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Mapping the distribution and habitat suitability of the critically endangered *Aubregrinia taiensis* in Ghana

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ABSTRACT: *Aubregrinia taiensis* is a rare and critically endangered tree species with a highly restricted native range distribution in Ghana, Côte d'Ivoire, and Liberia. In this study, we present a detailed spatial analysis of the distributions of *A. taiensis* across range countries in West Africa. Habitat Suitability Models (HSMs) for the species were developed using the machine-learning maximum entropy (Maxent) method. Bioclimatic environmental variables from the WorldClim database were used to simulate the future distribution of the species based on two greenhouse gas emission scenarios (RCP 4.5 and RCP 8.5) for 2050 and 2070. Our results confirm the species' narrow and highly fragmented population. The current range of *A. taiensis* in Ghana is estimated as 65,123.78 km^2, spanning the upper limits of the south-western wet-evergreen forest, to the lower portions of the forest-savannah transition zone. Four main bioclimatic variables, Bio 10 (mean temperature of warmest quarter), Bio 1 (annual mean precipitation), Bio 5 (maximum temperature of the warmest month), and elevation, were found to influence the occurrence and suitability of *A. taiensis*. Further, our models indicated significant range contractions of 76.4% and 89.6% under both emission scenarios. By 2070, climatic changes could push the species to the brink of extinction. Specific conservation interventions are proposed.
Keywords: biodiversity hotspots; endangered flora; climate change impacts; habitat modeling; Maxent.

Distribuição geográfica e adequação de habitat de *Aubregrinia taiensis* em Gana

RESUMO: *Aubregrinia taiensis* é uma espécie arbórea rara e criticamente ameaçada de extinção, com distribuição nativa altamente restrita em Gana, Costa do Marfim e Libéria. Neste estudo, apresentamos uma análise espacial detalhada das distribuições de *A. taiensis* em países da África Ocidental. Modelos de Adequação de Habitat (HSMs) para a espécie foram desenvolvidos por meio da técnica de aprendizado de máquina por entropia máxima (Maxent). Variáveis ambientais bioclimáticas do banco de dados WorldClim foram usadas para simular a distribuição futura da espécie com base em dois cenários de emissões de gases de efeito estufa (RCP 4.5 e RCP 8.5) para 2050 e 2070. Nossos resultados confirmam a população limitada e altamente fragmentada da espécie. A distribuição atual de *A. taiensis* em Gana é estimada em 65.123,78 km^2, abrangendo os limites superiores da floresta úmida-perene do Sudoeste até as zonas mais baixas da zona de transição floresta-savana. Quatro variáveis bioclimáticas principais — Bio 10 (temperatura média do mês mais quente), Bio 12 (precipitação anual), Bio 5 (precipitação do trimestre mais seco) e altitude — influenciaram a ocorrência e a aptidão de *A. taiensis*. Além disso, em ambos os cenários de emissão, nossos modelos indicaram uma redução significativa da distribuição, de 76,4% e 89,6%. Até 2070, essa redução poderá pôr *Aubregrinia taiensis* em risco de extinção. Diante disso, são propostas intervenções específicas de conservação para mitigar esse risco.
Palavras-chave: hotspots de biodiversidade; flora ameaçada de extinção; impactos das mudanças climáticas; modelagem de habitat; Maxent.

1. INTRODUCTION

Aubregrinia taiensis (Aubrév. & Pellegr.) Heine is a threatened and rare tropical forest tree belonging to the family Sapotaceae. The species has a limited native distribution range in West Africa, sighted only in Ghana, Côte d'Ivoire, and Liberia (HAWTHORNE, 1995; BGCI, 2023). With a declining and highly fragmented population distribution across range countries, *A. taiensis* is currently classified as "critically endangered" on the International Union for Conservation of Nature's Red List of Species (International Union for Conservation of Nature – IUCN, 2025; DABO et al., 2025). Additionally, the tree is amongst the threatened species prioritised as requiring urgent conservation intervention in Ghana (Botanic Gardens Conservation International - BGCI, 2023).

