Available online at http://www.ifgdg.org

Int. J. Biol. Chem. Sci. 12(1): 24-42, February 2018

ISSN 1997-342X (Online), ISSN 1991-8631 (Print)

International Journal of Biological and Chemical Sciences

Original Paper http://ajol.info/index.php/ijbcs http://indexmedicus.afro.who.int

Vulnerability of *Khaya senegalensis* Desr & Juss to climate change and to the invasion of *Hypsipyla robusta* Moore in Benin (West Africa)

Akotchiffor Kévin Géoffroy DJOTAN*, Augustin Kossi Nounangnon AOUDJI, Donald Romaric Yehouenou TESSI, Sunday Berlioz KAKPO, Alain Jaurès GBÈTOHO, Koura KOUROUMA and Jean Cossi GANGLO

Laboratoire des Sciences Forestières, Faculté des Sciences Agronomiques, Université d'Abomey-Calavi. BP: 1493 Calavi, Bénin.
**Corresponding author; E-mail: geoffroydjotan@yahoo.fr; Tel: 0022995475392*

ACKNOWLEDGMENTS

This work is a contribution to the achievement of data use in the framework of the Biodiversity Information for Development (BID) projects funded by the European Union and facilitated by the Global Biodiversity Information Facility (GBIF).

ABSTRACT

Khaya senegalensis Desr & Juss is an urban tree species with high quality wood, unfortunately disturbed by *Hypsipyla robusta* Moore. However, how vulnerable this species is with regard to climate change and to *Hypsipyla robusta* over time and space is unknown. This study aimed at assessing as well the climate change impacts on both species as the overlapping extent of their suitable areas over time and space. To this end, the MaxEnt approach for Ecological Niche Modelling was used to compute suitable areas for both species under current and future climates (Africlim RCP 4.5 and RCP 8.5). Spatio-temporal Analysis was performed using Geographic Information System. Upon 2055, climate change will impact negatively 15-16% of Benin while the positive impacts will account only for 2-3%, and the stable areas will represent 74-75%. As for *Hypsipyla robusta*, climate change will provide only habitat loss of about 66% of the country. So, many plantation sites are exposed to biological attack from the pest, but wouldn't be more in future, giving hope for *Khaya senegalensis'* high quality wood production. Meanwhile, there will be an ecological imbalance due to the drastic potential habitat loss for the insect.

Keywords: *Khaya senegalensis*, Forest pests, Wood quality, Ecological modelling.

INTRODUCTION

Life on Earth without natural resources is quite impossible (Pamlin and Armstrong, 2015). However, threats on these natural resources nowadays are numerous, huge, and likely to threaten human's life itself (Myers et al., 2009). The sources of the threats are mainly twofold, anthropic causes and global changes causes. These factors together are combining to magnify threats on both resources and human security (Myers et al., 2009; Bello et al., 2017). *Khaya senegalensis*

DOI : https://dx.doi.org/10.4314/ijbcs.v12i1.3

Desr & Juss is one of the species exposed to anthropic pressure (Houehanou et al., 2013) because of its multi-uses that benefit people (Sokpon and Ouinsavi, 2002).

The wood of *Khaya senegalensis* is of high quality (Sokpon et al., 2004) and is selectively harvested (Glèlè Kakaï and Sinsin, 2009). According to Botha et al. (2004), these pressures on the species may expose it to threats. *Khaya senegalensis*, a West African's urban tree (Orwa et al. 2009), plays important roles in the livelihoods of hundreds of millions of rural and urban peoples across the globe (Emanuel et al., 2005). So, the species is greatly harvested by Fulani herders across the country for fodder (Gaoue and Ticktin, 2016).

Modelling of 5197 tree species using the Hadley Center's third generation coupled ocean-atmosphere General Circulation Model predicted the diminution of the repartition areas for about 81%-97% of the 5197 African tree species (McClean et al., 2005). So, *Khaya senegalensis* is also likely to be exposed to the impacts of climate change on some ways. The same species is expected to be exposed to higher rates of insect attack and mortality (Botha et al., 2004). Most of these attacks come from *Hypsipyla robusta* Moore (Sokpon and Ouinsavi, 2004). A recent study found that insects develop resistance to pesticide and that it is also difficult to access adequate materials to handle and apply those pesticides (Agboyi et al., 2015). It is therefore urgent to seek for practical ways to conserve and manage sustainably this resource.

Methods for characterizing environmental requirements of species have been used over the past two decades, to anticipate species' distributional potential in novel regions or under scenarios of environmental change (Owens et al., 2013). Known globally as Biodiversity Informatics, the domain of computation is helping transversally many scientists from many fields all over the world. Its use (Gbesso et al., 2013; Saliou et al., 2014) provided huge importance in conservation and sustainable management of natural resources.

Through those methods and the relation between *Khaya senegalensis* tree and its harsh driller *Hypsipyla robusta*, this study aimed at assessing how vulnerable *Khaya senegalensis* is with regard to climate change and to *Hypsipyla robusta* over time and space in West Africa and particularly in Benin. It then intended to assess as well the climate change impacts on both species as the overlapping extent of their suitable areas over time and space.

MATERIALS AND METHODS

Study areas and species

K. senegalensis is one of the most important tree species in the Meliaceae family in West Africa. It grows up to 30 m high and 3 m girth, with a dense crown and short bole covered with dark grey scaly bark (Burkill, 2004). The bark is bitter and gum can flow from it when it is wounded. It is a semi deciduous tree that doesn't tolerate shade (Sokpon and Ouinsavi, 2002). *K. senegalensis* is found in various vegetation types, including gallery forest, dry dense forest, woodland forest, and savannah and in both the Sudano-Guinean and the Sudanian ecological regions of Benin (Sokpon and Ouinsavi, 2002). Used in urban planning in Benin, the stems of the species are being devoid of their bark and leaves. The species is greatly believed for its numerous medicinal uses, and is known to be used ethno medicinally as a therapy for several human and animal disorders (Nacoulma-Ouedraogo, 2008). Sokpon and Ouinsavi (2002) identified 55 diseases that can be treated by *Khaya senegalensis*, showing them how great its importance is in pharmacy or medicine for people's health, and ethnobotany.

Hypsipyla robusta is an insect species in the Pyralidae family. It is a harsh driller of *Khaya senegalensis*' wood (Sokpon and Ouinsavi, 2004). Specifically, with shoot-borer activity, it is apparently restricted in its feeding to plants belonging to the family Meliaceae (Griffiths, 2001). The distribution of the mahogany shoot borer coincides with that of its principal host plant species (Griffiths 2001). The two most important *Hypsipyla* species with respect to shoot borer activity are *H. grandella* (Zeller) occurring in the Americas, and *H. robusta* Moore, occurring through areas of Africa and the Asia/Pacific region (Griffiths, 2001).

Data collection

We collected occurrence data of *Khaya senegalensis* and *Hypsipyla robusta* on GBIF site (www.gbif.org). These downloads can always be viewed on http://www.gbif.org/occurrence/download/0003585-160526112335914 and on http://www.gbif.org/occurrence/download/0003589-160526112335914. Present data for *H. robusta* was completed with documentation. We had also downloaded present bioclimatic variables data (1950 à 2000) on https://webfiles.york.ac.uk/KITE/AfriClim/GeoTIFF_150s/baseline_worldclim/ (Platts et al., 2015) at the resolution 2.5 minutes (150s); format GeoTIFF at the extent of Africa. For projection in future, bioclimatic variables data are downloaded from AfriClim https://webfiles.york.ac.uk/KITE/AfriClim/GeoTIFF_150s/africlim_ensemble_v3_worldclim/ (Platts et al., 2015).

The file set used is the ensemble v3 worldclim. The Scenarios used are the Representative Concentration Pathways 4.5 that is realistic (Meinshausen et al., 2011), and the Representative Concentration Pathways 8.5 that is pessimistic (Meinshausen et al., 2011), by 2055.

Model fitting

Data have been appropriately cleaned using QGIS, Excel, Earth Explorer and Google Earth. Occurrence data served to define the geographical background as recommended by Acevedo et al. (2012). Environmental layers have been put in appropriate format. The maximum entropy species distribution model algorithm (MaxEnt, version 3.3.3k" Princeton University, Princeton, New Jersey, USA) was used to calculate the maximum entropy species distribution (Philips et al., 2006; Pearson et al., 2007). The default parameters as recommended by Dossou et al. (2016) have been used.

Statistical analysis

Statistics helped selecting variables that might be included in the model. Those statistics were twofold. First group of statistics were those computed by the modelling algorithm itself (MaxEnt). It includes the Jackknife chart, the Area Under the Curve (AUC) value, the response curves, and the threshold table (Elith et al., 2006). Second group of statistics include those we calculated ourselves. There were the computation of correlation table between variables using ENMTools (Warren et al., 2010), the computation of model evaluation criteria such as the True Skill Statistics -TSS- (Allouche et al., 2006), and the Partial ROC (Peterson et al., 2008). The choice of the variables was based on both groups of statistics with regard to the ecology of the species. Classification thresholds were selected in the table of threshold of MaxEnt outputs based on the objectives of our study.

