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Research Article

Bioclimatic Modeling of Current Geographic Distribution and Future Range Shifts of Selected Edible Mushrooms in Nigeria

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ABSTRACT

Mushrooms, as part of the fungal kingdom, are essential components in nutrient cycling and carbon retention in terrestrial ecosystems. Monitoring the impact of climate change on fungi in their natural habitat is difficult because most species reside below the soil surface. As a result of a few reported occurrence records in Nigeria, we model the species distribution of two edible mushrooms, namely, *Pleurotus ostreatus* and *Macrolepiota procera*, using MaxEnt to predict the potential future range shifts under different climate change scenarios. In this study, we have calculated high model performances based on the Area under Curve (AUC) values generated (0.778-0.873). Using this modeling approach, the two species were predicted to have an expansion of their localized fundamental niches, pointing to the influence of precipitation as an important macroclimatic predictor. Highly suitable habitats for the two species were discovered primarily in Southern Nigeria, with less habitat suitability in the North-central Zone in 2050. The predicted models in this study do not tell missing geographical information, which could be achieved through citizen science for occurrence records and biodiversity conservation. However, they may be used to explore potentialities, such as understanding the possible distribution patterns of the two mushroom species in Nigeria. This can serve as a useful baseline to enhance the utilization and conservation efforts of these macrofungi as a result of climate change, habitat loss, and rapid urbanization.

Keywords: Biodiversity, Climate change, Conservation, Macrofungi, *Macrolepiota procera, Pleurotus ostreatus*

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INTRODUCTION

The impact of climate change has since been considered the most significant risk to humans (Tiedje *et al*., 2022) and the entire ecosystem. Furthermore, the situation has become more severe, and 3.3 billion people on the planet are currently believed to have become highly vulnerable to the effects of changing climates, following a recent assessment by the Inter-Governmental Panel on Climate Change (IPCC) (Intergovernmental Panel On Climate Change, 2023). They also reported that unsustainable growth patterns have placed humans and the environment at greater risk from climatic threats (IPCC, 2023). By the end of this decade of the twenty-first century, the IPCC predicts that the global average temperature will have increased by 1.8 to 4°C. It has become evident that the temperatures are changing; over the last century, temperatures rose 1° C faster than the average global warming rate (IPCC, 2023).

Nearly the entire terrestrial ecosystem on Earth has many fungi (Bahram & Netherway, 2022). The enormous and diverse collection of species known as fungi, classified as a distinct kingdom, are essential to the cycling of nutrients and the retention of carbon (Corbu *et al*., 2023). Mycorrhizal and saprotrophic fungi, which includes the mushrooms, are two of the major functional categories in the fungal kingdom, which play a role in controlling the overall carbon as well as the cycling of nutrients (Stuart & Plett, 2020). Mycorrhizal fungi, including arbuscular mycorrhizal fungal species, ectomycorrhizal fungi, and ericoid mycorrhizal fungal species, constitute mutually beneficial associations with plants. In these associations, the fungal organisms can acquire carbon from the plants they colonize andconvey nutrients to their plant host (Wahab *et al*., 2023). Such mutually beneficial relationships may boost the capability of plants to retain CO_2 in the soils (Hannula & Morriën, 2022). By retaining nutrients from decomposed organic matter, saprotrophic fungal species, as opposed to mycorrhizal fungal species, sustain the entire global flow of nutrients while contributing to the carbon cycle (Janowski & Leski, 2022). In order to regulate the worldwide carbon cycle, a phenomenon directly related to the effects of climate change, fungi are therefore crucial (Gao *et al*., 2022). Yet, scientists are still lacking a good understanding regarding the way predicted changes in the climate could influence the range and distribution of fungi.

