Vulnerability of African Rosewood (*Pterocarpus erinaceus*, Fabaceae) natural stands to climate change and implications for silviculture in West Africa

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ABSTRACT

*Pterocarpus erinaceus* is a native tree species of the Guineo-Sudanian and Sudano-Sahelian zones where natural stands are under constant pressure and heavily exploited for timber, animal feeding and others uses. A part from the overexploitation, climate change could also become a serious threat to the species natural distribution. For that purposes, this study aims to assess the vulnerability of *P. erinaceus* potential niche to climate change within its natural distribution area in West Africa. Niche predictions are based on 6,981 natural occurrence of the species and 19 global bioclimatic variables available through WorldClim. The future niche of the species is predicted according to three concentration pathways (RCPs 2.6, 4.5 and 8.5) of BC model for 2050 and 2070, thanks to Maxent software.

*P. erinaceus* is currently reported from Senegal to Cameroon. Its potential niche covers the Sudano-Sahelian zone and the Dahomey gap on approximately 17.42% of the total area of these countries. In general, the niche of the species is not sensitive to climate change, regardless of the climate scenario and the year. Compared to its initial niche, the niche of the species will increase from 22.33% to 43.61% in 2050 and from 27.12% to 53.61% in 2070. However, this ecological expansion observed mainly in the Gulf of Guinea, will be associated with a considerable decrease in the Sahel and central Nigeria. This study shows the importance of promoting the development of innovative silvicultural strategies for the extension and restoration of natural stands of *P. erinaceus* in order to meet sustainably the timber needs of the West African region. It helps also to strengthening the roles of natural forests in providing ecosystem services and mitigating climate change effects.

1. Introduction

Human activities such as deforestation, agriculture, overgrazing and bush fires, coupled with the adverse effects of climate change, are contributing to the loss of many important native plant species (Assogbadjo et al., 2010). Among the most heavily traded tropical hardwood currently in the world, *Pterocarpus erinaceus* is now considered endangered (Du menu, 2019; IUCN, 2018; CITES, 2018). It is an endemic species of the Guinneo-Sudanian-Sahelian zones (Duvall, 2008; Ouedraogo et al., 2006) widely exploited in West Africa for timber and also for a range of uses including fodder for animals, raw materials for crafts (tannins, dyes, sap, resin, etc.) and medicinal products (Rabiou et al., 2017).

In addition to the anthropogenic pressures on *P. erinaceus*, its natural stands are threatened by climate change (Maley, 2004). Indeed, the question of the impact of current climate change on forest ecosystems becomes more important in environmental research and could be one of the major drivers of ecological change in the coming decades (Virkkala et al., 2013; Parmesan et al., 2006). Moreover, the Intergovernmental Panel on Climate Change (IPCC) concludes that most of natural ecosystems will be affected at different intensities (IPCC, 2014; Alkemade et al., 2009; Delire and Ngomanda et Jolly, 2008). This leads to changes in the distribution of species, as well as reductions in population size and local population extinctions (Busby et al., 2010; Boko et al., 2007; Parmesan et al., 2006).

In accordance with the foregoing, *P. erinaceus* natural stands are affected by logging, repetitive mutilations and various pressures...
throughout its range. Small-diameter trees now occur, reflecting a decline in natural stands due to decades of overexploitation, making it a threatened and endangered species (IUCN, 2018; CITES, 2018), to the extent that its silviculture is out of control and preventing the recovery of degraded stands. The intensity of the exploitation of the species sparked off concerns about its sustainability among range countries in West Africa. Faced with this situation, some countries have decided to impose felling and export bans (case of Ghana) or have taken a moratorium prohibiting exploitation of the African Rosewood (case of Togo). In Togo, the illegal and excessive logging of *P. erinaceus*, led the Government to impose in June 2016 a 10-year moratorium. This moratorium which covers the period from 2016 to 2026, has resulted in the temporary suspension of all authorisations to log the species from neighbouring countries and other range countries in the sub-region as well (Yawo, 2019). For Togo this measure is aimed at limiting the over-exploitation of *P. erinaceus* in order to avoid local extinction and to allow the natural stands to regenerate themselves.