Aubregrinia taiensis was first described by Aubreville and Pellegrini (1935) at the Tai National Park in Côte d'Ivoire. Pennington (1991) later retained the genus *Aubregrinia* in the monograph of Sapotaceae, indicating that it has only one species related to Breviea. The species bears a striking morphological resemblance to another related genus of the same family, *Donella ubangiensis*, with *A. taiensis* distinguished mainly by a less fluted trunk and low buttresses (HAWTHORNE; GYAKARI, 2006). Hawthorne (1995) described the distribution and ecology of *A. taiensis* as "a bit of a mystery," scattered in moist forest, and nowhere known to be even remotely familiar in Ghana or Côte d'Ivoire. In a co-occurrence study by Ouattara et al. (2023), only one immature individual was sighted after 5 years of frantic botanical survey work in and around the Tai National Park in Côte d'Ivoire. Some estimates indicate that two in five plants face the threat of extinction due to climate change and other anthropogenic causes (PENCE et al., 2022). This underscores the need for further research to better understand the distribution and range dynamics of threatened species and to guide conservation actions.

Species Distribution Models (SDMs) or Habitat Suitability Models (HSMs) are useful tools for understanding species' current distributions and anticipated potential future shifts in response to climate change (PETERSON et al., 2011; RATHORE; SHARMA, 2023; DONG et al., 2024). HSMs are often based on georeferenced primary occurrence data, correlated with environmental predictor variables to determine potential distribution or areas of survival for a particular species (PETERSON; SEBERON, 2008; GUISAN et al., 2017). It is typically based on ecological niche theory, which postulates that individual species tend to thrive within specific ranges of environmental conditions (CHASE; LEIBOLD, 2003). HSMs can serve as proxies to determine species' responses to future climatic changes and plan conservation actions (PETERSON et al., 2011; COBAN et al., 2020).

A wide range of computer algorithms exists to undertake HSMs. Still, the Maxent machine-learning maximum-entropy approach has gained popularity due to its ability to fit responses of varying complexity with high predictive performance (PHILIPS et al., 2006; ELITH; GRAHAM, 2009; KASS et al., 2021). Maxent has been widely used in ecological niche studies and other disciplines that require suitability modelling and the prediction of potential future range shifts due to climate change (BUCKLEY et al., 2010; WISZ et al., 2008; COBAN et al., 2020; DONG et al., 2024). HSMs can provide valuable information for threatened species conservation actions, including field surveys to identify unknown populations and site selection for restoration and recovery actions (RAXWORTHY et al., 2003; BOURG et al., 2005; ASASE et al., 2021).

This contribution investigates the current and potential population distribution areas of *A. taiensis* in Ghana. We calibrate HSMs using primary occurrence data and evaluate distributional trends and range changes across present and future climate scenarios. The research questions explored include: (1) What are the current and future potential population distribution of *A. taiensis* in West Africa, particularly Ghana? (2) What are the main climatic variables that influence the distribution of the species using the maximum entropy (Maxent) modelling technique, and (3) how will anticipated future climatic changes affect the range and distribution of *A. taiensis* in Ghana? Finally, we discuss the implications of these results on conservation interventions across range countries.

2. MATERIAL AND METHODS

2.1. Occurrence and Climatic Input Data

Geo-referenced past and present occurrence data were obtained from several sources within the native range countries. These included the Global Biodiversity Information Facility (GBIF, www.gbif.org), taxonomic scientific literature, past and present species inventory records from Forest management authorities, and data from on-the-ground botanical surveys conducted by researchers from the CSIR-Forestry Research Institute of Ghana (CSIR-FORIG) between 2019 and 2024. Table 1 summarizes occurrence data sources and the number of records obtained.

Guided by the apparent shortcomings of GBIF data sources (Yesson et al., 2007), occurrence records were carefully checked and vetted to remove erroneous and duplicate datapoints, reducing geolocation overlaps to below 5%. Further, to minimise the effects of spatial autocorrelation and pseudo-replication in areas with higher occurrence, the filtering distance between points was visually inspected, and no pairs of points were closer than 10 km apart (BORIA et al., 2014).

