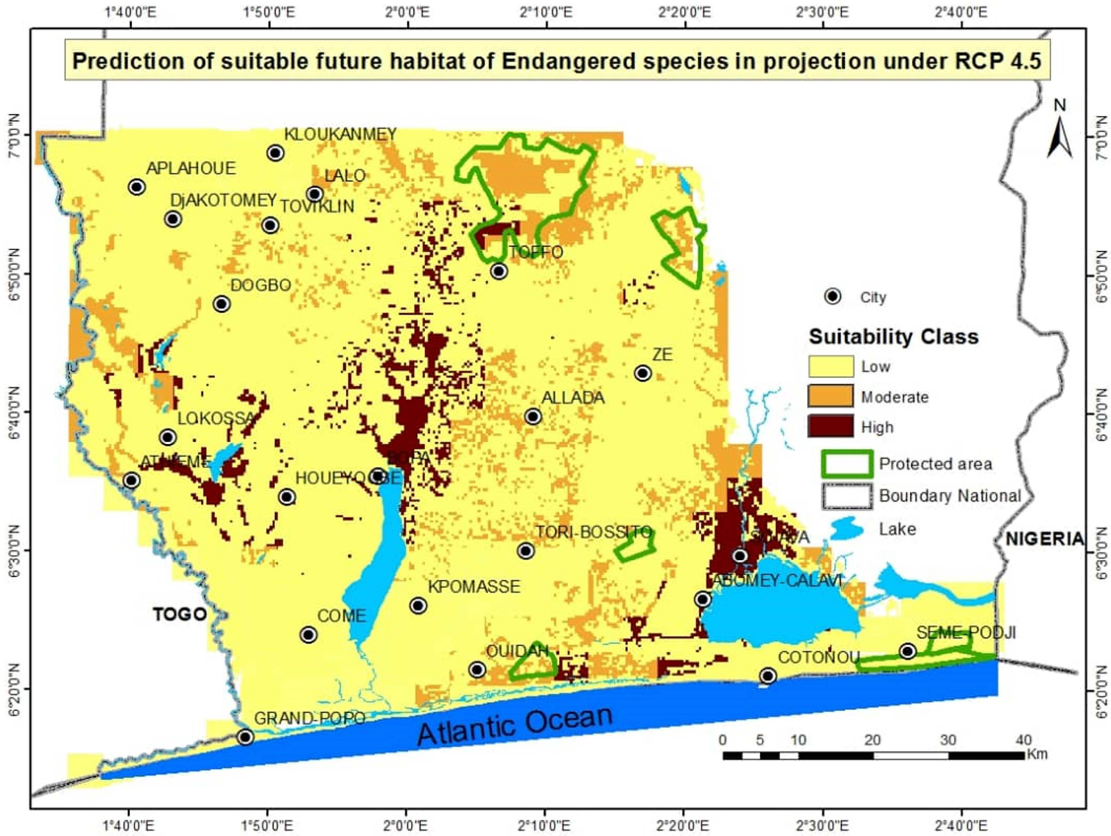

Figure 7. *Prediction of future surface areas distribution of classified endangered ligneous (EN) on the IUCN red list based on RCP4.5 scenario by the horizon of 2055.*

