

Research paper

Potential future distribution shifts for *Afzelia africana* Sm. ex Pers. and *Pterocarpus erinaceus* Poir. in the context of climate change in Benin

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Abstract. Climate change poses significant challenges to the survival of ecologically and economically important tree species. This study uses species distribution modelling to assess the current and future potential habitats of *Afzelia africana* and *Pterocarpus erinaceus* in Benin under moderate (RCP4.5) and high (RCP8.5) climate change scenarios. They are multipurpose trees listed on the IUCN Red List due to threats such as illegal logging and low natural regeneration rates. By integrating bioclimatic variables and occurrence data using the method of the Maximum Entropy under MaxEnt program, the results reveal critical habitat shifts, including significant contractions in highly suitable areas under severe climate conditions. Under current climatic conditions, approximately 85% of Benin's territory is identified as a potentially suitable habitat for *Afzelia africana* and *Pterocarpus erinaceus*, indicating a significant area for their conservation. Future projections suggest that national parks, some of which currently include unsuitable zones, will offer increasingly suitable habitats, emphasizing their importance in climate adaptation strategies. The extensive availability of suitable habitats highlights the potential for future reintroductions or natural population expansions, ensuring the continued survival and ecological roles of these species in the region. Practical implications include conducting spatial prioritization using habitat suitability maps to extend current protected area networks, and focusing restoration efforts on medium-suitability areas. These findings provide a foundation for informed conservation strategies that align with climate adaptation goals.

Key words: species distribution modelling, threatened trees, suitable habitat, MaxEnt, GIS.

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Introduction

Biodiversity is vital for human survival and ecosystem stability, yet forest ecosystems worldwide face significant degradation. Between 2015 and 2020, global forest loss reached 10 million hectares annually, primarily driven by agricultural expansion, illegal logging, and fires (FAO, 2022; WRI, 2023). This crisis is particularly concerning in Benin, where forest resources are severely limited. Forests now cover only 27.4% of the country's land area (30,851 square kilometers), a sharp decline from 42.9% in 1990. The country suffers one of the highest annual deforestation rates globally, at 2.5%, due to the rising demand for

wood energy, population growth, and agricultural expansion (Global Forest Watch, 2023; AFR100, 2022).

With a significant proportion of Benin's population living in rural areas (Sakketa, 2023), natural resources in many regions are increasingly under pressure, leading to the risk of extinction for several important tree species (Gyamfi *et al.*, 2023). Deforestation, selective logging, intensive agriculture, and charcoal production, driven by local communities to sustain their livelihoods, have rendered numerous tropical tree species critically vulnerable (Knoke *et al.*, 2023). Human-induced forest degradation has resulted in substantial reductions in forest cover, threatening

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ecosystem services and biodiversity associated with these ecosystems (Ekka *et al.*, 2023; Shah *et al.*, 2023). The destruction of natural habitats has profoundly affected species distribution, often confining their historical ranges to small and fragmented populations (Lim *et al.*, 2024; Maclean & Early 2023). Furthermore, tropical forests remain heavily exploited for various purposes, including the extraction of high-quality timber and the harvesting of roots, bark, leaves, and fruits for traditional medicine (Inatimi, 2023; Sher *et al.*, 2023). In Benin, *Azizelia africana* Sm. ex Pers. and *Pterocarpus erinaceus* Poir. are classified as endangered due to a combination of factors, including over-exploitation for timber, agricultural expansion, and habitat loss (Adomou *et al.*, 2009).

Azizelia africana is one of the most used multipurpose forest species in Africa. It is found in dry forests and woodlands, in several types of natural forest, ranging from the dense forest of the Guinean-Congolian zone to the woodland forest of the Sudanian zone (Boakye *et al.*, 2023; Houehanou *et al.*, 2023). *A. africana* has been evaluated as threatened by the International Union for Conservation of Nature (IUCN), due to the pressure faced by its population by human uses (Hills, 2020). It is used as food (flour from seeds as a substitute for wheat flour in biscuits), fodder (livestock feeding), timber (excellent wood), and in traditional medicine (Bamigboye *et al.*, 2024; Ndukwe *et al.*, 2023). The multiple uses of *A. africana* in West Africa have led to permanent pressure on its natural populations. It is frequent to observe adult trees of *A. africana* in savannahs as well as in woodlands and dense forests but its natural regeneration is rarely observed within the same habitats (Nodza *et al.*, 2024).

Pterocarpus erinaceus is a species native to open forests and wooded savannahs, widely recognized by rural populations for its diverse uses. The leaves and bark of the tree are edible, and its foliage and immature cones are occasionally harvested during the end of the dry season to supplement human diets. The foliage and immature cones are also sold in markets in the dry season for fattening sheep, goats, cattle, and horses; the leaves are used in abortifacient mixtures and as a febrifuge (Rabiou *et al.*, 2015; Sanneh, 2023; Agbodan *et al.*, 2023). The bark is used for ringworm of the scalp, dressing for chronic ulcers, blennorrhagia and in a gargle for tooth and mouth troubles. The species is overexploited due to logging and foliage harvesting and thus is an endangered species on the red list of Benin (Ngwa, 2023; Nodza *et al.*, 2024).