Table 1. Sources of sighting records for *A. taiensis* within the range countries
Tabela 1. Fontes de registros de avistamentos de *A. taiensis* em países de distribuição

Data source	Number of records			
	Ghana	Cote d'Ivoire	Liberia	Total
GBIF	11	9	3	23
Inventory records	4	4	-	8
Taxonomic literature	5	3	2	10
Field surveys	27	1	-	28
Total geo-referenced	38	10	3	51

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For climatic variables, 15 were obtained from the WorldClim database (version 4.3; Fick, Hijmans, 2017) at a spatial resolution of 30 arc-seconds (approximately 1 square kilometer, 30s, ~1 km²). Four variables that combine temperature and precipitation (Bio 8, Bio 9, Bio 18, and Bio 19) were excluded due to known artefacts (Escobar et al.,

2.2. Model calibration

The Maxent computer modelling procedure was closely followed (version 3.4.4; PHILLIPS; DUDÍK, 2008; BOOTH et al., 2014). All layers (occurrence and environmental), including clipped rasters (ASCI files) of the study locations from WorldClim, were uploaded to Maxent using the extraction tool in QGIS, a computer spatial analysis software. Further, 25% random subsets of the occurrence data were used for model calibration, with a maximum of 10 iterations across 39 sample replications. The Jackknife test was enabled in the model's parameter settings to assess the extent to which each environmental factor contributed to the prediction. Additionally, response curves were generated to depict the relationship between the probability of occurrence and ecological variables (COBAN et al., 2020; DONG et al., 2024).

2.3. Post-Modelling Evaluation and Future Projections

During post-modelling evaluation, model parameters such as the Receiver Operating Characteristics test (ROC) Area Under the Curve (AUC), were used in assessing the predictive power of the model; selecting the best performances as those with an AUC ratio ≤1 (FIELDING; BELL, 1997; ASASE et al., 2020; COBAN et al., 2020).

To predict and assess potential future distribution and range losses for the species in Ghana, the current distribution was compared with model-predicted future range changes under climate change impact scenarios. We used the widely adopted Representative Concentration Pathways (RCP) scenarios adopted by the fifth Intergovernmental Panel on Climate Change (IPCC, 2014). These greenhouse gas emission scenarios have enabled researchers to conduct

2014; Asase et al., 2020). To reduce data dimensionality and multilinearity in the model, environmental variable datasets were first subjected to a Pearson correlation analysis, and each pair of variables with a correlation coefficient (r > 0.8) was excluded (PETERSON et al., 2007; ASASE et al., 2020). This was to avoid using non-independent variables in the model calibration.

climate studies of the past, present, and future (Coban et al., 2020; Asase et al., 2021; Dong et al., 2024). While RCP4.5 is depicted as an intermediate medium stabilisation and the most probable scenario, RCP8.5 indicates a high baseline emission, generally considered the basis for a worst-case climate change scenario (Van VUUREN et al., 2011; HAUSFATHER; PETERS, 2020). RCP.4.5 and RCP 8.5 datasets for 2050 and 2070 were obtained from the WorldClim database as raster files, clipped to the study location, and uploaded to Maxent for future distribution modelling. All Bias values for the selected variables were applied to the projection data for both years.

Subsequently, to evaluate the extent of range shift and contraction for the species, data points for suitable areas on the HSM were converted to polygons and trimmed using the raster-vector convertor function in QGIS (COBAN et al., 2020). The estimated ground area occupied by these polygons was calculated in square kilometres (km²) using the Intersection Analysis feature in QGIS. The differences in range sizes were then computed and compared to determine contraction.

3. RESULTS

Of 73 *Aubregrinea taiensis* sighting/occurrence records from different sources across the native range countries, only 51 were georeferenced and thus suitable for digitised mapping (Figure 1). Plotting these points on a map confirms the rarity and narrow distribution range of the tree species in West Africa (Figure 1). The maxent model evaluation parameters showed that after 39 replicated test runs, the model achieved maximum training and test sensitivities of 0.055 and 0.263, respectively.