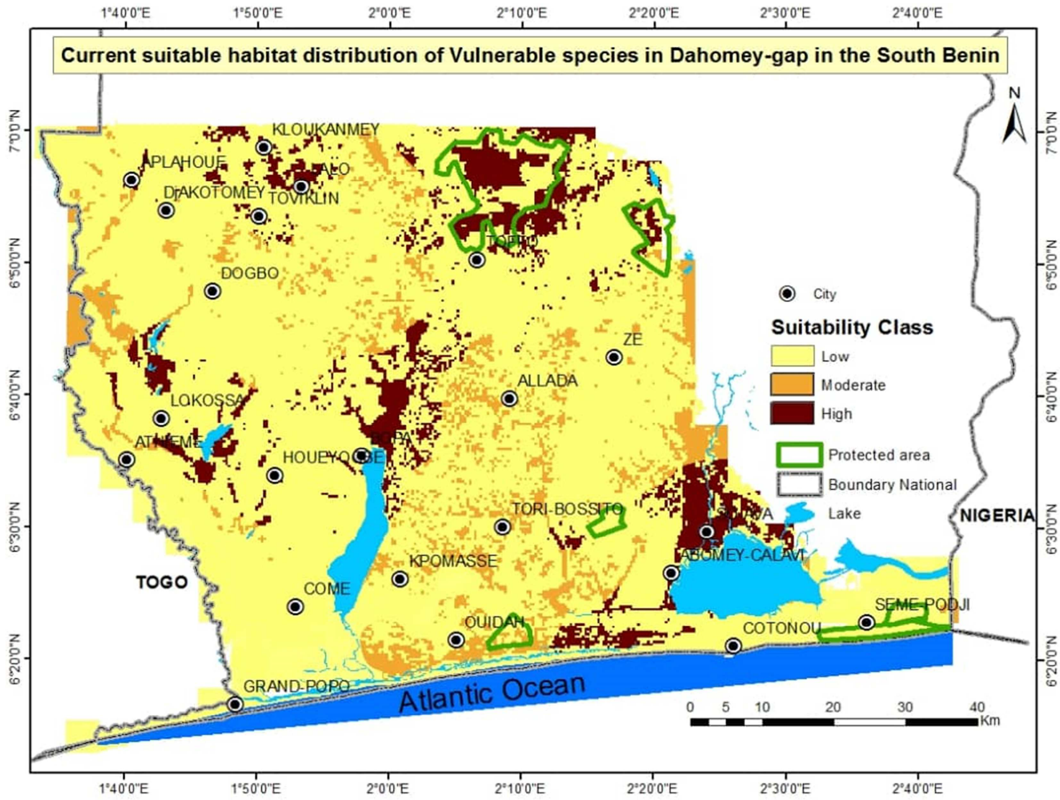

Figure 8. Prediction of current surface areas distribution of classified vulnerable (VU) woody on the IUCN red list.

The future projection of surface areas conservation under the optimist scenario RCP4.5 at the 2055 horizon (Figure 7) shows that 29.13% of the very favorable surface areas conservation will disappear in favor of the moderately favorable surface areas.