Therefore, the development of global adaptation strategies and management of natural stands of *P. erinaceus* throughout its range, including dry and wet areas, is necessary. In fact, *P. erinaceus* is the main woody species of the former Sudano-Guinean dry forest, which is succeed after the tropical rainforest with a wide distribution, from the Sahara to the equatorial forest. The modification of the distribution areas is achieved through diffusion and maintenance processes, conditioned by a multitude of interacting factors. Knowledge of the specific properties of these changes, which may have an impact on species or their habitats, is a central element of adaptation strategies (Mensah et al., 2014). These climatic factors are environmental issues that deserves special attention when planning for forest resource use and species conservation. Thus, in order to predict the impacts of climate change on the spatial distribution of *P. erinaceus* in West Africa, which is its natural range, it is important to identify the main climate parameters that guide this distribution.

In a changing environment, predicting variations in species distribution and vulnerability of a species’ niche is important, for developing appropriate adaptive management strategies and programs (Ferrarini et al., 2016, 2019a). Consequently, the aim of this paper is to contribute to better understanding of the adaptive capacities of *P. erinaceus* in order to develop strategies for its conservation and silviculture in West Africa. Specifically, it is (i) to identify explanatory climatic variables influencing the spatial distribution of *P. erinaceus* in West Africa and (ii) to assess the vulnerability of the *P. erinaceus* niche to climate change.

2. Methodology

2.1. Study zone

The study was conducted over the whole area of occurrence of *P. erinaceus* in West Africa (Figure 1). This delineation of West Africa, linked to biogeographic affinities, is more rigorous from an ecological point of view and is widely adopted in the scientific literature (Luisellia et al., 2017; White, 1983). West Africa is home to a wide variety of ecosystems and climates (CILSS, 2016). This climate is of tropical type with a very pronounced latitudinal gradient under the influence of two contrary trade winds (Funk et al., 2015; Nicholson, 2013). It varies from the Guinean type (annual rainfall exceeding 1800 mm) in the South to the Sudanian type and then the Sahelian type (with annual rainfall exceeding 100 mm of water) in its northernmost part. This latitudinal stratification of climate strongly influences vegetation and species distribution in the region, with steppe formations in the north, savannahs in the center, and forests in the south. The Guinean forests of West Africa, extending from Guinea to Cameroon, with an interruption in southern Togo and in Benin where the savannah reaches the coast (White, 1983), constitute one of the major hotspots of biodiversity in the world thanks to a very important biodiversity and a high rate of endemism (Mittermeier, 2004; Myers, 1988).

2.2. Species distribution models input data

2.2.1. Occurrence data of Pterocarpus erinaceus

A total of 6,981 georeferenced occurrences data of *P. erinaceus* covering the entire geographic extent of the species (from Senegal to eastern Chad) were used as species known presence input data (Figure 1). These occurrences data are from author's field surveys and available complementary datasets. These datasets were gathered from: (i) the Global Biodiversity Information Facility website (GBIF, 2018; https://www.gbif.org/occurrence/download/0019891-181108115102211), (ii) the African plant species database “RAINBIO” (Dauby et al., 2016), (iii) the datasets of University of Lomé’s herbarium (Radji et al., 2018).

Figure 1. Occurrences of *Pterocarpus erinaceus* Poir. in West Africa and model training area. The training area includes all the known occurrences of the species in West Africa. The data are from GBIF, RAINBIO, Herbarium of University of Lomé and authors own field data.
All the data comprises of only the punctual localisation (longitude and latitude) of the species in West Africa.