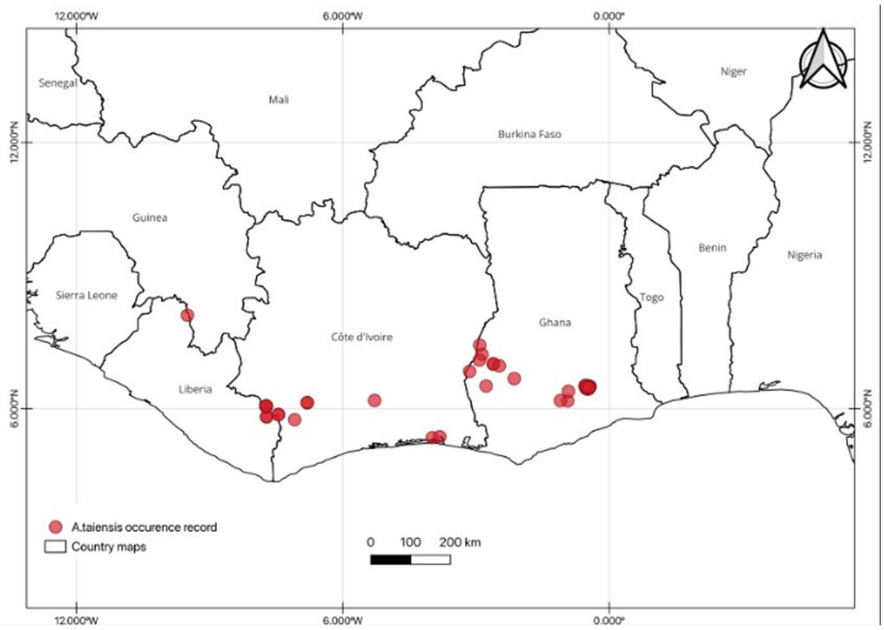

Figure 1. Population distribution of *A. taiensis* in Ghana, Côte d'Ivoire, and Liberia based on present and past occurrence records
Figura 1. Distribuição populacional de *A. taiensis* em Gana, Costa do Marfim e Libéria com base em registros de ocorrência presentes e passados.

The receiver operating characteristic (ROC) curves showed AUCs of 0.934 and 0.946 for the training and test data, respectively (Figure 2). The test data (blue line) in Figure 2 denotes the model's fit, which is the real test of the model's predictive power (FIELDING; BELL, 1997; PHILLIPS; DUDIK, 2008).

Furthermore, the Maxent model image outputs with multiband colouration represented a Habitat Suitability Map (HSM) for the species in Ghana (Figure 3). Warmer colours on the HSM indicated areas with more accurately predicted conditions for the species' occurrence. Therefore, on the HSM, red indicated a high probability of suitable conditions for the species, green indicated conditions typical of those where the species is found, and lighter shades of blue indicated a low predicted probability of suitable conditions (PHILLIPS et al., 2006). Also, a habitat suitability index (ranging from 0 to 1) was provided to assess the model's suitability. The HSM for A. taiensis showed very low suitability in the Northern parts and in some portions of the southwestern wet-evergreen forests in Ghana.

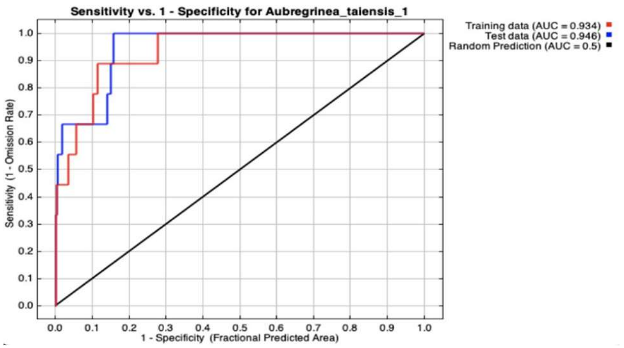

Figure 2. The receiver operating characteristic (ROC) curve indicates the AUC for training and test data from the Maxent model.
Figura 2. Curva ROC (Receiver Operating Characteristic) indicando a AUC (Área sob a Curva) para os dados de treinamento e de teste do modelo Maxent.

Additionally, the Maxent model produced a percentage-based tabular ranking of environmental variables, indicating which variables were most informative for predicting the species distribution in Ghana (Table 2). These percentage contribution values are heuristically defined; largely depending on the particular algorithm adapted by the programme to optimise outputs (PHILIPS; DUDIK, 2008). The test revealed that although all bioclimatic environmental variables were necessary for the modelling, Bio 10, Bio 1, Bio 5, and Elevation variables contributed more than the rest. Figure 4 shows the Jack-knife test output from Maxent, indicating the contribution of each bioclimatic variable to the model under the regularised training gain.