Monitoring the reaction of fungi to climate changes in their natural habitat is difficult due to the fact that most fungi reside either on substrates or below the surface. However, a notable group of fungi, known as macrofungi, generates noticeable fruiting bodies that emerge above the soil (Ma *et al*., 2022). These varieties of mushrooms can be employed to record the presence of mushrooms and investigate how they respond to their environment (Martinez-Medina *et al*., 2021). Considerable diversity exists in fruiting body types and their nutritional roles in the nitrogen and carbon cycle, particularly within the Agaricomycetes group, which is a prominent and plentiful category of fungi (Sanchez-Garca *et al*., 2020). Previous studies suggest that the evolving climate has already influenced the growth, development, distribution, and physiological processes of macrofungi (Han *et al*., 2023). Examining a particular case, it has been observed that the specific timing of macrofungi fruiting is influenced by climate and has undergone changes over the centuries (Shiryaev, 2021); the fruiting trends of a number of species of fungi showed altitudinal upward changes between the years 1960 and 2010 (Diez *et al*., 2020). However, very little research projected that possible future changing climate circumstances would alter the range and distribution of macrofungi in Nigeria. To predict future ecological shifts, it is crucial to comprehend how these fungi respond to changes in the climate (Yu *et al*., 2023).

According to Arneth *et al*. (2020), projections concerning how biological diversity will alter due to the effects of climate change are essential for notifying scientists and policymakers of possible challenges in the years to come, bolstering the connection between the biological alterations and changing climates, and assisting in the development of preventive measures to mitigate the detrimental impact caused by climate change on the preservation of biodiversity. Species distribution modeling (SDM) is a method to forecast and define the exact range of any given species (Piirainen *et al*., 2023). This could be accomplished with presence-only data and ostensible ambient variables (Elith *et al*., 2020). CLIMEX, GARP, HABITAT, and Maxent are standard techniques for determining the current and projected geographical distribution of a particular species under various changing climate conditions (Corbu *et al*., 2023). The maximum entropy (MaxEnt) algorithm, one of the presence-only modelling techniques, is receiving a greater spotlight primarily as a result of its comparatively better prediction accuracy (Tesfamariam *et al*., 2022). Maxent modeling calculates the impacts of changing climates on numerous species of fungi (Alkhalifah *et al*., 2023). This approach was utilized to examine the current and projected distribution of macrofungi. Thus, the current investigation aimed to predict the potential influence of climate change on the distribution of two significant macrofungi species in Nigeria.

MATERIALS AND METHODS

Study Area and Species Occurrence Records

This study is on the distribution of two edible mushrooms in Nigeria, a country in the sub-Sahara with an area of 923,770 km^2. The research area covers most of the Southern and small parts of

Northern Nigeria. Occurrence records were obtained during field surveys in forests with an enormous number of trees. The locations where a species is present enable the exploration of the relationship between the species' geographic distribution and the associated environmental conditions across the entire study area (Rotenberry & Balasubramaniam, 2020). Data on the locations of the two edible mushrooms (*Pleurotus ostreatus* and *Macrolepiota procera*) were obtained from macro fungi surveys. The records include measurements of longitude and latitude obtained using a GPS (Global Positioning System) device.

Environmental Variables acquisition and processing

Using the WorldClim database (http://www.worldclim.org/), 19 bioclimatic indicators along with associated data on elevation (Scientific Data Curation Team, 2020) and Climate data were obtained from the Africlim database (**http://www.york.ac.uk/environment/research/kite/resource**; accessed on 10 September 2023). We downloaded 45 bioclimatic variables using the 2.5 arc-minutes resolution. Representative Concentration Pathways (RCP 4.5) for the future scenario (2055) were downloaded and utilized to determine the potential future geographical distributions of the two fungal species. Other files were downloaded for the current scenario, covering 1950 to 2000.Therefore, bioclimatic variables with odd spatial artifacts in species distribution modeling were excluded from further analyses. Moreover, since environmental variables are usually spatially correlated, *VIFcor* was used for the multicollinearity test. Finally, five environmental variables were selected for the MaxEnt model development and calibration for analysis in the SDM package in R (Naimi, B., & Araújo, M. B. (2016).

Modeling and Data Analysis

The distribution of habitat under both present and projected effects of climate change circumstances was simulated using maximum entropy methods for modeling employed by MaxEnt version 3.4.1 (Phillips & Dudík, 2008). The MaxEnt model was configured with the following parameters: maximum iterations = 10,000, convergence threshold = 0.0001, output format = logistic, random test percentage = 25, regularization multiplier = 1, the maximum number of background points (as pseudo-absent points) = 10,000. 25% of the event data was employed for testing, while 75% of the records were employed for training the model. MaxEnt is a general model that performs well even with small samples for forecasting species distributions using solely occurrence data (Fourcade *et al*., 2014).