Climate change significantly affects the

geographic distribution of species and is recognized as one of the primary drivers of biodiversity loss. Resulting impacts further exacerbate the fragility of already degraded ecosystems (Rubenstein *et al.*, 2023; Wudu *et al.*, 2023). The rapid advancement of information and communication technologies has enabled the collection and analysis of georeferenced data on species and their habitats, providing valuable insights into biodiversity patterns, species distributions, and associated threats (Feng *et al.*, 2024; Peterson *et al.*, 2024). While significant work has been done on species distribution modelling and the impacts of climate change on biodiversity, there remains a critical gap in understanding how these processes affect *A. africana* and *P. erinaceus* within the specific context of West Africa, particularly in Benin. Both species are ecologically and economically valuable, yet they face increasing threats from habitat loss, overexploitation, and shifting climatic conditions.

This study integrates localized environmental factors and climate projections to provide a more accurate assessment of the current and future distributions of these species. By addressing this gap, the research not only enhances our understanding of the species' ecological needs but also supports the development of targeted conservation strategies. This is crucial for ensuring the sustainable management of *A. africana* and *P. erinaceus*, particularly as climate change intensifies and human activities continue to pressure their habitats. The primary objectives are to evaluate the environmental factors driving the distribution patterns of both species and to model their current and future distributions under various climate scenarios. By analyzing these projections, the study aims to develop effective conservation strategies that promote the sustainable use of these species and contribute to their long-term viability. This research provides key information on the potential impacts of climate change on species distribution, which will inform adaptive management and conservation practices that enhance the resilience of these valuable species in the face of shifting environmental conditions.

Material and Methods

Study area

Our study has been conducted with a focus on the Republic of Benin to better understand the distribution of the target species' populations (*A. africana*, *P. erinaceus*) in this country (Figure 1).

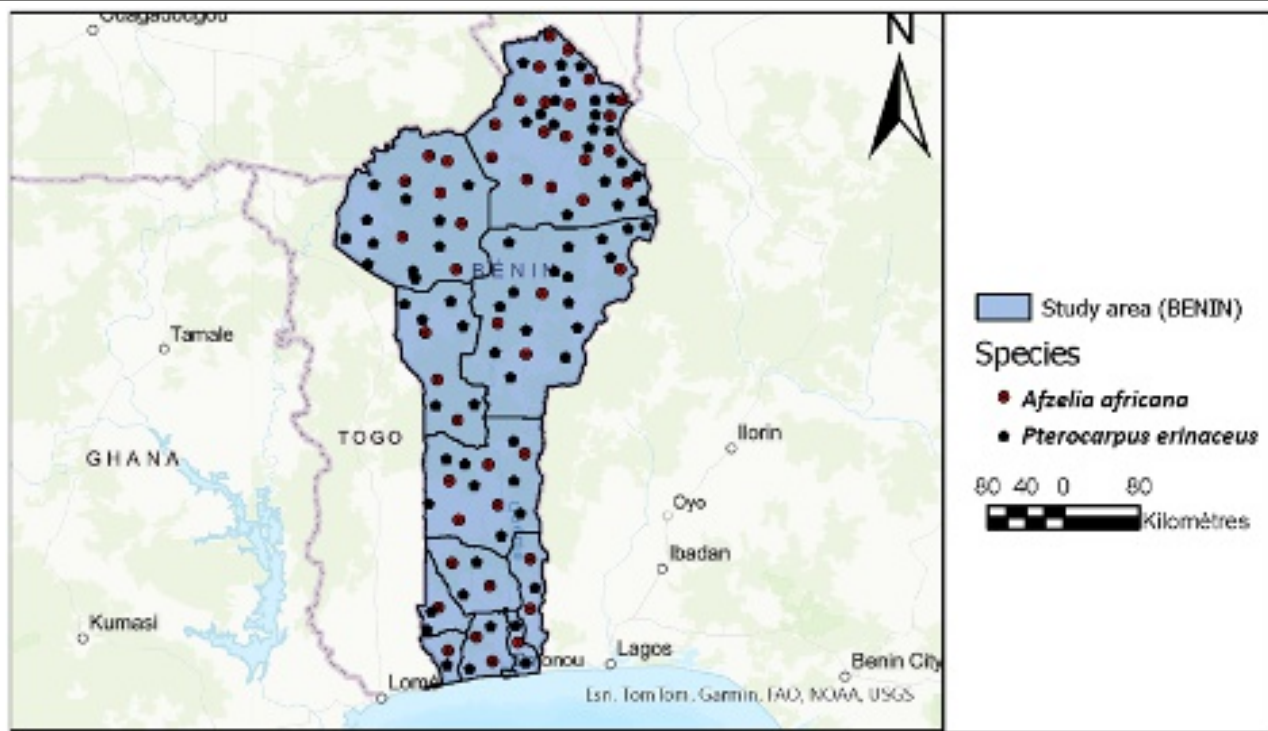


Figure 1. Study area and spatial distribution of *Afzelia africana* and *Pterocarpus erinaceus* in Benin.