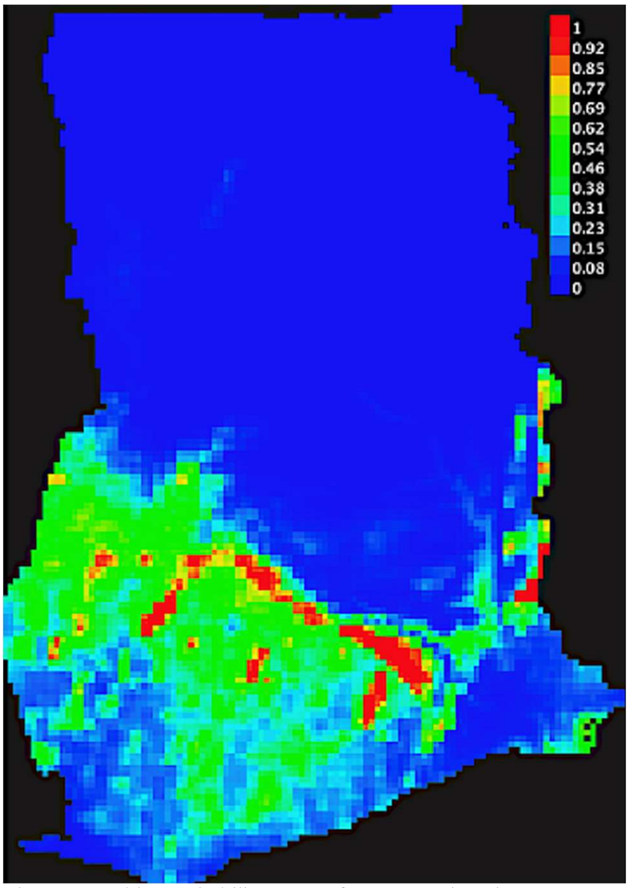

Figure 3. Habitat Suitability Map of *A. taiensis* in Ghana. Warmer colours indicate areas with better predicted conditions for the species' occurrence.
Figura 3. Mapa de Adequação de Habitat de *A. taiensis* em Gana. Cores mais quentes indicam áreas com melhores condições previstas para a ocorrência da espécie.

Table 3 and Figure 5 present the impact of future climatic conditions on the distribution of the A. taiensis population and habitat suitability in Ghana under the RCP 8.4 and RCP 8.5 emission scenarios. Our results indicate that the current native range of *A. talents* in Ghana is estimated at 65,123.78 km^2, spanning the upper limits of the Southwestern wet-evergreen forest to the lower portions of the forest-savannah transition zone. Both climate scenarios indicated significant habitat contraction of 76.4% and 89.8% for RCP4.5 and RCP8.5, respectively, by 2070.

Tabela 2. Contribuição percentual das variáveis ambientais WorldClim obtidas para o modelo
Table 2. Percentage contribution of the cropped WorldClim environmental variables to the model

Bioclimatic variable	Description	Unit	Contribution (%)
Bio 10	Mean temperature of the warmest Quarter	°C	44.1
Bio 1	Annual mean temperature	°C	14.5
Bio 5	Maximum temperature (warmest month)	°C	7.7
Bio 1	Annual mean temperature	°C	7.5
Bio 17	Precipitation of the driest quarter	mm	7
Elevation	Elevation	m	5.7
Bio 12	Annual precipitation	mm	5.4
Bio 14	Precipitation of the driest Month	mm	2.5

Bio 15	Precipitation seasonality (coefficient of variation)		2.4
Bio 6	Minimum temperature of the coldest month	°C	1.9
Bio 7	Temperature annual range (BIO5-BIO6)	°C	0.8
Bio 13	Precipitation of the wettest month	mm	0.6
Bioclimatic variable	Description	Unit	Contribution (%)