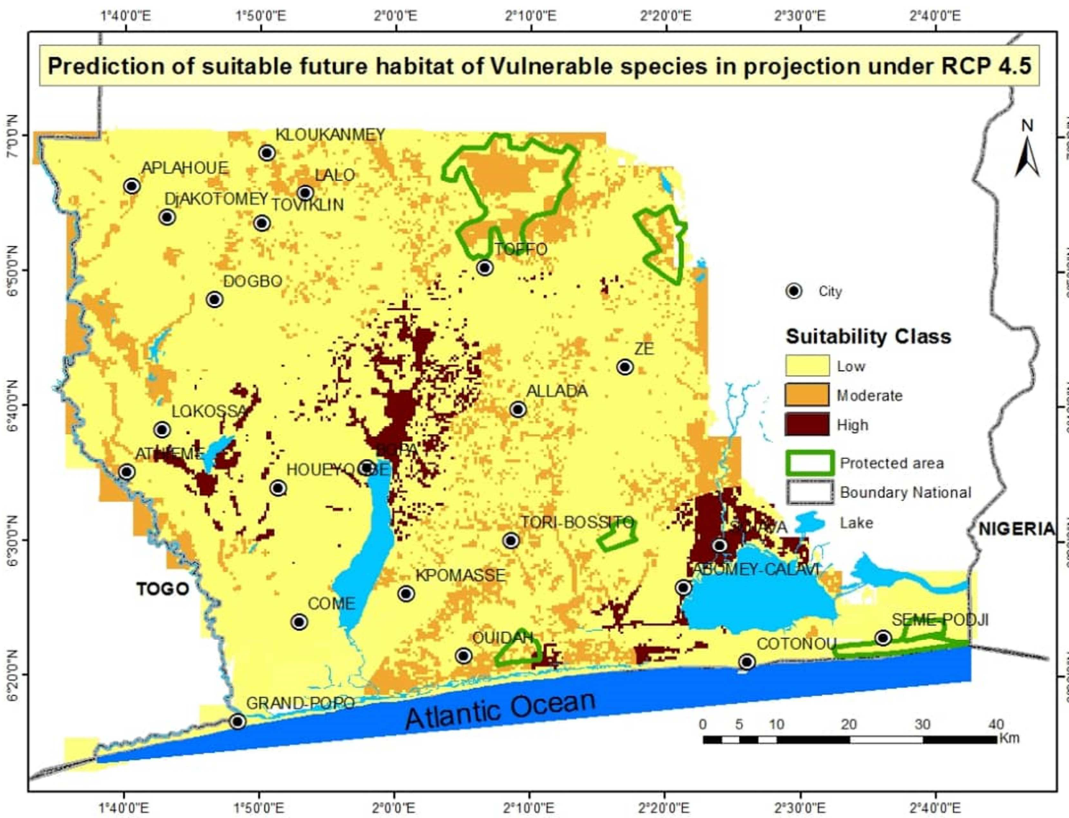

Figure 9. Predictions of future surface areas distribution of classified vulnerable (VU) woody on the IUCN red list according to RCP4.5 by the horizon 2055.