The Republic of Benin ($6^{\circ}30'N$ – $12^{\circ}50'N$ and $1^{\circ}3'40'E$), with an area of 114,763 km², is located in the “Dahomey gap” – the dry corridor which consists mainly of savannahs and splits the African rainforest block into two parts. Its climate is divided into three distinct areas, from the south to the north: a subequatorial zone (from $6^{\circ}30'N$ to $7^{\circ}30'N$), the Sudano-Guinean zone (from $7^{\circ}30'$ to $9^{\circ}30'N$) and the Sudanian zone ($9^{\circ}30'N$ – $12^{\circ}N$) (Kakpo *et al.*, 2021).

Species distribution modelling with MaxEnt

The MaxEnt (Maximum Entropy, version 3.3.3k) modelling approach was employed to predict the potential distribution of *A. africana* and *P. erinaceus*. MaxEnt is a machine-learning algorithm that uses presence-only occurrence data and environmental variables to estimate the species' geographic distribution (Phillips *et al.*, 2006). It is particularly effective for modelling species distribution with limited data, as it maximizes the entropy (uncertainty) of the prediction while staying consistent with known constraints provided by the input data (Phillips *et al.*, 2006; Pearson, 2010). The algorithm was selected due to its robustness in handling complex, nonlinear relationships between species and environmental predictors, as well as its strong predictive performance compared to other methods. Occurrence records were processed to remove duplicates, incorrect georeferencing, and incomplete data to ensure reliability. Predictor variables

included bioclimatic data such as temperature and precipitation, derived from the WorldClim dataset (Fick & Hijmans, 2017).

While MaxEnt provides robust predictions, it is not without limitations. The reliance on presence-only data can introduce sampling bias, as areas with more survey effort might skew the model's predictions. Additionally, MaxEnt assumes that occurrence data represent the species' fundamental niche, which may not fully account for dispersal limitations, interspecies competition, or historical habitat changes (Lisovsky & Dudov, 2021). These factors were noted and will be addressed in future studies to refine predictions.

Data collection

Occurrence data

For species distribution modelling, all the occurrence data of the two species found in Benin were used. Before searching the occurrence data of the two species, we got the different synonyms known of them as well as the subspecies, or varieties. All records were then downloaded from various database sites and mainly from the Global Biodiversity Information Facility (GBIF) site (www.gbif.org). Records lacking coordinates were georeferenced using locality descriptions when available, utilizing GEOlocate (2023) and gazetteer information from DIVA-GIS (2023). As the species occurrence records were compiled from multiple sources, rigorous preprocessing

was conducted using ENMTools to ensure data reliability (Warren *et al.*, 2010). Key steps in data cleaning included: duplicate entries, which could overinflate the presence of a species in specific locations, were systematically removed; occurrence points with implausible or incorrect geographic coordinates (points falling in oceans, mangroves, rivers or outside the study region) were excluded; records lacking precise geographic coordinates were discarded to ensure all retained data could be mapped accurately; and to address sampling bias, spatially correlated records were filtered by applying a minimum distance threshold (5 km) between occurrences, reducing clustering and enhancing model robustness. These steps are necessary to reduce sampling bias, improve spatial accuracy, and avoid overfitting the model, which is critical when using presence-only data in tools like MaxEnt (Xu *et al.*, 2024). The geographical distribution of the species in the study area is illustrated in Figure 1.

Environmental data

In addition to the occurrence data, environ-

mental variables are the major requirement for the analysis of the current and future distribution of species. The 19 bioclimatic variables were downloaded for current conditions from the WorldClim project (Hijmans *et al.*, 2005), and the biophysics variables (soil, land cover). Environmental variables were carefully selected based on their ecological relevance to the species and their potential to explain distribution patterns. A correlation analysis (Pearson's correlation) was conducted to ensure minimal redundancy among variables. Variables with correlation coefficients > 0.7 were excluded to prevent bias in the model. Variables like temperature and precipitation directly affect the growth, reproduction, and survival of tree species in tropical ecosystems. Studies (Fick & Hijmans, 2017) demonstrate their importance in modelling plant distributions. Variables retained showed significant contribution (> 5%) in preliminary runs of MaxEnt (10 runs of the models), as measured by percent contribution and permutation importance, confirming their predictive value (Table 1).

Table 1. Environmental variables used and their sources.

Bioclimatic/ biophysical variables	Description	Contribution of predictor variables to the model for each species		Resolution	Sources
		<i>Afzelia africana</i>	<i>Pterocarpus erinaceus</i>		
Bio_2	Mean diurnal range (max temp – min temp) (monthly average)	X	X		
Bio_4	Seasonal temperature variation	X	X	2,5 min	(Fick & Hijmans, 2017)
Bio_5	Max temperature of warmest period		X		
Bio_12	Annual precipitation	X	X		
Soil (biophysical v.)	Global soil types	X	X	~0,54 min	(GLCF, 2023)