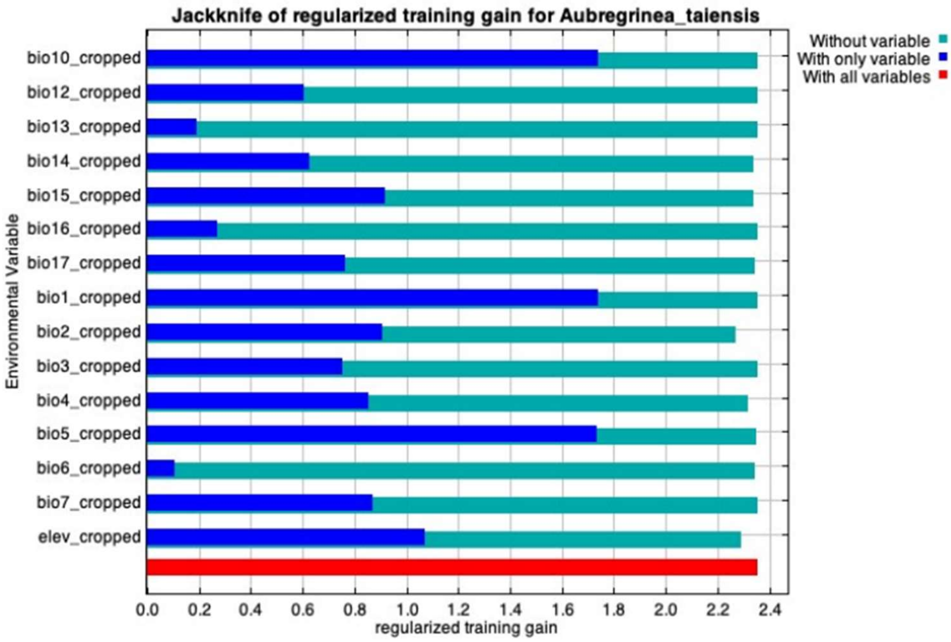

Figure 4. Jack-knife test results from Maxent modelling of A. taiensis in Ghana.
Figura 4. Resultados do teste de Jackknife da modelagem Maxent de A. taiensis em Gana.

Table 3. Predicted range contraction of *A. taiensis* in Ghana based on the two climate change models (RCP 4.5 and 8.5).
Tabela 3. Redução da distribuição prevista de *A. taiensis* em Gana com base nos dois modelos de mudança climática (RCP 4.5 e 8.5).

Climate scenarios	Current range (km^2)	Predicted range (km^2)		Percentage range loss	
		2050	2070	2050	2070
RCP 4.5	65,123.78	41,762.193	15,343.471	36.0	76.4
RCP8.5	65,123.78	54,584.527	6,619.972	16.8	89.8