Spatial analysis

The continuous maps of logistic probability distributions generated by MaxEnt were used to define the suitable areas, the degree of this suitability across the country, and the overlapping of studied species' suitable areas. Excel 2016 and QGIS Wien 2.16.3 were used to compute environmental preferences of the species for the six most important variables previously retained. The process was done both for *Khaya senegalensis* and *Hypsipyla robusta*. We overlaid the maps of suitability areas. The raster computations were based on the "10 percentile training presence" used by Fandohan et al. (2015) and the "Equal test sensitivity and specificity" used by Ganglo et al. (2017).

RESULTS

Khaya senegalensis

Model evaluations indicated that Model for *Khaya senegalensis* was robust and yielded predictions statistically significant, better than random. The training data AUC and the test data AUC were, with the selected variables respectively 0.930 and 0.974. The mean test data AUC was 0.903 and the standard deviation 0.048. The TSS was 0.76. As for Partial ROC evaluation method, all AUC ratios among 1000 replicates were well above 1.0, (1.12 and 1.81 being respectively the minimum and the maximum values).

That's for AUC ratio equal to 1.12; the model is significant with P-value less than 0.001. Those statistics indicated that the model showed excellent performance and was stable, and the model prediction was accurate. The distribution of the species in the landscape of interest is shown on Figure 1, indicating that both species showed good distribution pattern across that landscape.

Table 1 and Figure 2 give estimates of relative contributions of the environmental variables to the MaxEnt model. The isothermality (bio3 in 10 °C), the minimal temperature of the coolest month (bio6 in 10 °C), the annual temperature range (bio7 in 10 °C), the mean temperature of the coolest quarter (bio11 in 10 °C), the rainfall of the driest month (bio14 in mm), and the rainfall of the wettest quarter (bio16 in mm) were the variables that contributed the most to the models. Therefore, those variables control the distribution of the species. High temperatures in coolest quarter are unfavorable for *Khaya senegalensis* (Figure 19). It tolerates extremes values of isothermality and values between 57.5 °C and 67.5 °C are critical for the species (Figure 20). Figures 3, 4, 5, 6, 7 and 8 show respectively Partial ROC chart, spatial distribution of the species at present, projected distribution of the species at horizon 2055 under RCP4.5, projected distribution of the species at horizon 2055 under RCP8.5, the projected distribution of climate change impacts on the species at the horizon 2055 under RCP4.5, and the one under RCP8.5 with regard to climate changes.

The contribution table and the jackknife chart of regularized training gain (Table 1 and Figure 2) show the contribution of each of the six most contributing variables, and it came out that the mean temperature of the coolest quarter [Bio11] is very influent on the distribution of *Khaya senegalensis*. The receiver operating characteristic showed how well the training and test data AUCs are above 0.90 (Figure 3). The continuous probability maps range from 0 to 1, represented with colors ranging from red (0) to green (1). So, the more the area ranges toward green the more is this area projected suitable for the species (Figures 5, 6 and 7). For climate change impacts on the species, Figures 7 and 8 show stable areas in green, positive impact areas in violet, and negative impact areas in red.

Hypsipyla robusta

Model for *Hypsipyla robusta* was robust and generated predictions statistically significant, better than random. The training data AUC and the test data AUC are, with the selected variables respectively 0.902 and 0.880. The mean test data AUC is 0.856 and the standard deviation is 0.070. The TSS was 0.79. As for the Partial ROC, all AUC ratios among 1000 replicates were well above 1.0, (1.01 and 1.80 being respectively the minimum and the maximum values). That's for AUC ratio equal to 1.01; the model was significant with P-value less than 0.001. Those statistics showed that the model performed well, predicted accurately, and is stable.

Table 2 and Figure 9 give estimates of relative contributions of the environmental variables to the MaxEnt model. The most contributing variables were the mean annual temperature (bio1 in 10 °C), the minimal temperature of the coolest month (bio6 in 10 °C), the mean temperature of the coolest quarter (bio11 in 10 °C), the rainfall of the driest month (bio14 in mm), the rainfall of the wettest quarter (bio16 in mm), and the rainfall of the driest quarter (bio17 in mm). *Hypsipyla robusta* prefers high temperatures in coolest months (Figure 21) and needs a minimum of rainfall in driest quarter (Figure 22). Figures 10-15 show respectively Partial ROC chart, continuous suitability map of the current scenario, continuous suitability map for 2055 RCP4.5, continuous suitability map for 2055 RCP8.5, projected distribution of climate change impacts on the species by 2055 under RCP4, and projected distribution of climate change impacts on the species by 2055 under RCP4.5.

The contribution table and the jackknife chart of regularized training gain (Table 2 and Figure 9) show the contribution of each of the six most contributing variables, and it comes out that the mean temperature of the coolest month (bio6) is very influent on the distribution of *Hypsipyla robusta*. The receiver operating characteristic showed how well the training and test data AUCs are above 0.90 (Figure 10). The continuous probability maps range from 0 to 1, represented with colors ranging from red (0) to green (1). So, the more the area ranges toward green the more is this area projected suitable for the species (Figures 11, 12 and 13). For climate change impacts on the species, Figures 14 and 15 show stable areas in green, positive impact areas in violet, and negative impact areas in red.

Khaya senegalensis in interaction with *Hypsipyla robusta* over the time in the space

Khaya senegalensis and *Hypsipyla robusta* share four variables out of the six most contributing ones retained. Those variables are the minimal temperature of the coolest month (bio6 in 10 °C), the mean temperature of the coolest quarter (bio11 in 10 °C), the rainfall of the driest month (bio14 in mm), and the rainfall of the wettest quarter (bio16 in mm).

Taking into account the biotic factor consisting in the fact that *Hypsipyla robusta* is a harsh driller and shoot borer of *Khaya senegalensis*, in addition to abiotic factors, we got the maps of interaction results over the time and the space. Figures 16-18 show respectively the current overlaps between the two species, overlaps in 2055 RCP4.5, and overlaps in 2055 RCP8.5.

Overall models outputs analysis for Benin

Models revealed that *Khaya senegalensis* can occur currently in Benin. Projections in the 2055 showed that it can occur in the future with some areas left out and some gain. The loss was assessed at 15-16% of Benin superficies while the gain was 2-3% of the country's total area, and the stable areas were projected to be 74-75% of Benin's total areas. As for *Hypsipyla robusta*, it was shown to be likely to occur currently with high prevalence in southern Benin, and moderately in the other part of the country. Projections into the 2055s showed that the species ecological niche may be going to disappear from the country. This loss was estimated at 66% of the country's total area; no stable areas were predicted. Added to the environmental influence, biological interactions between *K. senegalensis* an *H. robusta* showed significant overlapping zones in current situations and almost no overlapping in future**,** where the driller and borer may harm the tree by destroying the quality of its wood.

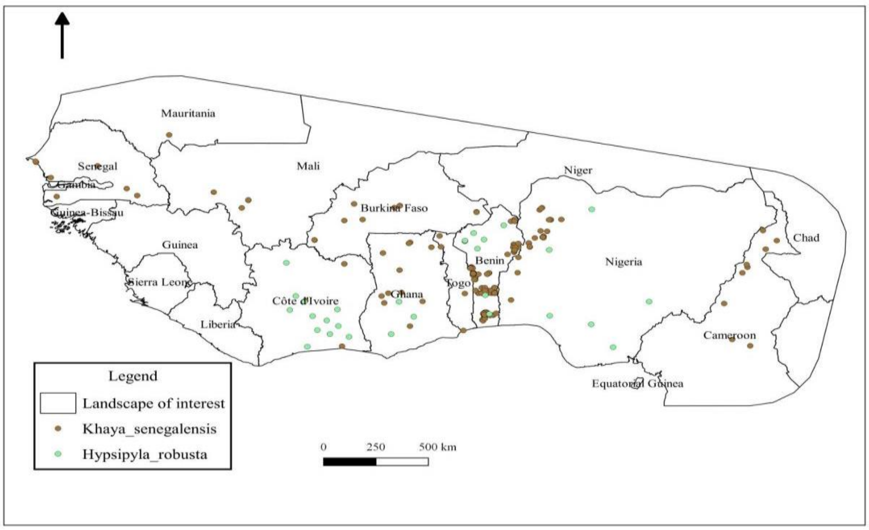

Figure 1: Spatial distribution of *Khaya senegalensis* and *Hypsipyla robusta* in the landscape of interest.

Table 1: Variables contribution.

Variable	Percent contribution	Permutation importance
Bio11	31.1	26.9
Bio3	20.8	21.7
Bio7	18.5	9.3
Bio6	10.7	14
Bio14	9.8	8.1
Bio16	9.2	20.1

Values are in percentages

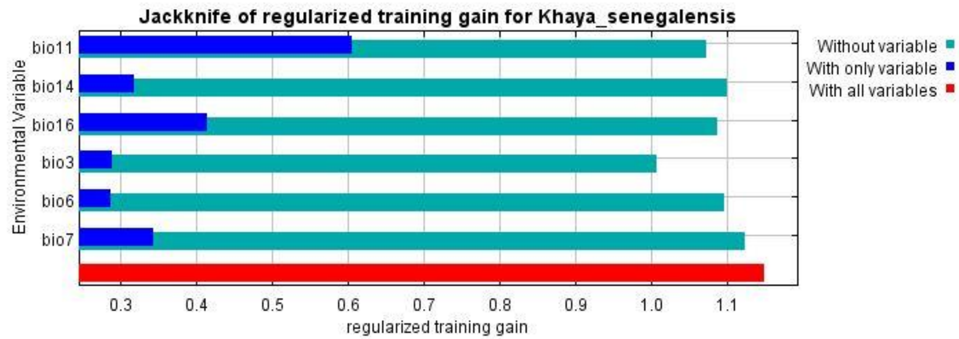

Figure 2: Jackknife of regularized training gain (*Khaya*).