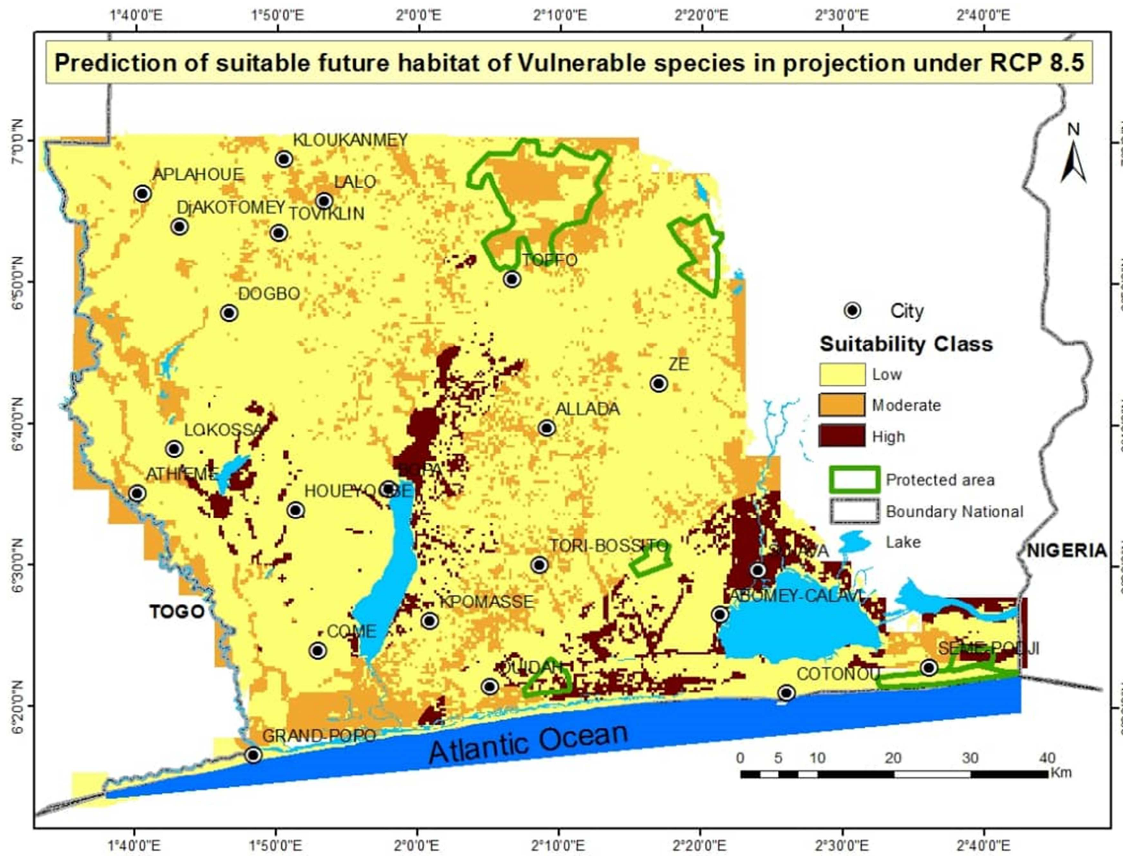

__Figure 10.__ Predictions of future surface areas distribution of classified vulnerable (VU) woody on the IUCN red list according to RCP8.5 by the horizon 2055.

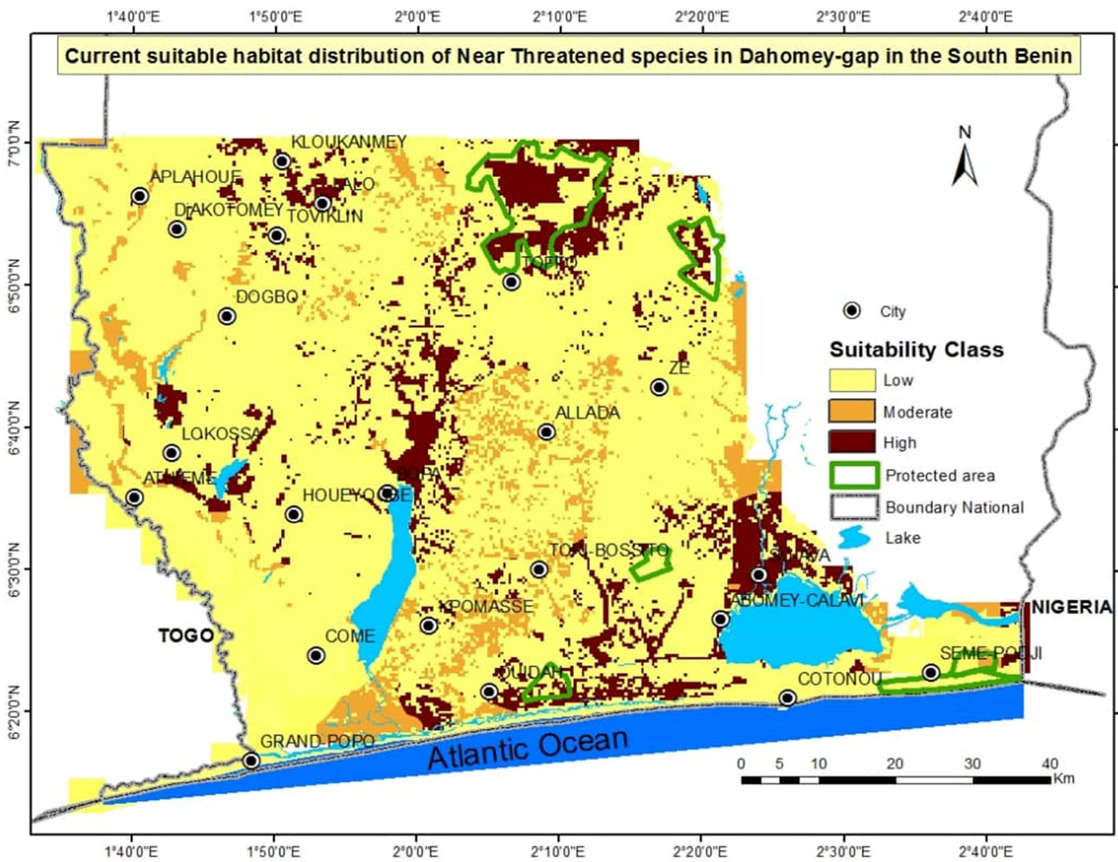

__Figure 11.__ Prediction of current surface areas distribution of classified near-endangered (NT) woody on the IUCN red list.