To assess the possible range of *Pleurotus ostreatus* and *Macrolepiota procera*, the model was run using five bioclimate variables and 1885 presence-only sites. The occurrence records were divided into two semi-independent groups that included 75% and 25% of the data used for model training and testing, respectively (Alkhalifah *et al*., 2023). To assess the error and compare the consistency of the models, the models were fitted to the entire data set using 10-fold cross-validation (Levman *et al*., 2023). The area under the curve (AUC) was used to assess the model's performance. The AUC can range from 0.5 to 1.0; values above 0.9 indicate a good performance (White *et al*., 2023). The jackknife test was used to discover bioclimatic variables important in assessing the potential spread of target species. In addition, the predicted model accuracy was estimated using the true skill statistic (TSS) (Poudel *et al*., 2023). The TSS value can vary from −1 to 1; positive values close to 1 indicate a strong association between the predictive model and the distribution, and negative values indicate a weak association (Hosni *et al*., 2022).

RESULTS

Evaluation of Model Performance and Variable Contribution

Table 1. Model evaluation statistics of the mean AUC and TSS.

Methods	*Macrolepiota procera*	*Pleurotus ostreatus*
AUC	0.89	0.89
COR	0.1	0.08
TSS	0.73	0.76
Deviance	0.66	0.64

The results of the model for the *Macrolepiota procera* and *Pleurotus ostreatus* were reliable, following the AUC and TSS values (>0.8) and (>0.7), indicating good predictions (Table 1). The environmental variable with the highest contributions for *Macrolepiota procera* is tasmax_6_wc150s (% contribution = 22.02% and Permutation importance = 9.47%), and *Pleurotus ostreatus* is pr_5_wc150s (% contribution = 29.41% and Permutation importance = 8.13%). They were the most significant environmental variables for the model forecasts, and the cumulative for the top three contributions was 63.21% (*Macrolepiota procera*) (Table 2a) and 76.77% (*Pleurotus ostreatus*) of the total contribution (Table 2b).

The environmental variables that contributed to the models for the two plants were mainly temperature and precipitation-related variables.

Table 2a. Environmental variables and their percentage contributions to *Macrolepiota procera*

Variable	Description	% Contribution	Permutation Importance
pr_4_wc150s		19.70	8.47
pr_8_wc150s		11.47	4.93
pr_12_wc150s		7.02	3.02
tasmax_2_wc150s		21.49	9.24
tasmax_6_wc150s		**22.02**	**9.47**
tasmax_8_wc150s		18.30	7.87

Table 2b. Environmental variables and their percentage contributions for *Pleurotus ostreatus*

Variable	Description	% Contribution	Permutation Importance
pr_3_wc150s		12.92	3.57
pr_5_wc150s		**29.41**	**8.13**
pr_9_wc150s		23.52	6.50
tasmax_7_wc150s		10.31	2.85
tasmax_12_wc150s		23.84	6.59

Current and Conditions of the Potential Distribution of *Macrolepiota procera* and *Pleurotus ostreatus*

We conducted modelling and prediction under current and future climatic scenarios. As shown in Figure 1a&b, our result represents our projections of suitable habitat for *Macrolepiota procera* and *Pleurotus ostreatus* under current climate conditions, whereas Figure 2a&b represents future climate conditions. Our projections suggest that a considerable portion of the Lagos region, covering another part of southern Nigeria, is an appropriate habitat for *Macrolepiota procera* and *Pleurotus ostreatus*. These regions correspond to most of the observed occurrences for the species.