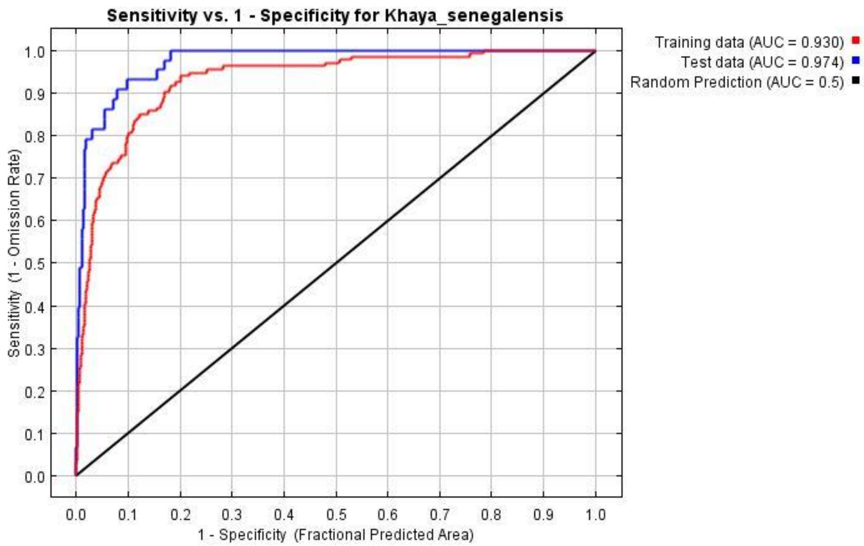

Figure 3: Receiver Operating Characteristic (*Khaya*).

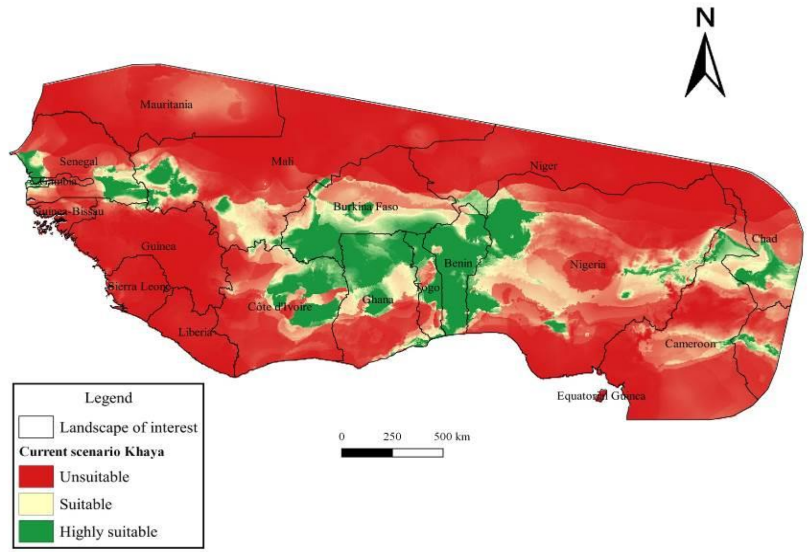

Figure 4: Spatial distribution of *Khaya senegalensis* under current climate.

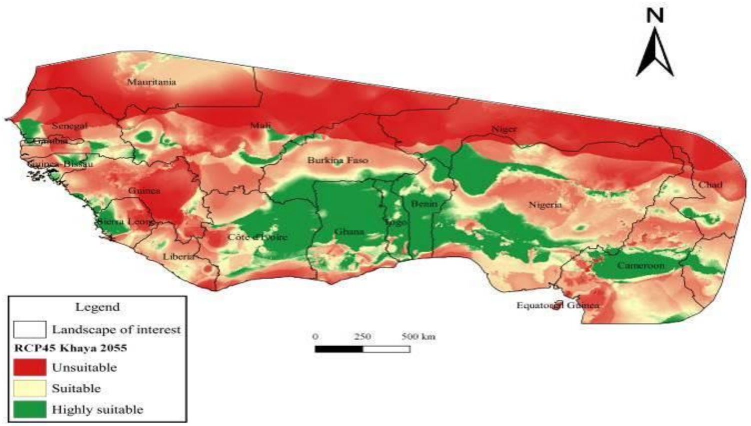

Figure 5: Projected distribution of the species by 2055 under RCP4.5 (*Khaya*).

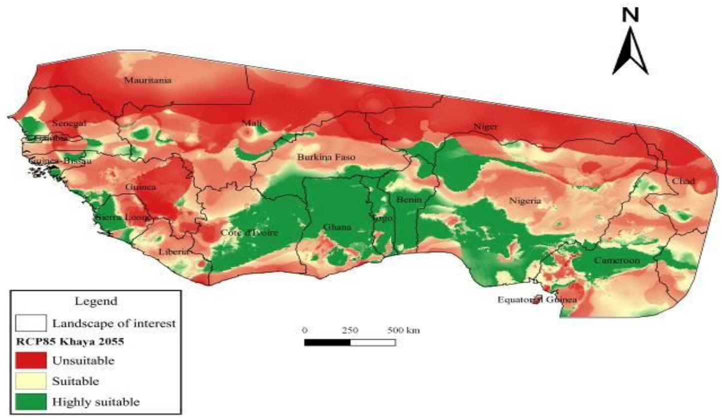

Figure 6: Projected distribution of the species by 2055 under RCP8.5RCP8.5 (*Khaya*).

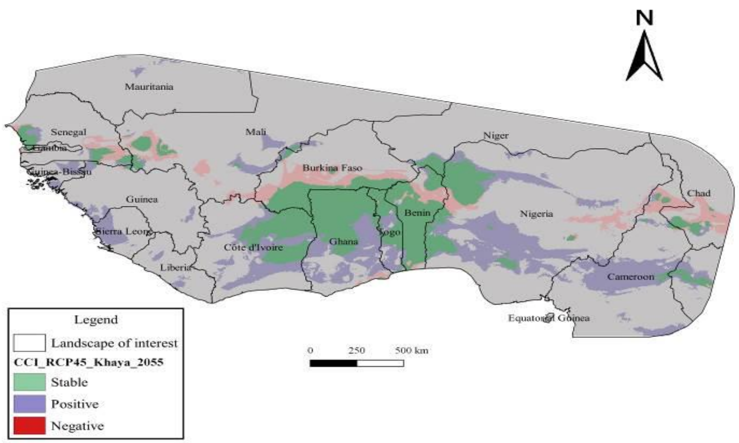

Figure 7: projected distribution of climate change impacts on the species by 2055 under RCP4.5 (*Khaya*).

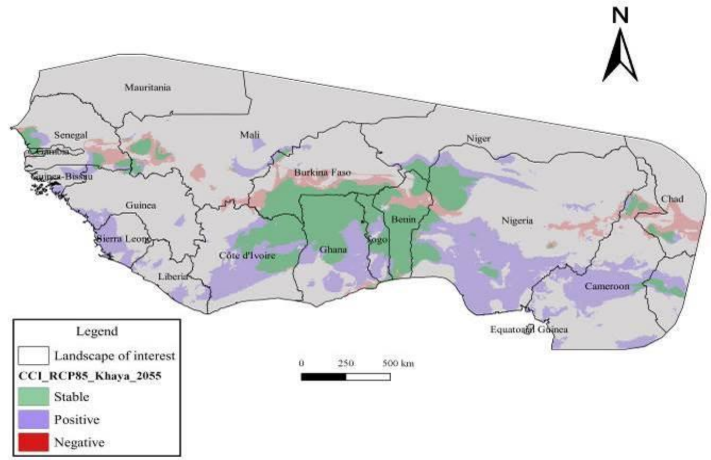

Figure 8: projected distribution of climate change impacts on the species by 2055 under RCP8.5 (*Khaya*).

Table 2. Variables contribution.