### 2.2.2. Climate data

A set of 19 bioclimatic variables (Table 1) available through the WorldClim database (Fick and Hijmans, 2017; Hijmans et al., 2005) was used as environmental layers to model the potential niche of the species. These data were acquired at a resolution of 2.5 arc-minutes (corresponding to about 4.5 km × 4.5 km) in the study area right-of-way, namely between -28° and 18° longitude and between 0° and 28° latitude for current climate than for its future predictions, thus fully covering the entire known range of the species (Araújo and Guisan, 2006; Heikkinen et al., 2006). For projections of future climate of the West African sub-region, projections of the BCC-CSM1.1 model (Wu et al., 2014) were used at two different time horizons (2050 and 2070). For this purpose, three scenarios of greenhouse gas concentration were considered. This is the optimistic RCP 2.6 scenario (in this scenario, the earth/atmosphere system will start to lose energy from the second half of the 21st century, after a first half with a slight energy gain), the medium or realistic RCP 4.5 scenario (the system will gain in energy mainly the first half of the century and will stabilize during the second half) and the pessimistic RCP 8.5 scenario (the system will continuously gain in energy). The process of acquiring, processing and formatting climate data was carried out thanks to the Raster library (Hijmans, 2019) under the R software (R Core Team, 2017).

#### 2.3. Niche modeling

The modeling of the current potential distribution of the species and the impact of climate change on its future niche was performed using the Maxent software (Phillips et al., 2017). Based on the maximum entropy theory which is a measure of dispersedness (Baldwin, 2009; Phillips and Andersonson Schapire, 2006), this program has been widely used successfully in species distribution modeling, even in areas with relatively poorly inventoried (Elith et al., 2011, 2006). It has the advantage of being less sensitive to the size of the known occurrence data used as model inputs (Hernandez and Graham, 2006; Wisz et al., 2008).

Entropy based methods use simple presence data to predict the potential distribution of species by calculating the probability of the presence of the species in an area defined by the environmental characteristics of its known occurrence (Yi et al., 2016; Merow et al., 2013). Many other studies demonstrate the effectiveness of Maxent software in predicting current and future distribution of species around the word (Kearney et al., 2018; Yi et al., 2016; Trisurat et al., 2011).

In this study, the Maxent software has been set to ignore duplicate occurrence data within a single 2.5-arc-minute climate grid in order to avoid data availability bias between intensively inventoried regions and poorly inventoried ones (Radosavljevic and Anderson, 2014). Two criteria were used to select the models namely the training omission rate and the AUC (Area Under the Curve) (Phillips et al., 2018). The training omission rate is the percentage of known presence data (training points) that are omitted by the distribution model. The maximum omission rate was set to 10% of training points. The AUC is a measure of the performance of the model. According to Swets (1988), a model is only valid from an AUC higher than 0.6. It is qualified as "excellent" if AUC is greater than 0.9; "Good" for AUC between 0.8 and 0.9; and "acceptable" for AUC between 0.7 and 0.8. For each selected model, the “Cloglog threshold” at the maximum of 10% omission rate was used to evaluate the probability of the presence of the species in the study area. Considering that the obtained model is a grid of probabilities of the presence of the species, the “Cloglog threshold” value correspond to the minimal value from which the probability of presence of the species is higher than an aleatory distribution.

Jackknife tests was performed on the 19 climatic variables in order to evaluate the importance of each of these environmental variables, take in isolation or with other variables in a post hoc prediction of the species potential distribution in West Africa. It also made it possible to circumscribe climatic tolerance of the species for each of the variables.

The superimposition of future potential distribution of *P. erinaceus* to its current distribution in Quantum GIS version 2.14 software made it possible to identify: (i) areas that will become suitable to the species in the future (niche expansion); (ii) areas which will become climatically unsuitable to the species (niche regression), (iii) areas which will remain suitable for the species (niche conservation) and (iv) areas that remain unsuitable for the species (out niche). The rates of expansion, regression and conservation of niche by *P. erinaceus* considering each climatic scenario were calculated in West Africa.

### 3. Results

#### 3.1. Niche of *Pterocarpus erinaceus* in West Africa

As result of the applied methods, the distribution model developed has a good performance based on training omission rates ((not exceeding 10% and AUC> 0.8) (Table 2). With a potential niche covering about 17.58% of its territory, *P. erinaceus* has a wide distribution in West Africa. It can potentially grow naturally in all West African countries with the exception of the two exclusively forested countries of Liberia and Sierra Leone (Figure 2). Its climatic niche reaches the coast only in Senegal, Guinea and the forest interruption zone of Dahomey (from south-eastern Ghana to southern Benin) (Figure 2).