Future Climate Conditions of the Potential Distribution of *Macrolepiota procera* and *Pleurotus ostreatus*

Under future climate change scenarios in 2055, the potential distribution for *Macrolepiota procera and Pleurotus ostreatus* will decrease according to the model predictions. The forecasts under RCP scenarios indicate a variety of distribution patterns and constant appropriate range shrinkage. Under the RCP scenarios, we projected that environmental conditions suited for the two plants would shift towards the Southern part of Nigeria, with less habitat suitability in the Northcentral zone in 2050. In the western region (especially Oyo, Lagos, Ogun, and Ondo states) and some parts of Edo, Ebonyi, Cross River, and Imo states, the potential distribution of *Pleurotus ostreatus* will increase under RCP4.5 in 2055. However, in the same RCP4.5 scenario in 2055, the suitable habitats for the distribution of *Macrolepiota procera* will decrease with little increase in Delta, Imo, Abia, and Akwa-Ibom States.

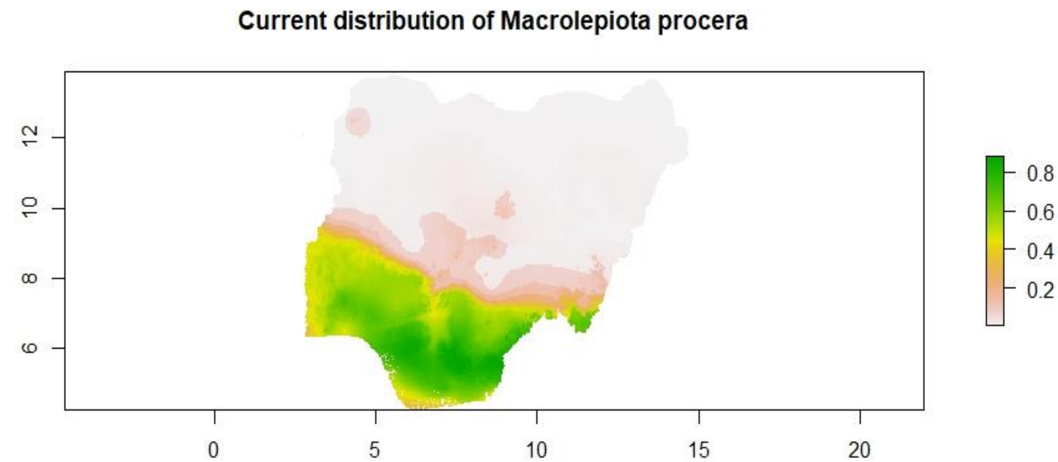

Figure 1a. Predicted habitat suitability of *Macrolepiota procera* under current climatic conditions.

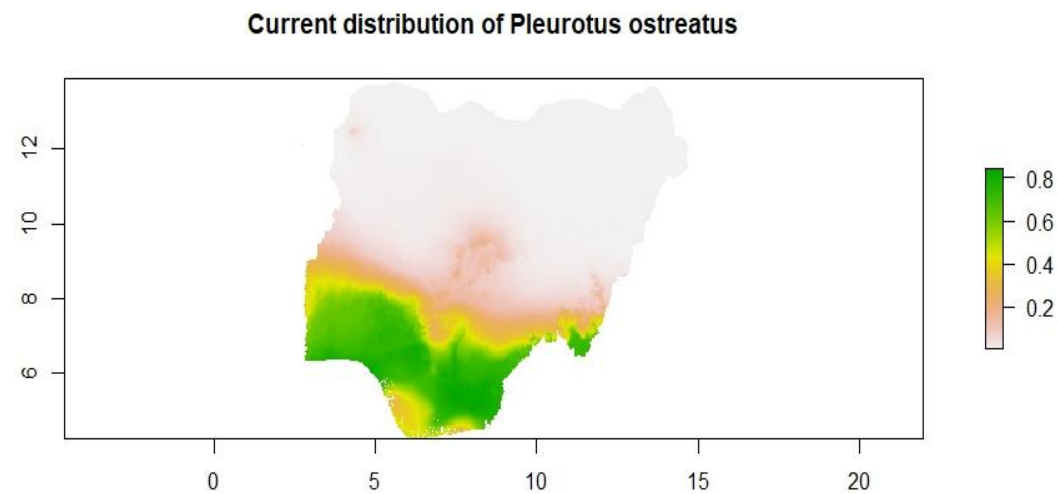

Figure 1b. Predicted habitat suitability of *Pleurotus ostreatus* under current climatic conditions.