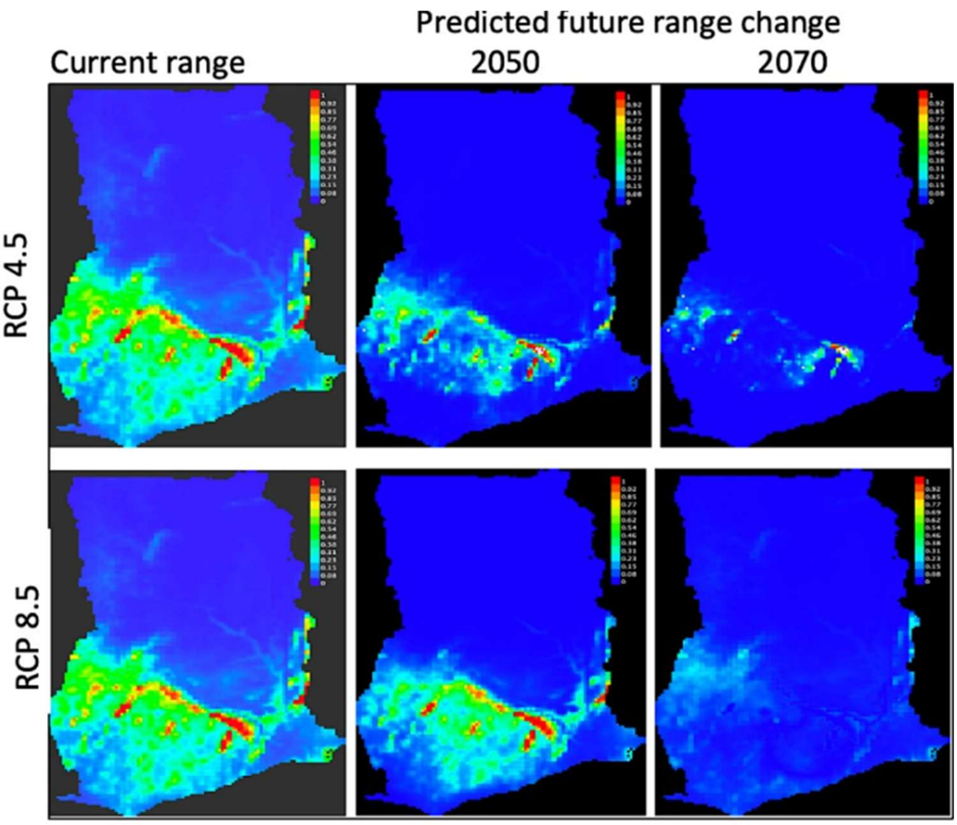

Figure 5. Model transfers to future climate conditions for the *A. taiensis* distribution in Ghana under two greenhouse gas emissions scenarios (RCP 4.5 and RCP 8.5).
Figura 5. Projeções climáticas de modelos para condições futuras da distribuição de *A. taiensis* em Gana sob dois cenários de emissões de gases de efeito estufa (RCP 4.5 e RCP 8.5).

4. DISCUSSION

The advent of computers and modelling algorithms has enabled scientists to understand the current distribution of plant species and to predict better their potential range based on climate scenarios (THIBAUD et al., 2014; JOSE V; NAMEER, 2020; COBAN et al., 2020; ASASE et al., 2020). Such models can be highly valuable for targeting conservation and restoration actions, such as field surveys to accelerate the discovery of unknown populations (PEARSON et al., 2007).

This study presents the first detailed analysis of the geographic distribution of the Aubregrinea taiensis population across range countries in West Africa, with particular emphasis on Ghana. The distribution mapping confirms the species' restricted, highly fragmented native range, as reported in earlier studies (HAWTHORNE; GYAKARI, 2006; OUATTARA et al., 2023). Past and present known occurrence records in West Africa indicate that *A. taiensis* will be more prevalent within the area classified as the Eastern Guinean Forest's Ecoregion of West Africa. (ECOREGIONS, 2021). This area extends from the east banks of the Sassandra River in western Côte d'Ivoire to the edge of Lake Volta in Ghana. Tropical and subtropical moist broadleaf forest species characterise it. Remarkably, the model predicted certain suitable areas in Ghana where no occurrence of *A. taiensis* has ever been recorded. In such cases, Asase et al. (2020) suggest that intensified survey efforts could lead to the rediscovery of new populations within such areas.

Modelling the present and future distribution of the species in Ghana with Maxent further revealed the species' vulnerability to future climatic changes. Granted, the accuracy of HSMs depends on the quality of occurrence data, selection of predictor variables, and the algorithm adopted (ARAÚJO; GUISAN, 2006; ASASE et al., 2020). Further, the problem of model under- and over-fitting is often encountered with small data sets. These problems can be overcome as shown in several other studies (PEARSON et al., 2007; PAPEŞ; GAUBERT, 2007). The present study has shown that the habitat suitability of *A. taiensis* in Ghana extends from the upper limits of the southwestern wet-evergreen forest to the forest-savannah transition zone, covering an estimated area of 65,123.78 km². Areas with higher predicted occurrence conditions for the species were found in Ghana's southeastern semi-deciduous forests. Known forest reserves in these areas, such as the Wurobong and Southern Scarp Forests, still shelter remnant and viable populations of species. This finding confirms the results of field surveys conducted by the CSIR-Forestry Research Institute of Ghana between 2019 and 2024 for the species (CSIR-FORIG, 2024).

Furthermore, this study shows that the present and future geographic distribution of *A. taiensis* was closely correlated with environmental variables. The main independent bioclimatic variables, according to the model, that determine the occurrence and suitability of *A. taiensis* were Bio 10 (Mean temperature of warmest quarter), Bio 1 (Annual mean temperature), Bio 5 (Maximum temperature of the warmest Month), and Elevation. These variables indicated varying influence on the probability of the species' occurrence, as shown by the model response curves (Figure 6). For instance, the likelihood of species occurrence seems to increase with elevation, confirming the findings of Hawthorne and Gyakari (2006) that *A. taiensis* is mainly found in Hilly montane forests. Similarly, *A. taiensis* occurrence and suitability appear to increase with annual precipitation (Bio 12). Rainfall has been shown to influence species' distribution (Amissah et al.,.2018; Engelbrecht et al., 2007; Toledo et al., 2012), and drought tolerance is a particularly relevant constraint on tropical species (BALTZER et al., 2008; ENGELBRECHT et al., 2007).