The Jackknife test shows that annual precipitation (BIO 12) explains better the distribution of *P. erinaceus* in West Africa. Temperature seasonality (BIO 4) is the variable that best complements annual precipitation in defining the climate niche of the species (Figure 3). These two variables explain respectively 67.1 % and 13.6 % of the current distribution of the species. All other variables have marginal contributions to the species distribution model (contribution less than 5%).

**BIO1**: Annual Mean Temperature; **BIO2**: Mean Diurnal Range (Mean of monthly (max temperature · min temperature); **BIO3**: Isothermality (BIO2/BIO7) (* 100); **BIO4**: Temperature Seasonality (standard deviation *100); **BIO5**: Max Temperature of Warmest Month; **BIO6**: Min Temperature of Coldest Month; **BIO7**: Temperature Annual Range (BIO5-BIO6); **BIO8**: Mean Temperature of Wettest Quarter; **BIO9**: Mean Temperature of Driest Quarter; **BIO10**: Mean Temperature of Warmest Quarter; **BIO11**: Mean Temperature of Coldest Quarter; **BIO12**: Annual Precipitation; **BIO13**: Precipitation of Wettest Month; **BIO14**:

| Variable | Description |
|----------|-------------|
| BIO1     | Annual Mean Temperature |
| BIO2     | Mean Diurnal Range |
| BIO3     | Isothermality (BIO2/BIO7) (*100) |
| BIO4     | Temperature Seasonality (standard deviation *100) |
| BIO5     | Max Temperature of Warmest Month |
| BIO6     | Min Temperature of Coldest Month |
| BIO7     | Temperature Annual Range (BIO5-BIO6) |
| BIO8     | Mean Temperature of Wettest Quarter |
| BIO9     | Mean Temperature of Driest Quarter |
| BIO10    | Mean Temperature of Warmest Quarter |
| BIO11    | Mean Temperature of Coldest Quarter |
| BIO12    | Annual Precipitation |
| BIO13    | Precipitation of Wettest Month |
| BIO14    | Precipitation of Driest Month |
| BIO15    | Precipitation Seasonality (Coefficient of Variation) |
| BIO16    | Precipitation of Wettest Quarter |
| BIO17    | Precipitation of Driest Quarter |
| BIO18    | Precipitation of Warmest Quarter |
| BIO19    | Precipitation of Coldest Quarter |

Source: [http://worldclim.org/bioclimate](http://worldclim.org/bioclimate)
Precipitation of Driest Month; BIO15: Precipitation Seasonality (Coefficient of Variation); BIO16: Precipitation of Wettest Quarter; BIO17: Precipitation of Driest Quarter; BIO18: Precipitation of Warmest Quarter; BIO19: Precipitation of Coldest Quarter.

Considering the threshold of the model (which is 0.35 for a maximum of 10% training omission rate), it appears that *P. erinaceus* prefers niches where the annual precipitation is between 600 and 1350 mm and a seasonal temperature of between 110 and 250 °C (Figure 4).

### 3.2. Impact of climate change on the *P. erinaceus* niche in West Africa

Regarding the climatic scenario considered, the climatic niche of *P. erinaceus* will extend significantly in West Africa, mainly in the gulf of Guinea and secondarily to the Sahel. This expansion will be between 23.26% and 29.26% by 2050 and between 44.82% and 55.50% by 2070 relative to the extent of its initial niche (Table 2). However, this expansion will not occur without losses within the initial niche of the species. Indeed, losses ranging from 7.67% to 22.60% will be recorded respectively for the optimistic and pessimistic scenarios of changing climate but these losses will be largely supplanted by the acquisitions of new niches which will vary from 38.52% to 69.30% compared to the initial climatic niche of the species.