Variable	Percent contribution	Permutation importance
Bio6	40.2	16
Bio17	35	38.7
Bio11	15.5	17.5
Bio1	4.1	9.3
Bio14	2.7	8.1
Bio16	2.6	10.4
Values are in percentages		

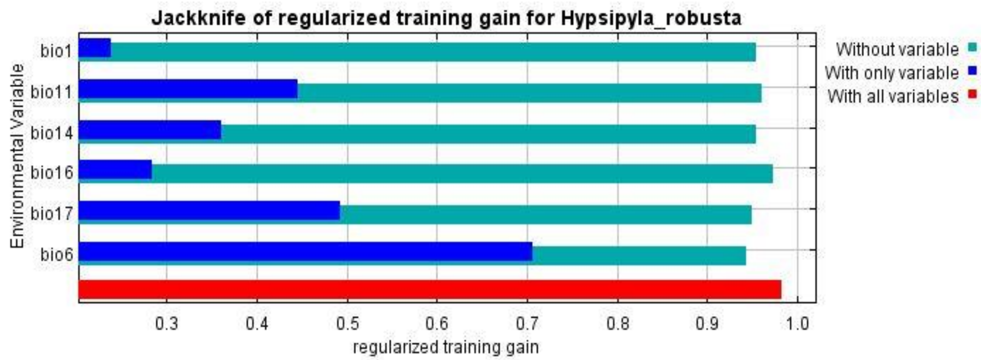

Figure 9: Jackknife of regularized training gain (*Hypsipyla*).

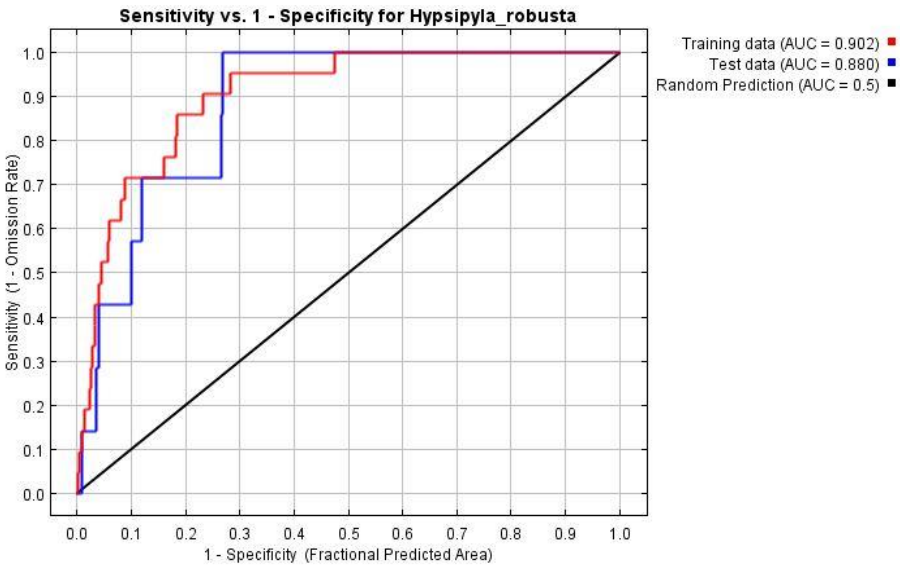

Figure 10: Receiver Operating Characteristic (*Hypsipyla*).

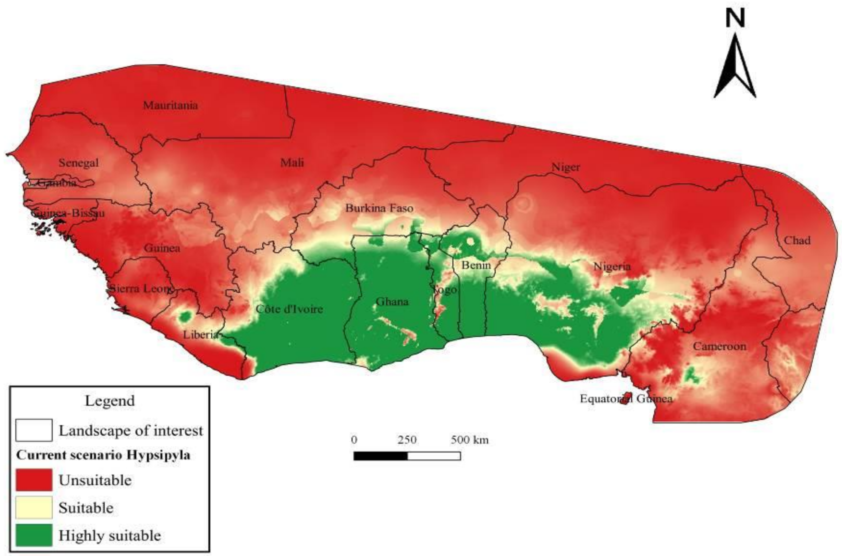

Figure 11: Distribution of *H. robusta* at present.

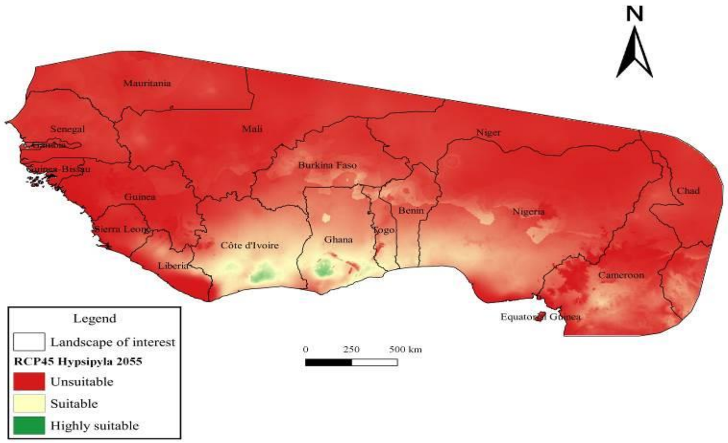

Figure 12: Projected distribution of *H. robusta* by 2055 under RCP4.5.

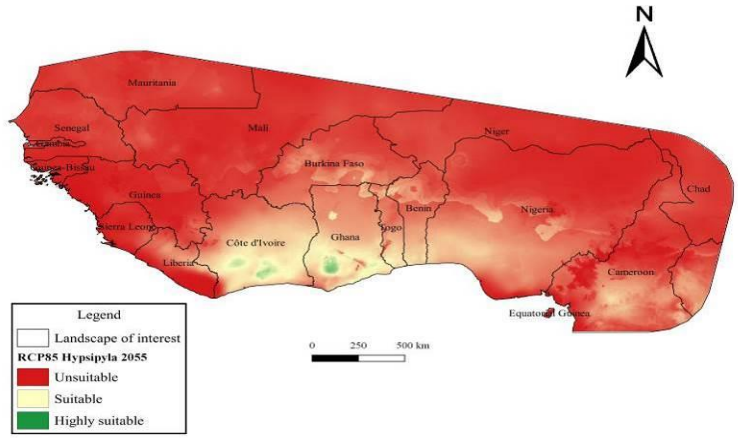

Figure 13: Projected distribution of *H. robusta* by 2055 under RCP8.5.

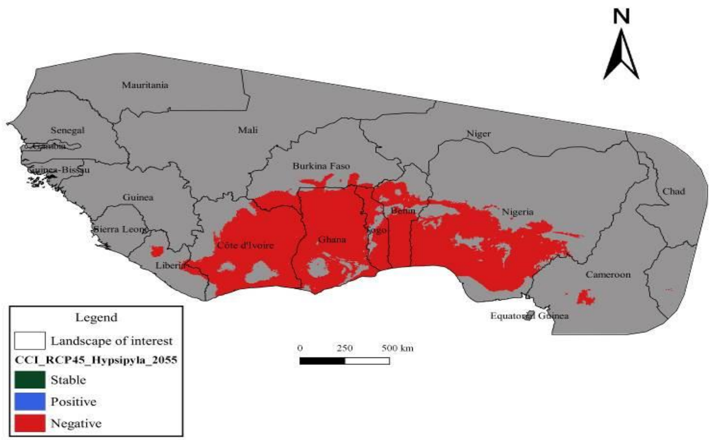

Figure 14: projected distribution of climate change impacts on the species by 2055 under RCP4.5 (*Hypsipyla*).

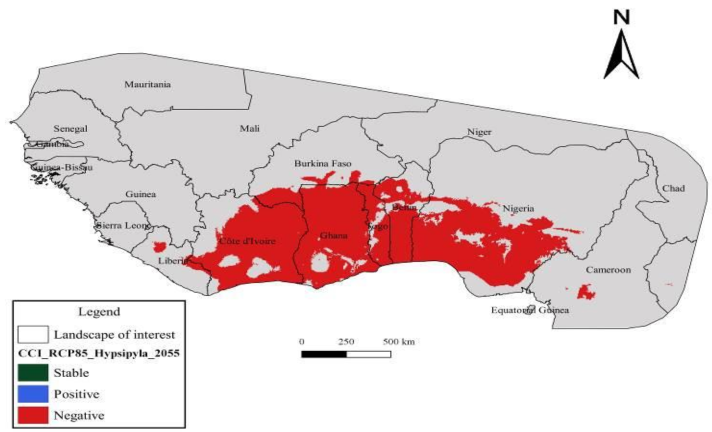

Figure 15: projected distribution of climate change impacts on the species by 2055 under RCP8.5 (*Hypsipyla*).