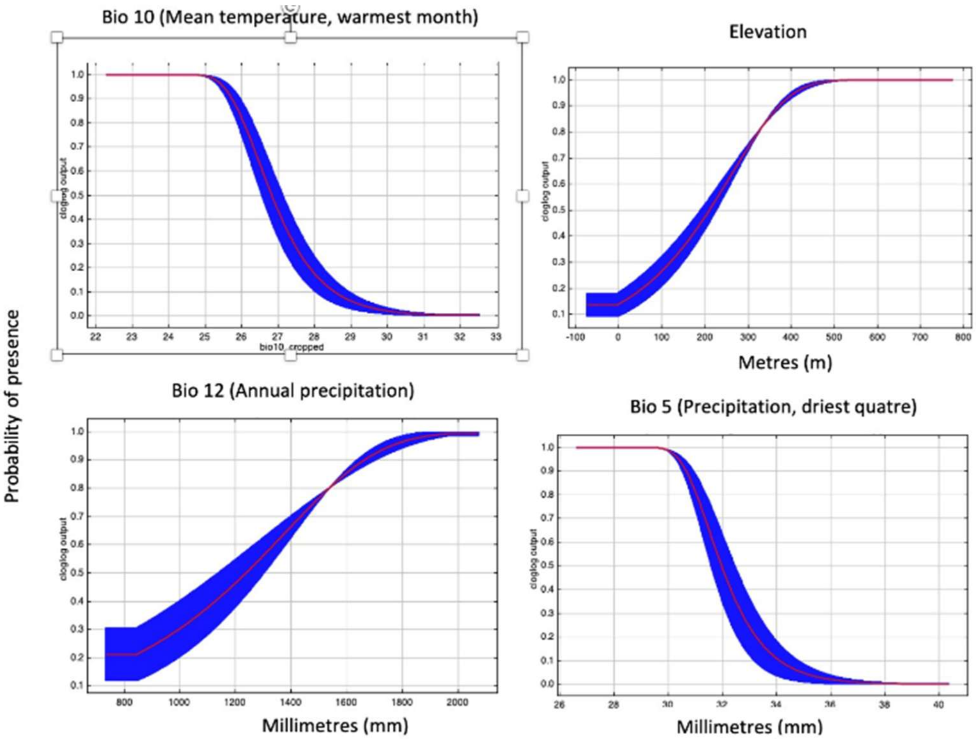

Figure 6. Model Response curves for *A. taiensis* in Ghana.
Figura 6. Curvas de resposta do modelo para *A. taiensis* em Gana.

The modelled future geographic distribution of *A. taiensis* in Ghana showed significant range shifts and contractions under both greenhouse gas emission scenarios. It is alarming to note that both models under the optimistic mid-range carbon-emission scenario (RCP 4.5) and the more pessimistic high-carbon-emission scenario (RCP 8.5) indicate significant range contractions of 76.4% and 89.6% by 2070. These scenarios undoubtedly push the species to the brink of extinction. Anticipated future climatic changes would severely impact the distribution range and habitat suitability of the already imperiled A. taiensis. The ability of plant species to adapt or move into new areas of suitable conditions will be critical for their future survival (Pearson; Dawson, 2003). Granted, some possible adaptation may occur due to differences in genetic and physiological tolerance and dispersal ability at the individual level.

5. CONCLUSIONS

This study confirms the restricted native range of A. taiensis in West Africa, particularly in Ghana. Future climate change would cause severe habitat loss for the species. We therefore recommend specific precautionary actions for all stakeholders, especially forest management authorities in range countries. These may include: developing conservation action plans for the species, conducting guided field surveys to discover new populations for in situ protection, identifying and protecting seed sources, conducting genetic studies to enhance resilience, and conducting research on propagation improvements.

Taking further steps to address other factors besides climate change, such as deforestation, habitat degradation, clear-cutting, agricultural expansion, and bushfires, will, no doubt, complement these actions in securing the future of this important but threatened tree species.

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