In the case of the optimistic scenario, most of the niche losses will occur in the southern parts of the initial climate niche, namely in northern Côte d’Ivoire, southern Mali and Burkina, and central Nigeria. At the same time, the climatic niche of *P. erinaceus* will extend more and more northwards to the Sahel, but also to the coast throughout the Gulf of Guinea (from Côte d’Ivoire to Nigeria). Mauritania, which until now offered only a very limited suitable area for the species in its border region with Senegal, will see this niche expanded by more than 100 times the area of the initial niche (Figures 5A and 5D).

In the case of the other scenarios (RCPs 4.5 and 8.5), more significant niche losses will occur in the Sahel and in the westernmost part of the initial climate niche of *P. erinaceus* (Senegal, Gambia, Guinea Bissau, Guinea, South Mali and Burkina Faso). However, as for the optimistic scenario, the Gulf of Guinea will be increasingly preferred area to which the species will extend its niche to the coast (Figure 5F).

### 4. Discussion

The results of this study highlight the importance of the water availability factors in defining the potential distribution of *P. erinaceus* in West Africa. Indeed, in this study, it emerged that annual precipitation and temperature seasonality appear as the most determining factors in the distribution of *P. erinaceus* in West Africa (Figures 3 and 4). The results indicate that the species can withstand annual rainfall between 600 and 1350 mm. The current climate niche of the species confirms its Sudanian affinities from the Sahel to the coastal Guinean regions (Aubréville, 1950; Segla et al., 2015a), with a wide range of climatic tolerance. These results are consistent with the work of Duvall (2008), which indicates that *P. erinaceus* is a species of African savannahs and Sudano-Guinean dry forests with mean annual rainfall ranging from 600 to 1500 mm/year and mean annual temperatures varying from 15 to 35°. These climatic conditions allow natural stands of *P. erinaceus* to regenerate and grow in almost all climatic zones of the West African subregion.

Annual rainfall has also been identified by Tosso (2013) as one of the most important variables explaining the presence of *P. erinaceus* in its range. In Benin, in addition to these two variables, Saliou et al. (2015) have identified the precipitation of the coldest quarter and the precipitation of the driest quarter as equally important in the distribution of *P. erinaceus*. This indicates that the two latter environmental variables could be used as primary indicators for vulnerability assessments especially for natural stands of the species and in general for forests with climate change (Ferrarini et al., 2019a, 2019b; Rathore et al., 2019; Wan et al., 2018; Butt et al., 2016a,b). The species thus has a large ecological amplitude for annual precipitation and consequently a very high ecological plasticity allowing it to adapt to several environments or types of habitats with different climates. This justifies in terms of current potential distribution, the high habitat potential (17.42 % of the area of West Africa) that *P. erinaceus* has in its range (Figure 2).

In terms of future distribution, climate scenarios at different time horizons have indicated that, regardless of the scenario studied and the time horizon, the *P. erinaceus* niche will grow. Tosso (2013) also demonstrated, based on the IUCN A3 criterion for taxa assessment, that *P. erinaceus* is one of the species that will not be threatened by climate change in the time of horizon 2041–2060. Climate change will therefore have no detrimental effect on the presence of *P. erinaceus* in West Africa. The results show that climate change will have a beneficial effect on the expansion of the potential niche of *P. erinaceus* over different time horizons (Table 3, Figure 5).

Indeed, dealing with the trend of changing climatic conditions at different time horizons, the fifth report of the Intergovernmental Panel on Global Climate provides for an aridification of the Gulf of Guinea in the eastern coastal zone of West Africa and humidification of the Sahel (IPCC, 2014). The niche losses in the eastern part of the current niche of the African Rosewood could thus be associated with an excessive reduction of precipitation, beyond its climate tolerance range. In contrast, these decreases in precipitation have made the Gulf of Guinea, currently too wet, favorable to the species in the future. The low vulnerability of *P. erinaceus* to climate change is related to its ecology. Limited or even positive adverse effects are often predicted for woody species (Hamann and Wang, 2006; Coops and Waring, 2011), possibly with niche movements.