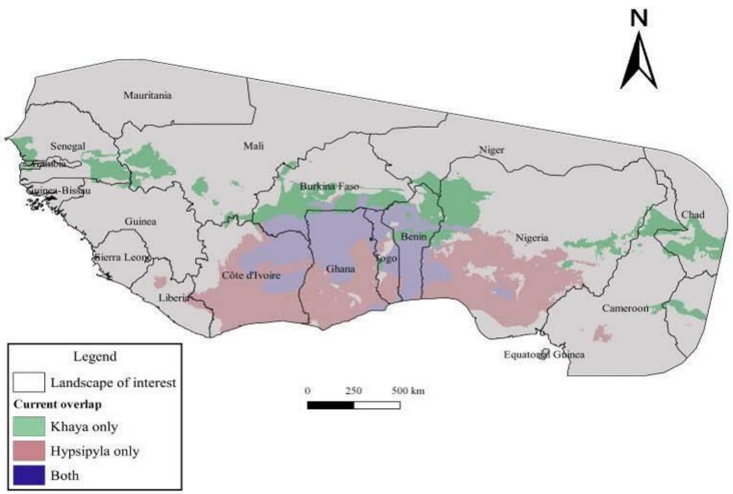

Figure 16: Current overlap (*Khaya* X *Hypsipyla*).

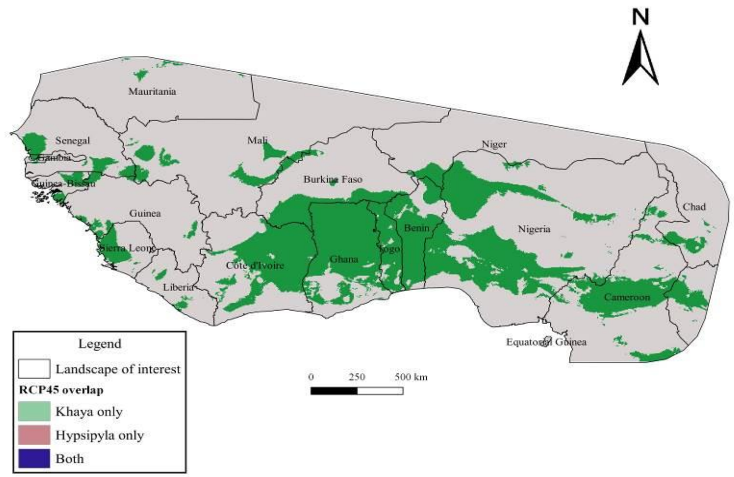

Figure 17: Overlap in 2055 RCP4.5 (*Khaya* X *Hypsipyla*).

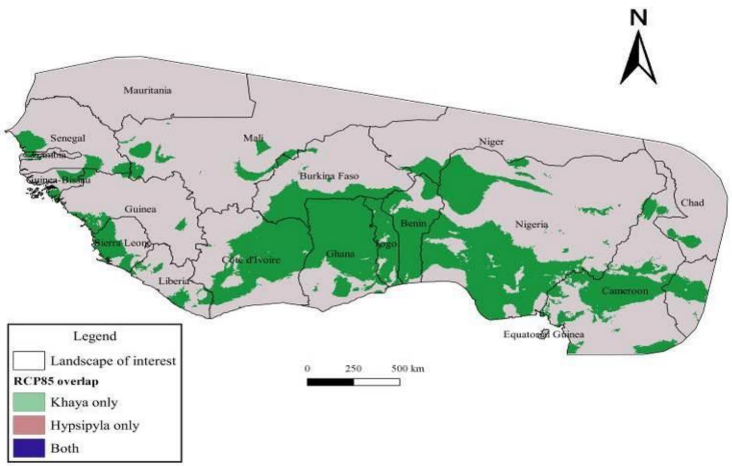

Figure 18: Overlap in 2055 RCP8.5 (*Khaya* X *Hypsipyla*).

For the overlaps maps, we defined following explained criteria in methods, three different types of areas. First, we computed areas where only *Khaya senegalensis* was projected to prosper (green color on the maps); secondly we calculated areas where only *Hypsipyla robusta* was projected to find its preference (red color on the maps), and finally areas where both species are likely to occur (violet on the maps).

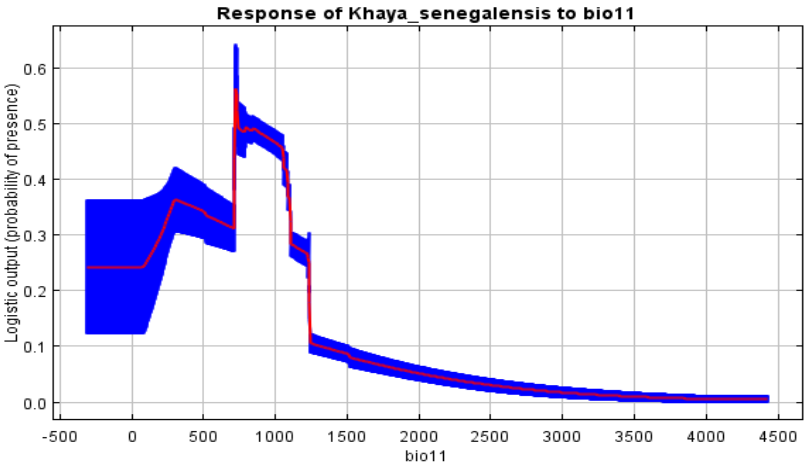

Figure 19: Response of *K. senegalensis* to the mean temperature of the coolest quarter.

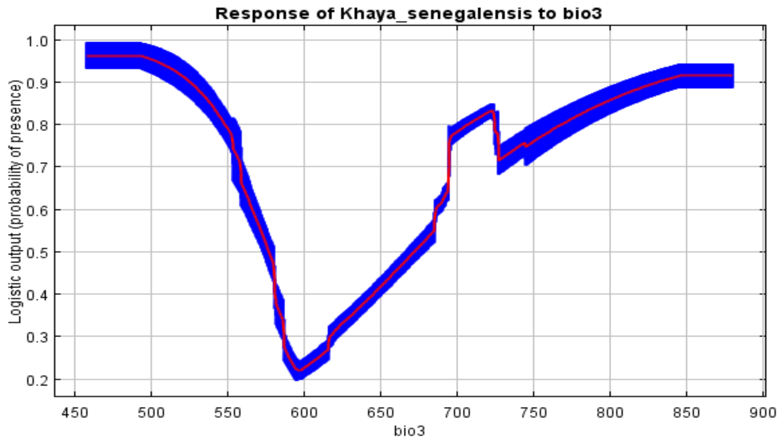

Figure 20: Response of *K. senegalensis* to isothermality.

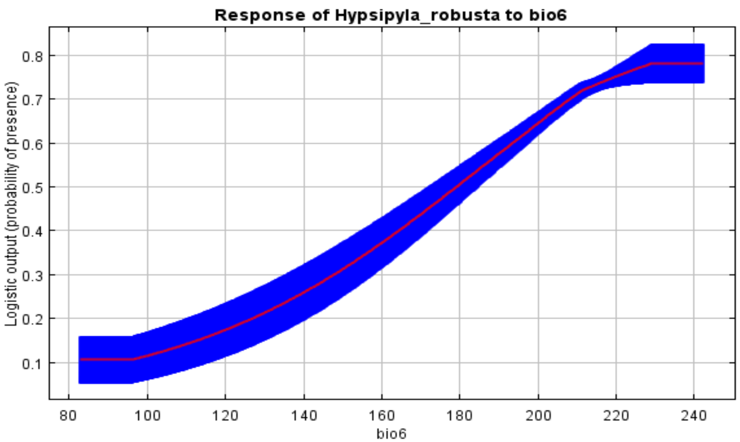

Figure 21: Response of *H. robusta* to mean temperature of the coolest month.

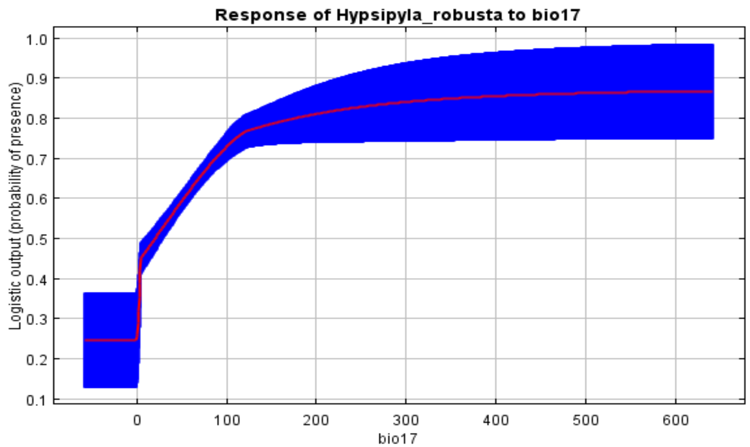

Figure 22: Response of *H. robusta* to the rainfall of the driest quarter.