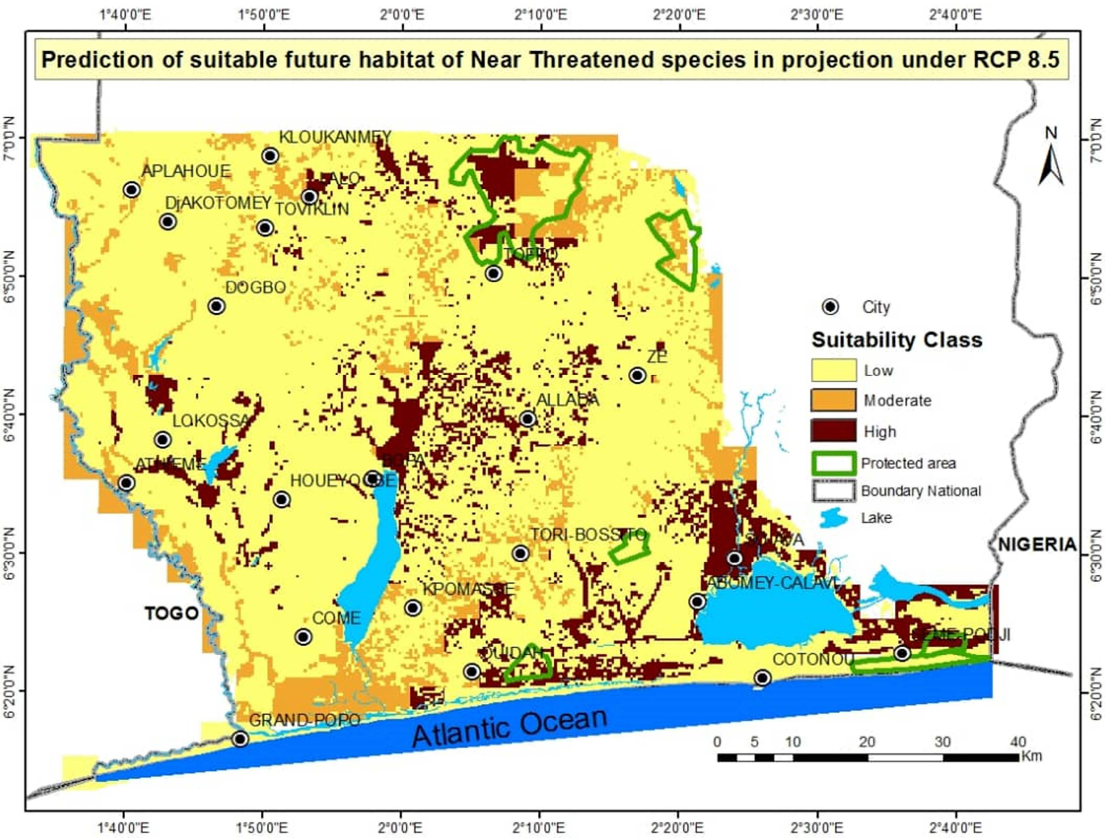

***Figure 12.** Predictions of future surface areas distribution of classified near-endangered (NT) woody on the IUCN red list according to RCP8.5 by the horizon of 2055.*