Future predictions

To evaluate the impact of climate change on species distribution, two models of climate projections datasets established by the project CMIP – 5 (Coupled Model Intercomparison Project Phase – 5) were used: MIROC5 and HadGEM2-ES, following the scenarios based on Representative Concentration Pathways (RCP) RCP4.5 and RCP8.5 recently used for African species in the same study area (IPCC, 2013; Idohou *et al.*, 2017; Fandohan *et al.*, 2015). These models were chosen based on their

relevance to the study region, availability of high-resolution data, and their representation of contrasting climate sensitivity and precipitation patterns under various Shared Socioeconomic Pathways (SSPs). MIROC5, developed by the University of Tokyo, is recognized for its detailed simulation of precipitation dynamics in tropical regions (Taylor *et al.*, 2012). HadGEM2-ES, developed by the UK Met Office, incorporates complex interactions between the atmosphere, biosphere, and land use, making it well-suited

for studies of biodiversity under climate change (Taylor *et al.*, 2012). The Representative Concentration Pathways are four scenarios of reference (RCP2.6, RCP4.5, RCP6.0, and RCP8.5) and are indicative of the trajectory of the evolution of greenhouse gases concentration. These are the most recent results for climate change modelling by combining various fields for the projections (socio-economic, demographic, land use, emissions of CO₂, etc.). The moderate emissions scenarios, RCP4.5, predict that emissions will peak in 2040 and then stabilize, while with the most severe, RCP8.5, they will continue to increase past 2100 (Dowling, 2015; IPCC, 2013). The other RCP scenarios were not used because RCPs' trends for the study area did not diverge dramatically until the late century (IPCC, 2013; Fandohan *et al.*, 2015).

Model performance and validation

The evaluation of the performance and the predictive capacity of each model was done based on the Area Under ROC Curve (AUC) value and the Partial ROC program approach. The area under the ROC (Receiver Operating Characteristics) curve (AUC) provides a measure of the accuracy of predictive distribution models (Lobo *et al.*, 2008). To apply the Partial ROC method, the species occurrence data were randomly divided into two parts: 80% for model calibration and the remaining 20% for model validation or evaluation. Partial ROC Analyses require the occurrence data for

evaluation, the model prediction (ASCII file in the output of MaxEnt), and an estimate of how much error (E) may be inherent in the occurrence data (Peterson *et al.*, 2008). In our study, the value of the error (E) considered was E=5%. As output, the partial ROC uses a random replication to give many results of an AUC ratio (division of the observed AUC by the random AUC). When the distribution of the AUC Ratios is well above 1.0, the model is judged as statistically significantly better than random (Peterson *et al.*, 2008). The Jackknife test was performed using MaxEnt to evaluate the relative importance of each environmental variable by systematically excluding them and measuring their effect on model gain.

Threshold and determination of suitable habitat

To identify which area was suitable for the species, the notion of the threshold has been used. Indeed, MaxEnt produced a continuous raster with values from 0 to 1 representing habitat suitability. To determine which probability value was the minimum value for a suitable habitat, it was considered to include 95% of the calibration. In this case, the minimum threshold of 5% was used to define minimum probability. That approach is a reasonable way to prioritize the correct prediction of presences over that of absences and to take into account the mediocre nature of biodiversity data (Idohou *et al.*, 2017; Peterson *et al.*, 2011).

Table 2. Relative contributions of the environmental variables to the model of each species (Percent contribution).

Species	Mean diurnal range (bio_2)	Seasonal temperature variation (bio_4)	Annual precipitation (bio_12)	Max temperature of warmest month (bio_5)	Types of soil (soil)
<i>A. africana</i>	25.3%	9.4%	18.7%	–	46.4%
<i>P. erinaceus</i>	19.7%	4.3%	20.3%	4.3%	51.4%

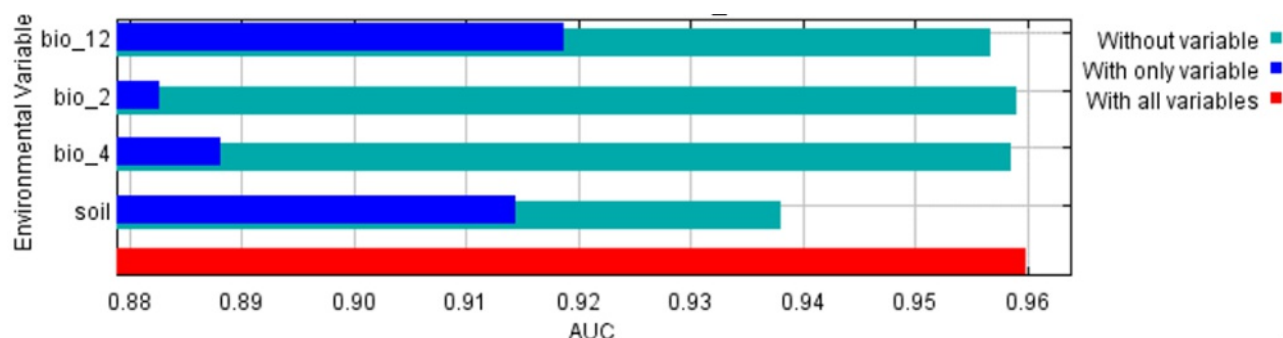


Figure 2. Results of the Jackknife test using AUC on test data.