DISCUSSION

Biodiversity informatics and applications

Many scientists (Pearson et al., 2006; Peterson et al., 2011; Gbesso et al., 2013; Saliou et al., 2014; Fadohan et al,, 2015; Ganglo and Kakpo, 2016; Idohou et al., 2016; Ganglo et al., 2017) used Geographical Information System, and Biodiversity Informatics to explore world resources issues. This is exactly what we did in the present study to present the impacts of climate changes on *Khaya senegalensis* and *Hypsipyla robusta*. Moreover, we considered the biological interaction between the two species in order to point out the impacts of the insect *Hypsipyla robusta,* which is a wood driller and shoot borer for *Khaya senegalensis*. Many scientists did such studies but few of them applied biodiversity informatics to the understanding of interactions between species. In instance, Usher (2010) modelled the malaria transmission potential (MTP) to find links between malaria transmission and climate and to use further scenarios to see if predicted climate change will affect the frequency and spread of malaria in West Africa and South Europe. That is to point out the application of this field of study in health and security related domains, and in biology. In Forestry and natural resources management, for example Fandohan et al. (2015) used Ecological Niche Modelling Tools to model vulnerability of protected areas to invasion by *Chromolaena odorata* under current and future climates. Such studies raise awareness of people on the dangers these resources are and will be exposed to, and give a range of solutions according to the obtained results, on the conservation of concerned resources. Similarly, our study was not only an application of Biodiversity Informatics to assess climate change impacts on biological resources, but also an application to forest pest management for the production of high quality forest biomaterials.

Climate changes impacts on *Khaya senegalensis*

The Beninese districts that do not meet fully *Khaya senegalensis*' environmental preferences were Karimama, Banikoara, Natitingou, Dangbo, So-ava, Semè-Kpodji, Adjara, Ifangni, Aplahoué, and Djakotomey. Some spots in Gogounou, Segbana and Djidja were not suitable. However the species could grow since the suitability value is not null, and the tree is not too exigent, and is considered dry areas savanna mahogany tree (Nikiema et al., 2008). Kandi is shown highly suitable for *Khaya*, this shows the evidence that the model does well the job because there is a plantation of *Khaya* in this urban district (Sokpon et al., 2004). Natitingou holds plantations of *Khaya* too, precisely in *Birni, Kouaba, Kouandé,* and *Tanguiéta* (Sokpon et al., 2004) where the suitability value is not null, and confirms the fact that since the probability is not null added to the tolerance of the species, the latter could grow. It is important to add that the soil could have been suitable for the establishment of *Khaya*'s plantations in the North part of the country. Those planted in *Atchérigbé* and in *Toffo* are in the highly favorable zone of the species. Particular areas in southern Benin where the species have low prevalence such as urban districts of *So-Ava, Dangbo, Adjara, Seme-Kpodji,* and *Ifangni* deserve further investigation, but we assume that it is due to the soil properties. Overall, the model revealed what we can observe currently in Benin where there are successful plantations of the species from the south to the north in *Toffo, Atchérigbé, Birni, Kouaba, Kouandé, Tanguiéta* and *Kandi* (Sokpon et al., 2004). Then, it is very important to point out that Benin is a relatively good ecosystem for the species, specifically from the North to the South of the country. Moreover, Nikiema and Pasternak (2008) in their study dedicated to the species gave a range of a zone including the whole Benin.

Climate changes are in favor of *Khaya senegalensis* occurrence in some areas and unfavorable for it in others. Idohou et al. (2016) found similar results of climate changes on wild palms in West Africa when they stated that much of the distribution of the wild palms will remain largely stable, albeit with some expansion and retraction in some species. Similarly to our findings, Gbesso et al. (2013) found that climate change could be an opportunity for a long term conservation of a species, in their case *Chrysophyllum albidum* G. Don. The realistic (RCP4.5) and the pessimistic (RCP8.5) scenarios showed approximately the same results. The significantly positive impacts zone accounts for 3% (RCP4.5) and 2% (RCP8.5) of Benin area, while the significantly negative impacts zone accounts for 15% (RCP4.5) and 16% (RCP8.5). 75% and 74% of national area are projected to be stable according respectively to RCP4.5 and RCP8.5. These results confirmed shifts and the negative impacts of climates changes on natural resources many authors wrote about (McClean et al., 2005; Alig, 2011). As our results showed, shifts in the distributions of species with climate change have now been documented for many species (Rosenzweig et al., 2008) and many more are expected to shift with future climate change. Unfortunately, few of them point out that the climate changes could be benefic somehow. It is important to transform the climate threats into opportunity in favor of natural resources. The only way to achieve this is to stand up earlier and assess the vulnerability of climate changes on these resources over time and space. Anticipating likely effects of climate changes on species distribution (Peterson et al., 2011) and transfer of model predictions to novel regions and/or time periods (Pearson et al., 2006) will make of changes, great opportunities to solve the world natural resources issue. In instance, through this study, we know where changes are in favor of *Khaya senegalensis* growth, so further actions toward the conservation of this species should be directed to these areas, and meanwhile, areas shown to be less suitable than former could be used for another species. As each species could be object of spatial analysis for plants prosperity in the time, biodiversity informatics through ecological niche modelling using MaxEnt can provide highly informative biogeographical information and discrimination of suitable vs. unsuitable areas for a species (Philips et al. 2006). Such information should be used appropriately for decision making concerning natural resources. Despite the well-recognized conceptual ambiguities and uncertainties about bioclimatic envelope modeling (Schwartz, 2012), MaxEnt remains a practical tool that allows assessment of the potential impact of climate changes on the distribution of suitable habitats of plants and animals (Elith et al., 2010). However, we are eager to remind that ecological niche modelling results have to be interpreted carefully. That is, it can happen to meet *Khaya senegalensis* at a place not predicted to hold it.

Climate changes impacts on *Hypsipyla robusta* occurrence over time and space

Hypsipyla robusta depends mostly on the minimal temperature of the coolest month and the rainfall of driest quarter (Figures 21 and 22). The southern part of Benin, from the coastal limit to the latitude of Parakou is highly exposed under the current scenario to the occurrence of *Hypsipyla robusta*. The species still has a chance to appear beyond this latitude but the environmental conditions will be limiting outside Tanguieta, Kobli, Materi, Kerou, Kouande, Pehonco and Bembèrèkè. According to Griffiths (2001), *Hypsipyla robusta* is likely to occur in Tanzania, Madagascar and in West Africa. Our results confirm theirs on the points that the prevalence of this species as shown by our model is very high in Southern Benin and moderate across the Northern Benin, and then the country is supposed exposed to presence of the species. This presence could be driven by the suitability of the areas to its host plant *Khaya senegalensis* since it is apparently limited in feeding on Meliaceae trees. We are also eager to recap that living form develop many aptitudes to adapt new environmental situations, mainly animals. For these reasons we recommend that our results be used with the greatest fitness, and therefore should be considered with close attention.

Hypsipyla robusta will face upon 2055, a severe regression of its climatic envelop. Here, even if this study considered *Hypsipyla* as a pathogen for *Khaya*, on the view of biodiversity conservation, it is important to point out that *Hypsipyla robusta* is going to disappear from Benin by 2055 according to our projections. It could create biological and ecological disasters since the insect is an element of the ecological supply chain. Both scenarios gave approximately the same results. There won't be any significantly positive impact zone for the species in Benin upon 2055s; the significantly negative impacts zone will account for 66% regardless the RCP. Any area does not save significant positive impacts for the species. Climate variability doesn't provide only negative effects on natural resources (Rosenzweig et al., 2008) but our findings on *Hypsipyla robusta* in West Africa in general and especially in Benin indicated that climate change could have only negative impacts on a species. Hounkpèvi et al. (2016) found that climate changes will make *Vitex doniana* distribution increases about 14 to 23% in the Protected Area Network of Benin by 2050, but the contrary shift is going to be observed for *Hypsipyla robusta* by 2055. In fact, *Hypsipyla robusta*, seen as natural resource will suffer from these changes. However, a forester who is willing to settle plantation of *Khaya senegalensis* will consider that the future climatic conditions provide best conditions for his business.

Biological interactions between *Khaya senegalensis* and *Hypsipyla robusta*

Here, it is not a competition between the two species; instead it is a parasitism from *Hypsipyla*. This parasitism destroys the quality of the wood of *Khaya senegalensis*. Each species has its suitability areas according to models. It emerges from the overlapping that at present, a large part of Benin is suitable for both species. Those areas may not guaranty a production of high quality wood of *Khaya senegalensis*. Meanwhile, some urban districts contain some areas where only *Khaya senegalensis* was projected to prosper. Those areas are within Malanville, Segbana, Kandi, Gogounou, Kalalé, Nikki, Prèrè, Djougou, Kopargo, Ouaké and Kérou. Conservation and production of high quality wood of *Khaya senegalensis* could succeed on these sites. A projection in the 2055s showed for both scenarios (RCP4.5 and RCP8.5) that almost no more areas will be available for *Hypsipyla robusta*, and then we can produce *Khaya senegalensis* easily in suitable areas as projected through the two RCPs. However, we need to be precautious because of the complexity of living forms. The production of *Khaya senegalensis* with high quality wood will be difficult if the extent of its pathogen's geographical preferences is widespread. Sokpon et al. (2004) stated that *Hypsipyla robusta* is a harsh driller of wood of *K. senegalensis*, in the plantations of this species. Several authors claimed how redoubtable *Hypsipyla robusta* is for *Khaya senegalensis* in the sub-region in Togo, Ghana, Ivory-Coast, Nigeria, Burkina-Faso (Opuni-Frimpong, 2012; Sokpon and Ouinsavi, 2004). Some recent studies reported similar problems between pests and tree species other than *Hypsipyla robusta* and *Khaya senegalensis*. Agboyi et al. (2015) reported the resistance of pests to pesticides in Togo and the higher cost in handling and application of the pesticides. Those authors recommended integrated pest management to face similar issues. Our findings are likely to ease the implementation of their recommendations. Results of this study gave us hope that the future will be better for *Khaya senegalensis*.