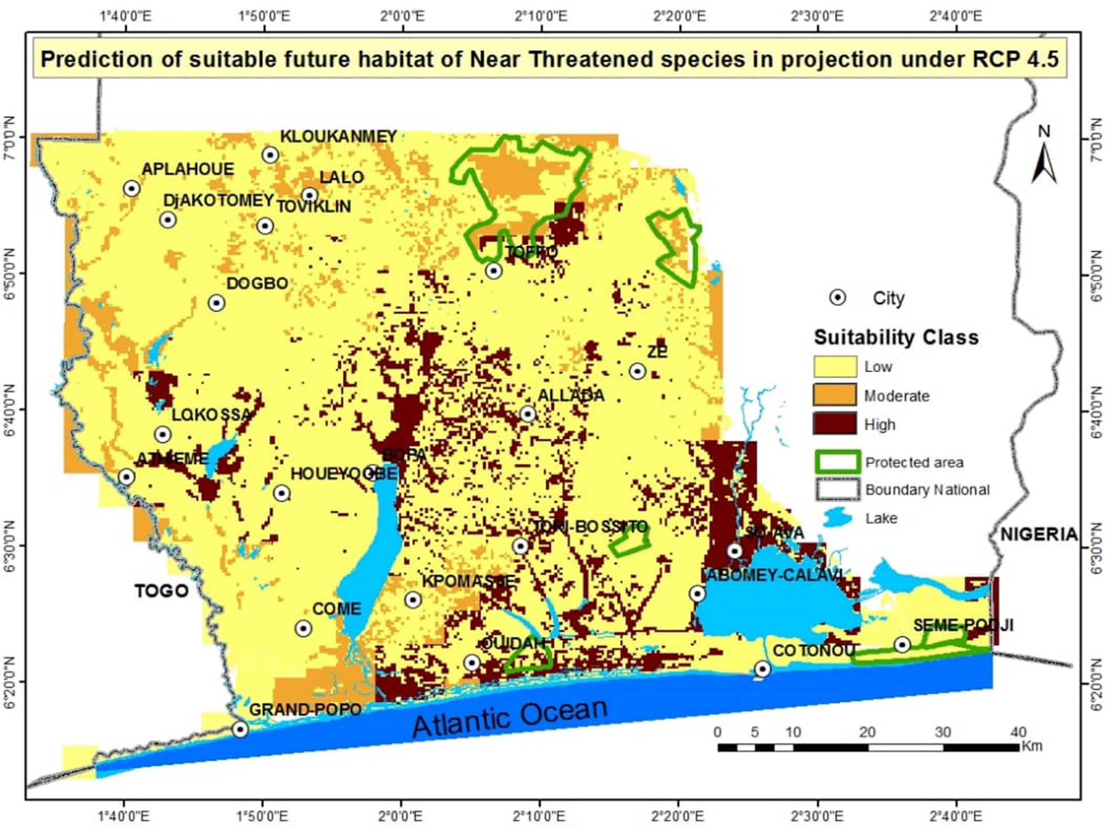

***Figure 13.** Predictions of future surface areas distribution of classified near-endangered (NT) woody on the IUCN red list according to RCP4.5 by the horizon 2055.*

3.2.4. Current and Future Habitats Favorable to Vulnerable (UV) Ligneous on the IUCN Red List

Current distribution zones of vulnerable woody have been distinguished as shown in Figure 9. The analysis of current surface areas distribution of classified vulnerable (VU) species in the studied zone shows that the later denote a choice for humid zones and the classified forest of Lama.

Currently, very favorable surface areas represent about 620 km^2 (about 9.25% of the total surface areas of the studied zone). Figures 9 and 10 show the evolution of surface areas distribution of endangered species and the projection of surface areas distribution according to the RCP 4.5 and RCP8.5 scenarios, respectively by the horizon 2055.

The projection of favorable habitats under the RCP4.5 and RCP8.5 scenarios show that the specie will lose nearly 37.09% and 23.38%, respectively of favorable habitats in favor of moderately favorable. The distribution of convenient habitats to vulnerable species is concentrated around the lakes and lagoons of the study area.

3.2.5. Current and Future Habitats Favorable to Woody Species Classified as Near-endangered (NT) on the IUCN Red List

The modeling of near-endangered species resulted in a surface area of 890km^2 very favorable to conservation (approximately 13.28% of the total surface area of the study zone). These very favorable surface areas to the conservation of near-endangered (NT) species are observed near water beds, hence humid zones. Humid zones represent then an essential habitat for the conservation (Figure 11).

The prediction for the horizon 2055 of the woody distribution from the climatic RCP4.5 and RCP8.5 scenarios has allowed evidencing the evolution of future potential habitats (Figures 12 and 13).