To show the predicted distributions and analyze them in the context of Benin, the results from all of West Africa at the Benin border were cut out. Four classes were considered for habitat suitability by calculating the probability value that determines each range from areas of low to high suitability with a middle class: medium suitability. The maps had been established using the software QGIS (version 16.0) with the raster files obtained after each model running in MaxEnt.

Results

Contribution of the variables in the model and model evaluation

The correlation test and the results of the Jackknife test revealed four common variables as most important for the distribution modelling of the two species: mean diurnal range of temperature (bio_2), seasonal temperature variation (bio_4), annual precipitation (bio_12), types of soil (soil) and one more for *P. erinaceus*: max temperature of warmest month (bio_5). The analysis of variables contribution showed that the variable types of soil is ranked as having the highest contribution for both species (Table 2). The results showed that the thermal climatic factors (bio_2, bio_4, and bio_5) are represented more and played a great role in controlling the potential distribution of *A. africana* and *P. erinaceus* than the only one hydrological factor represented (bio_12).

The results of the Jackknife test showed that the variable types of soil had significant importance in the modelling distribution of both species. In fact, it is the one that decreased the gain the most when omitted (Figure 2). The value of AUC obtained from simulations of the present data, respectively 0.988 for the *P. erinaceus*' model and 0.989 for the *A. africana*' model, allowed us to say that the models had excellent predictive ability.

Predicted distribution of the species following the current and future climate scenarios in Benin

Under current climatic conditions (Table 3), both species exhibit a strong presence across the study area, with a high proportion of suitable habitats. For *A. africana*, 62,536.93 km² of the habitat is highly suitable, while 27,488.52 km² falls under medium suitability, and only 9,638.82 km² is deemed unsuitable. Similarly, *P. erinaceus* shows 65,853.92 km² of a highly suitable habitat and 22,800.20 km² of medium suitability, with unsuitable areas covering 16,363.17 km². These findings underscore

the species' current widespread distribution and highlight the importance of maintaining these suitable areas for their conservation.

Under the moderate climate change scenario (RCP4.5), the habitat suitability for both species shows some shifts. For *A. africana*, both models predict slight reductions in highly suitable areas (12–13%), with corresponding increases in medium suitability, especially under the MIROC5 model. Unsuitable areas remain relatively stable, with minimal changes (+0.5% for HadGEM2-ES and -0.04% for MIROC5), indicating a relatively stable habitat under moderate emissions. For *P. erinaceus*, the highly suitable areas decrease slightly (3% for HadGEM2-ES and 4% for MIROC5), while medium suitability expands under HadGEM2-ES (+5%), suggesting potential shifts in habitat towards moderately suitable regions.

Under the high-emission scenario (RCP8.5), habitat suitability for *A. africana* and *P. erinaceus* faces considerable changes. For *A. africana*, highly suitable areas decrease sharply by 20–27%, especially under the MIROC5 model, with medium suitability expanding significantly (19% for HadGEM2-ES; 23% for MIROC5), suggesting possible habitat degradation but also an opportunity for adaptation in less ideal areas. Unsuitable areas increase under MIROC5, indicating a higher risk of habitat loss in certain regions. For *P. erinaceus*, highly suitable areas drop notably (8–11%) under both models, while medium suitability grows, particularly under MIROC5 (+14.9%). Low suitability areas also increase under HadGEM2-ES (+5%), but unsuitable regions remain stable, suggesting some resilience despite adverse climate changes (Figure 4).

For *A. africana*, the models indicate that while the species is currently distributed across a wide range of latitudes, future projections show a contraction in the northern parts, which could limit its adaptation to future climate conditions (Figure 3).

For *P. erinaceus*, the northward expansion suggests that this species may be more adaptable to temperature and precipitation changes than *A. africana* (Figure 4). However, this shift could place the species in areas with different ecological pressures, such as competition with other species or altered water availability.

The unsuitable areas are located in the far North and South of the country, covering parts of the departments of Alibori, Atacora, Atlantic, Oueme, Plateau, Mono, and Couffo. Considering all the models, the only protected areas often affected by the unsuitable areas are national parks (parks of Pendjari and Park of W).

Table 3. Evaluation of the potential habitat suitability area for the species studied in Benin under current and future climatic conditions (HadGEM2-ES, MIROC5, RCP4.5 and RCP8.5).

Species	RCP	Models	Unsuitable		Low suitability		Medium suitability		High suitability	
			Areas (km ²)	Trends (%)	Areas (km ²)	Trends (%)	Areas (km ²)	Trends (%)	Areas (km ²)	Trends (%)
<i>A. africana</i>	RCP4.5	Current	9638.82		15098.71		27488.52		62536.93	
		HadGEM2-ES	10252.29	0.5	13537.21	-1.3	43080.59	13	47892.89	-12
		MIROC5	9582.75	-0.04	12449.20	-2	45089.21	15	47641.82	-12
	RCP8.5	HadGEM2-ES	8578.44	-0.9	17428.91	2	50194.44	19	38561.2	-20
		MIROC5	7239.37	-2	21990.129	6	54860.27	23	30673.22	-27
<i>P. erinaceus</i>	RCP4.5	Current	16363.17		9745.70		22800.20		65853.92	
		HadGEM2-ES	13704.58	-2	9708.29	-0.3	29522.45	5	61827.66	-3
		MIROC5	13892.9	-2	7155.67	-2	23266.45	0.4	70447.96	4
	RCP8.5	HadGEM2-ES	13495.36	-2	15755.06	5	32807.37	8	52705.19	-11
		MIROC5	13704.59	-2	4561.21	-4	39963.05	14.9	56534.13	-8