Considering the Sudano-Sahelian character of the current niche of African Rosewood, which preferentially occupies savannah habitats (Aubréville, 1950; Segla et al., 2015a), the expansion of the climatic niche of *P. erinaceus* in the Gulf of Guinea and the Sahel could not be automatically assimilated to an expansion of its effective niche if the savannah habitat is not available. In tropical America, the work of Anadon et al. (2014) predicted an expansion of savannahs at the expense of forests as a result of climate change. This expansion of the savannahs in the West African context could allow *P. erinaceus* to be able to occupy the new niches which will be climatically favorable to it. However, it is important to remind that species are not always able to occupy the entire climate niche that is favorable to them. Indeed, studies on the distribution of some woody species have shown that the latter generally only effectively occupy part of their climatic niche (Svenning and Skov, 2004). This inability to occupy all of their niche is due to the importance of other environmental constraints such as soil, vegetation, competition between plant species, wildfires, grazing, human activities, etc (Ivory and Russell, 2016; Trisurat and Eawpanichet Kalliola, 2016; Lavorel et al., 2007). *P. erinaceus* trees are also attacked by termites as *Attinemus evuncifer*, *Anisotremus guineensis* and *Microtermes lepidus* (Ghenyedji et al., 2016).

The reduction and/or extinction of the distribution area of *P. erinaceus* in West Africa could therefore be induced by other factors, including anthropogenic factors. Several authors claim that it is rather the change in land use in relation to population growth that could be the first cause of the extinction of forest species (De Wasseige et al., 2012).

### Table 2. Characteristics of *Pterocarpus erinaceus* distribution model.

| Training records | Background points | Cloglog threshold | Regularized training gain | Iterations | AUC | Fractional predicted area | Training omission rate |
|------------------|-------------------|-------------------|--------------------------|------------|-----|--------------------------|------------------------|
| 1 906            | 11 868            | 0.350             | 1.107                    | 500        | 0.887| 0.248                    | 0.100                  |

AUC: Area Under the Curve.
Other studies reveal that *P. erinaceus* is not only one of the main species used as fodder in West Africa (Rabiou et al., 2017; Segla et al., 2015b; Agbahungba et al., 2001; Adjonou et al., 2010) but also used as prime timber and wood energy (Fontodji et al., 2011).

Anthropogenic threats to the African Rosewood in West Africa (Segla et al., 2015a, 2015b) cause a high vulnerability of the species indirectly through the climate change (Wan et al., 2018). Leadley et al. (2010) argue that climate change will undoubtedly become the greatest threat to species in the 21st century, in addition to their intrinsic effect, they are an engine for increasing other threats (Ferrarini et al., 2017; Anadón et al., 2014). In another hand, *P. erinaceus* will benefit from future changes whatever the scenario envisaged, by extending its niche to areas that were previously inaccessible including the Sahel and especially to coastal areas of the Gulf of Guinea. This
expansion of the niche will be between 23.26 % and 29.26 % by 2050 and between 44.82 % and 55.50 % by 2070 relative to the extent of its initial niche (Table 2).

Climatic resilience of the African Rosewood is an essential asset for its conservation and opens up interesting opportunities for its silviculture and valorization as a first-rate multi-purpose species in West Africa. Indeed, to address the persistent problem of forest and land degradation that is the main factor of vulnerability in the region, many countries have developed large-scale national or sub-regional programs with the assistance of bilateral and multilateral partners in the framework of climate conventions for conservative management of natural resources and enhancement of carbon sinks. These programs have defined short, medium and long-term goals for the restoration of degraded ecosystems and the expansion of forest areas in targeted landscapes and climate-sensitive areas. But it is apparent that very few of these programs rely on the use of local tree species for the restoration of degraded ecosystems and reforestation. The exotic species that are more adopted and most frequently known in West Africa are Tectona grandis, Eucalyptus spp, Acacia spp, etc. Due to an uncontrolled distribution and a lack of an awareness campaign, many of these alien species have become invasive and have been increasingly reported as a threat to local biodiversity (Uddin et al., 2013). Mostly, alien species are also reported to be a great problem for biodiversity conservation areas because of their negative effects on native flora and fauna. While an analysis of the issues in the forest sector in the context of climate change has shown that the use of exotic species at the stand level has elements that do not fit the principles of sustainable forest

Figure 4. Climatic range of P. erinaceus at the threshold of 0.35. (A) Annual precipitation; (B) Temperature seasonality (standard deviation * 100).