According to the RCP8.5 scenario, the near-endangered species will experience an important decreasing tendency of the favorable surface areas (32.02% of favorable habitat loss). In contrary, moderately favorable surface areas will increase up to about 60%. Meanwhile, RCP4.5 scenario predicts a reduction in very favorable surface areas distribution of 4.49% against an augmentation of moderately favorable habitats (23.30%).

3.3. Discussion

The Maxent model is very useful to investigate the geographical distribution of species because it provides very important information in terms of natural resource management, in particular to identify new areas that are potentially favorable for the conservation of a given species [49-51]. Indeed, this model accepts quantitative and qualitative data in combination with the presence of points. For the present study, the AUC values greater than 0.90 demonstrates a good ability of the model to predict the distribution of species [46]. However, this model has some weaknesses in predicting the impact of climate change on spatio-temporal dynamics distribution of species. Among these weaknesses, we can cite the uncertainties that are associated with the models used, difficulties in parameterizing ecological interactions, individual responses of species to climate change, the dispersion and adaptive responses [27, 51].

In this research, the average temperature of the wettest quarter (bio2), mean annual precipitation (bio12) and finally the type of soil appear to be the environmental variables which have contributed the most to the prediction of the model. The work of [52] has already revealed that the anomaly would exceed 4% and 1.28°C respectively for rainfall and temperature by 2050 and 3.5°C by 2100 for temperature, in particular in the study zone. The increase in projected temperature and the subsequent increase in current evapotranspiration could subject forest species to water or thermal stress and thus cause the decline of forests and natural ecosystems already subject to severe High pressure of demography.

Therefore, we can retain that the woody species studied are sensitive to temperature and rainfall. This state of affairs could be explained by the ecological characteristics of the habitats of these species, which are mostly located in wetlands. They can also be observed in forest ecosystems such as the Lama classified forest. These results confirm the unanimity of climatologists on the fact that the biophysical conditions (temperatures, precipitation, aridity, soil, slope, etc.) will become more severe in the future due to climate change [52]. In addition to these three environmental variables, the potential evapotranspiration is also determined as the variable that contributes significantly to the prediction of the probability of species occurrence. Indeed, the increase in evapotranspiration, particularly in the tropical zone, inclines the surface areas distribution of forest resources to ecological disturbances [53]. Previous studies have shown that climatic or land use variables are very useful in predicting the distribution of many bird species [54]. According [55], factors of habitats determining the distribution of species are enclosed within variations on a larger geographical scale, under appropriate climatic conditions. Moreover, in numerous ecological niche modeling studies, we find that climatic indices are often determined to be the best predictors of the current and future distribution of species [56, 57]. This difference of results can also be explained by the climatic scale at which these climatic indices were measured.

4. Conclusion

The study in the corridor of Dahomey Gap that was carried out in the southern part of Benin, showed that there are 17 threatened species classified on the basis of the IUCN international red list. Endangered species are found very favorable in wetlands areas and a part of the classified forest of the Lama. Under the future climate projections for radiative forcing RCP 4.5 and RCP 8.5, the models indicate important spatial dynamics of favorable habitats of threatened woody plants, which will lose a part of the currently very favorable habitat (between 20% and 30%). Therefore, global warming could call into question current strategies for the conservation of wood resources and this parameter must be taken into account in the design of projects for the management and conservation of natural resources. Better still, it is necessary for the forestry and local administrations of this study region to put in place provisions to protect areas favorable and very favorable to endangered species.

Acknowledgements

Authors thank the African Forest Forum (AFF), which is a non-governmental Pan African organization that is located in Nairobi, Kenya. It is an association of people that shares the research and engagement for lasting management, the utilization and the conservation of forests and forests resources in Africa for socio-economic welfare of its populations, the stability and environmental improvement.

AFF has contributed financially to this research in the band of “Scholarships for research on tendencies evaluation and climate change impacts and adaptation mechanisms of forests and forests resources in Africa 2020-2022”.

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