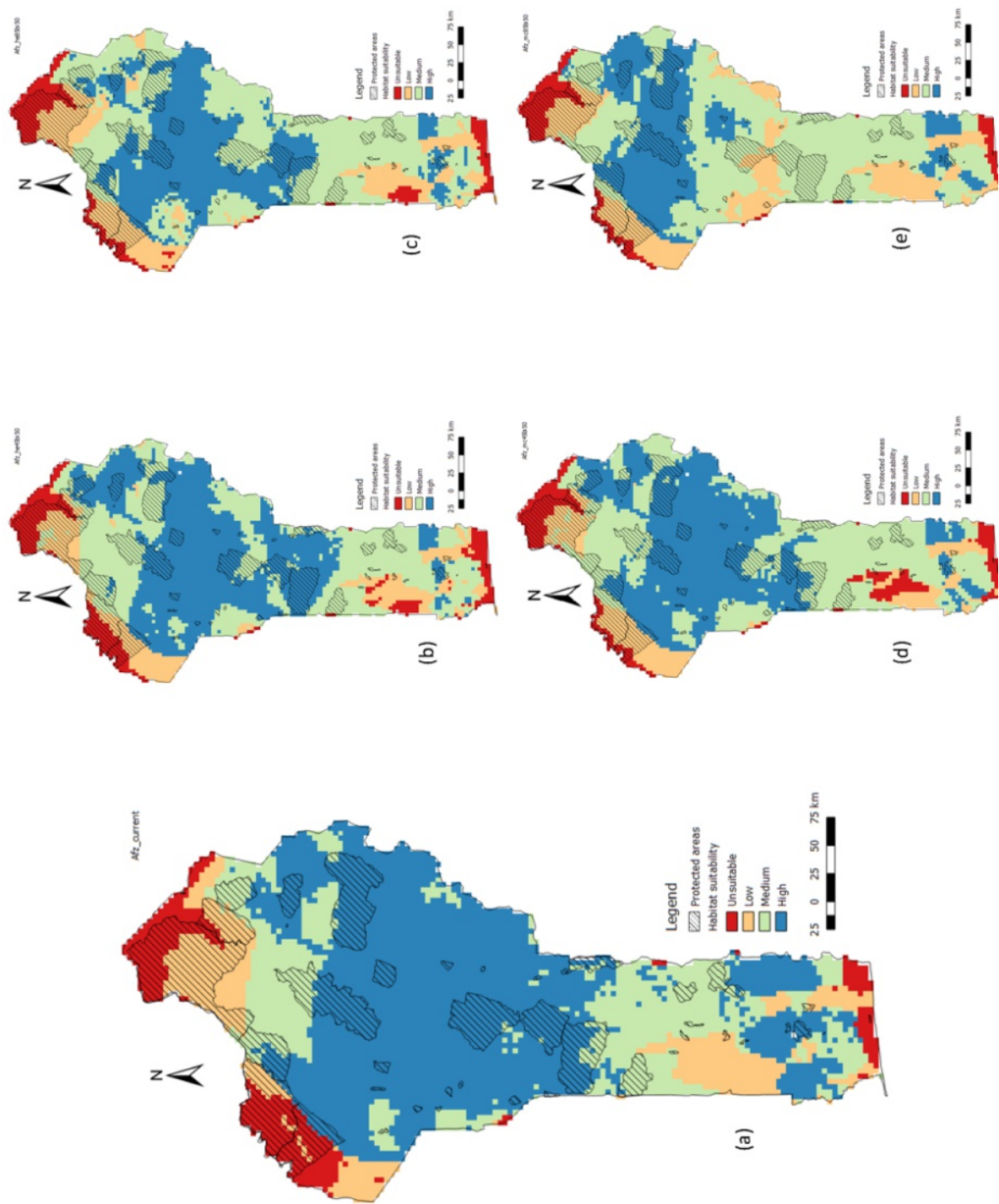


Figure 3. Predicted habitat suitability for *Afzelia africana* in Benin under current and future climate scenarios: (a) Current conditions, (b) MIROC5 RCP4.5, (c) MIROC5 RCP8.5, (d) HadGEM2-ES RCP4.5, and (e) HadGEM2-ES RCP8.5.