Figure 5. Evolution of the P. erinaceus niche in West Africa by 2050 following RCP 2.6 (A), RCP 4.5 (B) and RCP 8.5 (C) scenarios; and by 2070 in the RCP 2.6 (D), RCP 4.5 (E) and RCP 8.5 (F) scenarios.

Table 3. Trends in evolution of P. erinaceus niches according to climate scenarios.

| Climate scenario | RCP 2.6 | RCP 4.5 | RCP 8.5 |
|------------------|---------|---------|---------|
| Year             | 2050    | 2070    | 2050    | 2070    | 2050    | 2070    |
| Loss of niche    | -15.26% | -7.67%  | -13.50% | -20.36% | -22.60% | -13.80% |
| Residual niche   | 86.84%  | 94.32%  | 89.45%  | 82.99%  | 80.03%  | 89.40%  |
| New niche        | 38.52%  | 52.49%  | 57.73%  | 48.39%  | 51.86%  | 69.30%  |
| Balance sheet    | 23.26%  | 44.82%  | 44.23%  | 28.03%  | 29.26%  | 55.50%  |

RCP: Representative Concentration Pathways.
management in the economic, environmental and social components (Ching et al., 2018; Brenda et al., 2015).

With this concern, researchers and forest promoters are increasingly advocating the use of local tree species because of their adaptability to climate, their ability to establish and their high usefulness. To this end, the choice of *P. erinaceus* for reforestation programs is increasingly motivated by its status as a local species endemic to West Africa with a perfect eco-climatological adaptation to the Guinean, Sudano-Saharan and Sahelian zones and with no negative externality regarding its planting and for intensive silviculture in an ecosystem-based management context. But before promoting the use of this species in reforestation programs, it is essential to set up large-scale production strategies for high-performance and fast-growing seedlings to meet the needs of stakeholders in terms of establishment of forest plantations and for actions to restore degraded natural stands.

5. Conclusion

The modeling of the distribution of *P. erinaceus*, reveals that the species has a wide distribution in West Africa and the current potential niche covers about 17.58% of its range. Among the bioclimatic variables considered in this study, it appeared that BIO 12 (Annual Precipitation) and BIO 4 (Temperature seasonality) are the important factor determining the distribution of *P. erinaceus* in West Africa. These two variables are important factors to determine the distribution and they account respectively for 67.1 % and 13.6 % of the current distribution of the species. They could be used as primary indicators for assessments of the vulnerability of natural stands of *P. erinaceus* to climatic factors.

The vulnerability of the species’ niche to climate change reveals that whatever the climatic scenario envisaged, the climatic niche of *P. erinaceus* will spread significantly in West Africa, with an expansion of between 23.26 % and 29.26 % by 2050 and between 37.26 % and 44.26 % by 2090. It is predicted that this expansion will occur with niche losses ranging from 67 %–22.60 % respectively for the optimistic and pessimistic scenarios. Climate change would therefore not pose a threat to *P. erinaceus* but should favor the silviculture of the species in West Africa with new areas becoming climatically adapted to the establishment of plantations based on the species. This climatic resilience of the species is an asset for its conservation and opens up interesting opportunities for its valorization as a first-rate multipurpose species in West Africa.

Declarations

Author contribution statement

ADJONOU Kossi: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

ABOTSI Komla Elikplim, SEGLA Kossi Novinyo: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

RABIOU Habou, HOUETCHEGNON Towanou, SOUROU K. N. Bien-venu, JOHNSON Benziwa Nathalie: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

OUISSAVI Christine A. I. Nougboë, KOKUTSE Adzo Dzifa, MAHAMANE Ali: Conceived and designed the experiments.

KOKOU Kouami: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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