Perspectives for *Khaya senegalensis* conservation

Climate changes and *Hypsipyla robusta* environmental requirements are acting together against the prosperity of *Khaya senegalensis*. This tree is the quickest growing urban tree among local species of great value (Onefeli et al., 2014). It is very important to conserve the species through specific approaches according to the threats that are threefold: human pressure, climate changes, and *Hypsipyla* attack. There are little actions to avoid human pressure on *Khaya senegalensis*. So, what we suggest is to promote the trees plantation across the country. These plantations have to be settled in protected areas projected to be favorable despite the biological attack by the 2055s. Protected areas located in these suitable areas may be chosen for upgrading with the species. As *K. senegalensis* is an urban tree, the building plans in the country may make use of this aspect of urbanization. As stated, we suggest that the Government orders road builders to plant the species along the roads. It could also be a goal for mayors in their districts. Many showed signaled negative impacts of *H. robusta* in the plantation of *K. senegalensis*, and many approaches and technics of production have been used to reduce these impacts. Under some conditions such as growing in natural forests at low densities, in association with other species, or in open space the likelihood of *Hypsipyla robusta* attack is decreased (Howard et Michael, 2014). It is then worth on one side considering our spatial analysis results for plantations of Meliaceae in addition to the use of wide spacing, partial shading and control of competing vegetation in mixtures with non-susceptible species in groups or lines with less than 100 trees per hectare. On the other hand, it is interesting that research continues in finding silvicultural technics toward considerable reduction of *Khaya* attack from *Hypsipyla* (Grogan et al., 2002).

Attempts to control pests using conventional insecticides are common, and chemical control may become useful in extreme circumstances although its scope for large-scale application under operational conditions is limited (Agboyi et al., 2015). A pest may have natural enemies, and many of the naturally occurring parasites can limit the pest population to some extent (Agboyi et al., 2015). However, it has been reported by Nair (2001) that innate biological attributes of the insects associated to the trees and monoculture are some of factors that rise insect pest outbreaks. Moreover, Wylie (2001) reported that there is no single reliable, cost-effective, and environmentally sound chemical pesticide available to control *Hypsypila robusta*. So, despite a great number of natural enemy that a pest could has, biological control could neither be enough, nor could chemical control be, and silvicultural control to stop its attack on its host. However, Blach-Overgaad et al. (2010) and Bowe and Haq (2010) recognized that recommendation for management of threatened species, agroforestry species, pests, and invasive species can be based on Ecological Niche Modelling. Then, integrated approaches where spatial analyses are performed will certainly be better.

Conclusion

As demonstrated by the present study, biodiversity informatics has broad application and is very helpful in decision making about conservation and natural resources management. We pointed out above that *Khaya senegalensis* is very exposed to climate changes, to biological attack from *Hypsipyla robusta*, its harsh driller, and shoot borer in West Africa in general and particularly in Benin. We also showed that *Hypsipyla robusta* is going to disappear by 2055 due to climate changes. Details can be obtained from our results on the urban districts, even cities where future situations are unfavorable for the two species including where the species can be actually grown successfully, and provide eventually areas where *H. robusta* may be a problem for *K. senegalensis*. Meaningfully we provided information on high quality wood production. Because *Khaya senegalensis* is a threatened species due to its uses, we recommend further research on it to participate actively to its sustainable management. Description of damages pattern and the economics of forest pest invasion are some future research questions.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

AKGD and JCG were first, in charge of data collection, their processing and analysis. Secondly, they wrote the manuscript. The other authors contributed in the redaction and the revision of the manuscript.

ACKNOWLEDGMENTS

We address our sincere gratitude to Professor Town A. Peterson of the University of Kansas and his team. We also thank Lizanne Roxburgh of Endangered Wildlife Trust who trained us in ecological niche modelling.

REFERENCES

Acevedo P, Jiménez-Valverde A, Lobo JM, Real R. 2012. Delimiting the geographical background in species distribution modelling. *Journal of Biogeography,* **39**: 1383–1390. DOI:10.1111/j.1365-2699.2012. 02713.x

Agboyi LK, Djade KM, Ahadji-Dabla KM, Ketoh GK, Nuto Y, Glitho IA. 2015. Vegetable production in Togo and potential impact of pesticide use practices on the environment. *Int. J. Biol. Chem. Sci.,* **9**(2): 723-736. DOI: http://dx.doi.org/10.4314/ijbcs.v9i2.13

Alig RJ, tech. coord. 2011. Effects of climate change on natural resources and communities: a compendium of briefing papers. Gen. Tech. Rep. PNWGTR-837. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 169 p.

Allouche O, Tsoar A, Kadmon R. 2006. Assessing the accuracy of species distribution models: prevalence, kappa and the true skill statistic (TSS). *Journal of Applied Ecology,* **43**: 1223-1232. DOI: http://dx.doi.org/10.1111/j.1365-2664.2006.01214.x

Bello DO, Ahoton LE, Saidou A, Akponikpè IPB, Ezin VA, Balogoun I, Aho N. 2017. Climate change and cashew (*Anacardium occidentale* L.) productivity in Benin (West Africa): perceptions and endogenous measures of adaptation. *Int. J. Biol. Chem. Sci*., **11**(3): 924-946.

Blach-Overgaard A, Svenning J-C, Dransfield J, Greve M, Balslev H. 2010. Determinants of palm species distributions across Africa: the relative roles of climate, non-climatic environmental factors, and spatial constraints. *Ecography*, **33**: 380-391. DOI: 10.1111/j.1600-0587.2010.06273.x

Botha J, Witkowski, ETF, Shackleton CM. 2004. The impact of commercial harvesting on *Waburgia salutaris* ('pepper-bark tree') in Mpumalanga South Africa. *Biodiversity and Conservation* **13**(9): 1675–1698. DOI: https://doi.org/10.1023/B:BIOC.0000029 333.72945.b0

Bowe C, Haq N. 2010. Quantifying the global environmental niche of an underutilised tropical fruit tree (*Tamarindus indica*) using herbarium records. *Agriculture Ecosystems and Environment*, **139**: 51-58. DOI: https://doi.org/10.1016/j.agee. 2010.06.016

Burkill HM. 2004. *The useful Plants of West Tropical Africa* (vol 2, edn 2): Families E-I 1994 No. Royal Botanic Gardens: Kew; 648. Http://www.aluka.org/

Elith J, Graham CH, Anderson RP, Dudık M, Ferrier S, Guisan A, Hijmans RJ, Huettmann F, Leathwick JR, Lehmann A, Li J, Lohmann LG, Loiselle BA, Manion G, Moritz C, Nakamura M, Nakazawa Y, Overton JM, Peterson AT, Phillips SJ, Richardson K, Scachetti-Pereira R, Schapire RE, Soberon J, Williams S, Wisz MS, Zimmermann NE. 2006. Novel methods improve prediction of species' distributions from occurrence data. *Ecography*, **29**: 129-151, 2006.

Elith J, Kearney M, Philips S. 2010. The art of modeling range-shifting species. *Methods in Ecology and Evolution*, **1**: 330–342. DOI: 10.1111/j.2041-210X.2010.00036.x

Emanuel PL, Shackleton CM, Baxter JS. 2005. Modelling the sustainable harvest of *Sclerocarya birrea* subsp. caffra fruits in the South African lowveld. *Forest Ecology and Management*, **214**: 91–103. DOI: https://doi.org/10.1016/j.foreco. 2005.03.066

Fandohan AB, Oduor AMO, Sodé AI, Wu L, Cuni-Sanchez A, Assédé E, Gouwakinnou GN. 2015. Modeling vulnerability of protected areas to invasion by *Chromolaena odorata* under current and future climates. *Ecosystem Health and Sustainability*, **1**(6): 20. DOI: http://dx.doi.org/10.1890/EHS15-0003.1.

Ganglo CJ, Kakpo SB. 2016. Completeness of digital accessible knowledge of plants of Benin and priorities for future inventory and data discovery. *Biodiversity Informatics*, **11**: 23-39. DOI: https://doi.org/10.17161/bi.v11i0.5053

Ganglo JC, Djotan GK, Gbètoho JA, Kakpo SB, Aoudji AKN, Koura K, Tessi DRY. 2017. Ecological niche modeling and strategies for the conservation of *Dialium guineense* Willd. (Black velvet) in West Africa. *Int. J. Biodivers. Conserv.*, 9(12): 373-388. DOI: 10.5897/IJBC 2017.1151.

Gaoue OG, Ticktin T. 2016. Fulani Knowledge of the Ecological Impacts of *Khaya senegalensis* (Meliaceae) Foliage Harvest in Benin and its Implications for Sustainable Harvest. *Economic Botany* **63**: 256-270 DOI: 10.1007/s12231-009-9091-6.