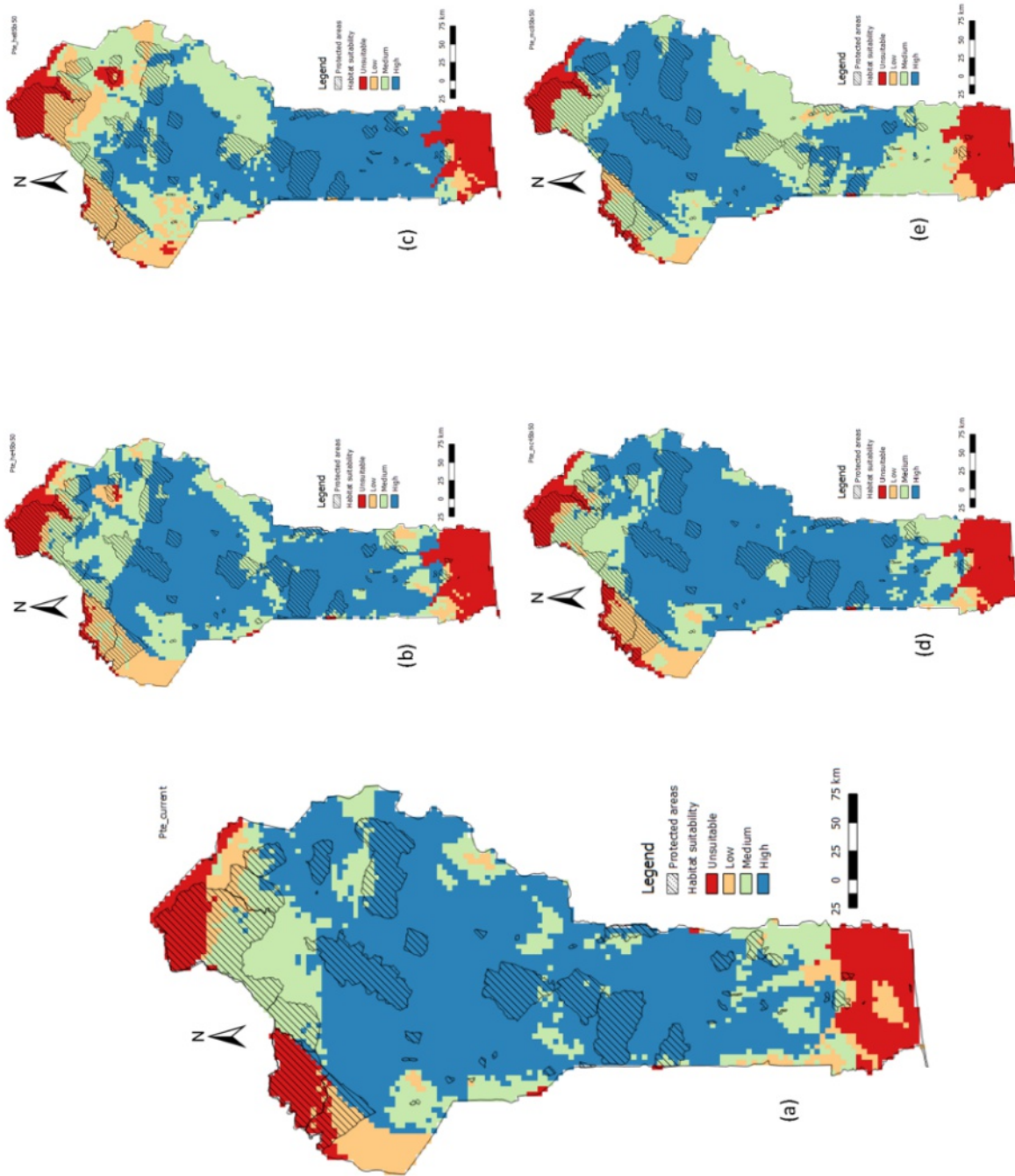


Figure 4. Predicted habitat suitability for *Pterocarpus erinaceus* in Benin under current and future climate scenarios: (a) Current conditions, (b) MIROC5 RCP4.5, (c) MIROC5 RCP8.5, (d) HadGEM2-ES RCP4.5, and (e) HadGEM2-ES RCP8.5.

Discussion

Modelling performance and overall trends

Species distribution models (SDMs) are used to inform a range of ecological, biogeographical and conservation applications (Guillera-Arroita *et al.*, 2015). SDMs establish correlations between occurrence data and climate characteristics, and at a very large scale, climate is the first factor explaining species distribution (Camenen, 2015). MaxEnt was able to establish the relationships between species and habitat based on the environmental variable and occurrence data and to determine the suitable area for each species even at sites where any data were available (Figures 3 and 4). Each model was evaluated with the value of AUC and the Partial ROC and the results showed their excellent performance for the different predictions.

Ecological requirement of species and determinant climatic factors

When analyzing the relative contribution of the environmental variable, it was noticed that the thermal climatic factors (respectively 34.7% for *A. africana* and 28.3% for *P. erinaceus*) affected more the distribution of the two species than the hydrological factor present in the models (18.7% for *A. africana* and 20.3% for *P. erinaceus*, respectively). They gave more useful information to understand the ecological requirements of the two species.

Among the environmental variables included in the models of both species, the variable types of soil had the highest contribution. This result showed its importance for the distribution of many plant species (Fandohan *et al.*, 2015). Ecologically, *A. africana* is found on a wide variety of soils (Gérard & Louppe, 2011). It is also the case for *P. erinaceus* with a preference for acid to neutral soil and shallow soil (Orwa *et al.*, 2009). But it does not mean that they have good growth. By using various occurrence data of the species, the models determine the suitable area corresponding to their ecological preference for their development.

Species distribution modelling

The suitable areas for both species are located mostly in the Sudano-Guinean zone and the Sudanian zone characterized by environmental conditions corresponding to the ecological preference of *A. africana* and *P. erinaceus*. *A. africana* is characteristic of the transitional zone between wooded savannahs and dense dry forests, as well as the dense semi-deciduous forest in more humid regions (Gérard & Louppe, 2011). *P. erinaceus* occurs

in semi-arid to sub-humid tree savannahs and regions with an annual pluviometry between 600 mm and 1200 mm (Duvall, 2008).

The analysis highlights species-specific trends, with *A. africana* showing heightened sensitivity to high-emission scenarios, as evidenced by notable habitat losses and a shift toward medium suitability zones. In contrast, *P. erinaceus* demonstrates relatively better adaptability, maintaining stable unsuitable areas despite reductions in highly suitable habitats. Geographic shifts in both species reveal northward and altitudinal movement of suitable habitats under future climate scenarios, reflecting broader patterns of range changes induced by climate shifts. Notably, MIROC5 projections suggest more substantial habitat changes compared to HadGEM2-ES, underscoring the variability in model sensitivity to climate factors. These trends emphasize the need for adaptive conservation strategies to address species-specific vulnerabilities and future habitat dynamics.

Under current conditions, most districts in the southern and central regions of the country were identified as suitable habitats for the species. However, there is no clear evidence that the species actually inhabit these areas. Other factors, such as interactions between species and the dispersal capacity of species, also play an important role in their distribution (Redon & Luque, 2011). The survey should be continued in the field to determine the real distribution area. With the occurrence data and our model's results, potential distributions of the species obtained were wider than the ones described by Akouègninou *et al.* (2006). The outputs of the models showed that the potentially suitable area for both species is substantial in size. The high rate of suitable habitats observed on the distribution maps ensures that there will be sufficient land for potential future reintroductions or for naturally colonizing populations of the species and some activities of afforestation for these species.

Future distribution of the species

In the current studies on niche modelling and species distributions modelling, it is common to notice the use of climatic models to project the potential change in the distributions of species. Many models of climate projections for 2050 and further exist following four different scenarios (IPCC, 2021). It is better to use the data that are available and carry out the studies required to make recommendations for conservation (Sanchez *et al.*, 2011).

Considering both species, the dynamics of suitability between unsuitable habitats and

suitable ones for all the models (current and future conditions) are stable. The trend values are approximately null in most cases (Table 3). For *A. africana*, the highest value of trends noted is a gain of 2% of the suitable area with MIROC5, RCP8.5. In the case of *P. erinaceus*, all the models show a gain of 2%. When comparing future predictions and predictions under current climate conditions, it was found that there is no real difference in terms of the area occupied by the suitable zone. But the national parks, which are partially unsuitable, presently show the more suitable area under future predictions (the case of *P. erinaceus* on Figures 4b, 4c, 4d, 4e). The two species are known as species that showed wide adaptation to climatic conditions (Duvall, 2008; Gérard & Louppe, 2011).

Biodiversity conservation has traditionally relied on systems of protected areas with static, artificially designated boundaries often established using criteria other than ecological ones, but climate systems, ecosystems, and species ranges are all dynamic (Monzón *et al.*, 2011). Although the results showed that the network of protected areas will remain a suitable habitat for the species, their current range (km²) of distribution in those ecosystems will be affected under current and future conditions.

Protected area networks must integrate new regions with increasing medium suitability, as projected by models like MIROC5 and HadGEM2-ES. *A. africana* and *P. erinaceus* provide vital ecosystem services and economic benefits, making it imperative to adopt sustainable harvesting practices and community-led restoration efforts to mitigate the impacts of habitat contraction. Climate adaptation strategies should prioritize reforestation using climate-resilient genotypes and agroforestry systems in medium suitability zones, enhancing resilience while benefiting local communities. Finally, addressing anthropogenic pressures, such as deforestation and land-use changes, alongside climate-related challenges, is critical for comprehensive and sustainable species conservation.

Conclusion

This study highlights the critical role of species distribution modelling in understanding the impact of climate change on the habitats of *A. africana* and *P. erinaceus*. Both species are economically valuable species, providing timber, non-timber products, and ecological services like carbon sequestration. By integrating current and future climate scenarios, the results reveal that while the network of protected areas in Benin is likely to remain favorable for the conservation of these species in the near future, substantial shifts in habitat suitability are anticipated. The contraction of highly suitable areas could impact livelihoods dependent on these species, particularly in rural communities. These findings suggest the need for adaptive conservation strategies to ensure the resilience of these species to changing environmental conditions. Regions identified as having medium and low suitability could be considered in conservation planning to support the creation of climate-resilient corridors and facilitate species reforestation.

The insights provided by this study serve as a foundation for targeted conservation policies, emphasizing the importance of adaptive management, restoration efforts, and the integration of socioeconomic and ecological considerations. By addressing these challenges, policymakers and conservationists can better safeguard the ecological and economic value of these species for future generations.

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