Gbesso FHG, Tente BHA, Gouwakinnou NG, Sinsin BA, 2013. Influence des changements climatiques sur la distribution géographique de Chrysophyllum albidum G. Don (Sapotaceae) au Benin. *Int. J. Biol. Chem. Sci*., **7**(5): 2007-2018. DOI: http://dx.doi.org/10.4314/ijbcs.v7i5.18

GBIF.org (6th June 2016) GBIF Occurrence Download DOI: http://doi.org/10.15468/dl.is3mds

GBIF.org (6th June 2016) GBIF Occurrence Download DOI: http://doi.org/10.15468/dl.k0adsn

Glèlè Kakaï R, Sinsin B. 2009. Structural description of two *Isoberlinia* dominated communities in the Wari-Maro forest reserve (Benin). *South African Journal of Botany,* **75**(1): 43–51.

Griffiths MW. 2001. The biology and ecology of *Hypsipyla* shoot borers. In *International Workshop on Hypsipyla shoot borers in Meliaceae*, Floyd RB, Hauxwell C (eds.), 20-23 August 1996. ACIAR Proceedings No. 97, pp. 74-80.

Grogan J, Barreto P, Veríssimo A. 2002. *Mahogany in the Brazilian Amazon: Ecology and Perspectives on Management.* David Lubin Memorial Library, Food and Agriculture Organization of the U.N.

Houehanou TD, Assogbadjo AE, Glele Kakaï R, Kyndt T, Houinato M, Sinsin B. 2013. How far a protected area contributes to conserve habitat species composition and population structure of endangered African tree species (Benin, West Africa). *Ecol. Complex*, **13**: 60-68. DOI: http://dx.doi.org/10.1016/j.ecocom.2013.01.002

Hounkpèvi A, Tosso F, Gbèmavo DSJC, Kouassi EK, Koné D, Glèlè Kakaï R. 2016. Climate and potential habitat suitability for cultivation and in situ conservation of the black plum (*Vitex doniana* Sweet) in Benin, West Africa. *Int. J. Agri. Agri. R*., **8**: 67-80.

Howard FW, Michael AM. 2014. *Hypsipyla grandella* (Zeller) (Insecta: Lepidoptera: Pyralidae: Phycitinae). Internet record from UF/IFAS University of Florida, Institute of Foods and Agricultural Science,

Idohou R, Assogbadjo AE, Glèlè-Kakaï R, Peterson AT. 2016. Spatio-temporal dynamic of suitable areas for species conservation in West Africa: eight economically important wild palms under present and future climates. *Agroforest Syst.*, **90**(3): DOI 10.1007/s10457-016-9955-6

Keay RWJ. 1989. *Tree of Nigeria*. Clarendon Press: Oxford.

McClean CJ, Lovett JC, Küper W, Hannah L, Sommer JH, Barthlott W, Termansen M, Smith GF, Tokumine S, Taplin JRD. 2005. African plant diversity and climate change. *Annals of the Missouri Botanical Garden,* **9**(2): 139-152.

Meinshausen M, Smith J, Calvin K, Daniel JS, Kainuma MLT, Lamarque JF, Matsumoto K, Montzka SA, Raper SCB, Riahi K, Thomson A, Velders GJM, van Vuuren DPP. 2011. The RCP greenhouse gas concentrations and their extensions from 1765 to 2300 *Climatic Change*, **109**(1-2): 213–241. Doi: 10.1007/s10584-011-0156-z.

Myers SS, Mastnt L, Engelman R. 2009. *Global Environmental Change: The Threat to Human Health. World Watch Report* 181, Samuel S. Myers MD, MPH, Mastnt L, Engelman R (eds). World Watch Institute: Washington, DC.

Nacoulma-Ouėdraogo OG. 2008. Plantes médicinales et pratiques médicinales traditionnelles au Burkina-Faso: cas du plateau central. Thèse de doctorat en sciences. Université de Ouagadougou, tomes III: 508-515.

Nair KSS. 2001. Pest Outbreaks in Tropical Forest Plantations: Is there a Greater Risk for Exotic Tree Species? Center for International Forest Research.

Nikiema A, Pasternak D. 2008. *Khaya senegalensis* (Desr.) A. Juss. [Internet] Record from PROTA4U. Louppe D, Oteng-Amoako AA, Brink M (eds). PROTA (Plant Resources of Tropical Africa / Ressources végétales de l'Afrique tropicale), Wageningen, Netherlands. http://www.prota4u.org/search.asp Accessed 12 April 2016.

Onefeli AO, Adesoye PO. 2014. Early Growth Assessment of Selected Exotic and Indigenous Tree Species in Nigeria. South-east *Eur. For.*, **5**(1): 45-51. DOI: http://dx.doi.org/10.15177/seefor.14-06

Opuni-Frimpong E. 2012. Incidence of Hypsipyla Robusta on Native Mahogany Trees: a Challenge for Sustainable Supply and Conservation of Mahogany Resources. Forestry Research Institute of Ghana, Presentation at IUFRO-FORNESSA REGIONAL CONGRESS 2012: Nairobi.

Orwa C, Mutua A, Kindt R, Jamnadass R, Simons A. 2009. Agroforestry Database: a tree reference and selection guide version 4.0 (http://www. worldagroforestry.org/af/treedb/).

Owens HL, Campbell LP, Dornak LL, Saupe EE, Barve N, Soberón J, Ingenloff K, Lira-Noriega A, Hensz CM, Myers CE, Peterson AT. 2013. Constraints on interpretation of ecological niche models by limited environmental ranges on calibration areas. *Ecological Modelling*, **263:** 10–18. DOI: https://doi.org/10.1016/j.ecolmodel.2013.04.011

Pamlin D, Armstrong S. 2015. Twelve risks that threaten human civilisation – The case for a new category of risks. Report for the Global Challenges Foundation.

Pearson RG, Thuiller W, Araujo MB, Martinez-Meyer E, Brotons L, McClean C, Miles L, Segurado P, Dawson TP, Lees DC. 2006. Model-based uncertainty in species range prediction. *Journal of Biogeography*, **33**: 1704–1711. DOI: 10.1111/j.1365-2699.2006.01460.x

Pearson RG, Christopher J, Raxworthy MN, Peterson AT. 2007. Predicting species distributions from small numbers of occurrence records: a test case using cryptic geckos in Madagascar. *Journal Biogeography*, **34**, 102-117. DOI; http://dx.doi.org/10.1111/j.1365-2699.2006.01594.x

Peterson AT, Papes M, Soberon J. 2008. Rethinking receiver operating characteristic analysis applications in ecological niche modeling. *Ecol. Model.*, **213**: 63–72. DOI: https://doi.org/10.1016/j.ecolmodel.2007.11.008

Peterson AT, Soberón J, Pearson RG, Anderson RP, Martínez-Meyer E, Nakamura M, Araújo MB. 2011. *Ecological Niches and Geographic Distributions*. Princeton University Press: Princeton

Philips SJR, Anderson P, Schapire RE. 2006. Maximum entropy modelling of species geographic distributions. *Ecological Modelling*, **190**: 231–259. DOI: https://doi.org/10.1016/j.ecolmodel.2005.03.026

Platts PJ, Omeny PA, Marchant R. 2015. AFRICLIM: high-resolution climate projections for ecological applications in Africa. *African Journal of Ecology*, **53**: 103–108. DOI: 10.1111/aje.12180

Rosenzweig C, Karoly D, Vicarelli M, Neofotis P, Wu Q, Casassa G, Menzel A, Root TL, Estrella N, Seguin B, Tryjanowski P, Liu C, Rawlins S, Imeson A. 2008. Attributing physical and biological impacts to anthropogenic climate change. *Nature*, **453**: 353–357. DOI: 10.1038/nature06937

Saliou ARA, Oumorou M, Sinsin AB. 2014. Variabilités bioclimatiques et distribution spatiale des herbacées fourragères dans le Moyen-Bénin (Afrique de l'Ouest). *Int. J. Biol. Chem. Sci*., **8**(6): 2696-2708. DOI: http://dx.doi.org/10.4314/ijbcs.v8i6.29

Schwartz MW. 2012. Using niche models with climate projections to inform conservation management decisions. *Biological Conservation,* **155**: 149–156. DOI: https://doi.org/10.1016/j.biocon.2012.06.011

Sokpon N, Ouinsavi C. 2002. Utilisations du *Khaya senegalensis* en médecine traditionnelle au Bénin. *Revue de Médecine et Pharmacopée Africaine*, **16**: 9-19.

Sokpon N, Ouinsavi C. 2004. Gestion des plantations de *Khaya senegalensis* au Bénin, *Bois et Forêts des Tropiques*, **279**(1) : 37-46. DOI : https://doi.org/10.19182/bft2004.279.a20247

Usher PK. 2010. Modelling Malaria Transmission Potential for Climate Change Scenarios in West Africa and Europe. *Earth & Environment*, **5**: 40-65.

Warren DL, Glor RE, Turelli M. 2010. ENMTools: a toolbox for comparative studies of environmental niche models. *Ecography,* **33**: 607-611. DOI: 10.1111/j.1600-0587.2009.06142.x

Wylie FR. 2001. Control of *Hypsipyla* spp. Shoot Borers with Chemical Pesticides: a Review. Paper presented at the International Workshop held at Kandy, Sri Lanka 20–23 August 1996, P 109.