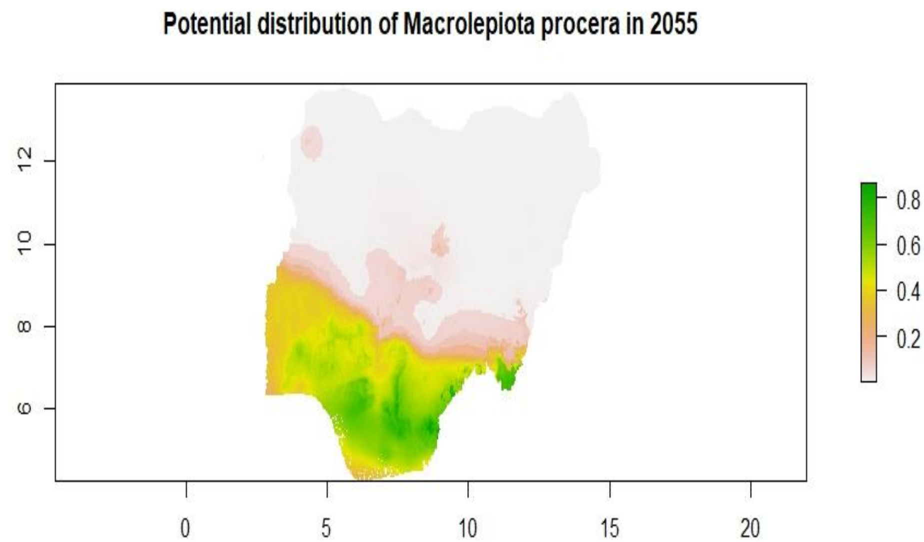

Figure 2a. Predicted habitat suitability of *Macrolepiota procera* under current climatic conditions.

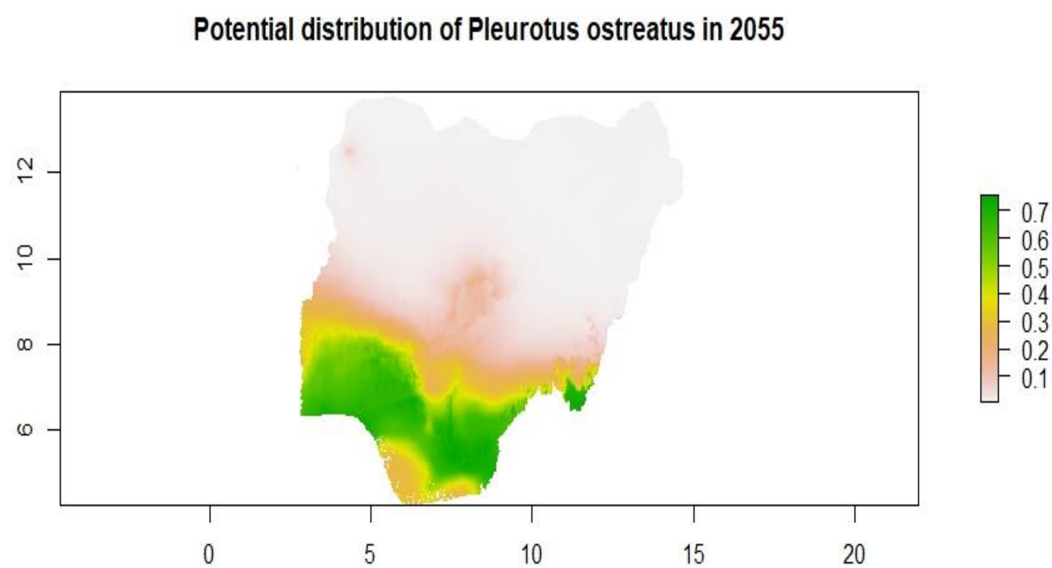

Figure 2b. Predicted habitat suitability of *Pleurotus ostreatus* under current climatic conditions

DISCUSSION

The widespread consensus is that worldwide climate change will modify the global geographic distributions of species (Salako *et al*., 2021; Oyebanji *et al*., 2021; Ngarega *et al*., 2022). This research demonstrates that ecological niche models (ENMs) serve as dependable instruments for examining and comprehending the factors impacting the potential distribution of species across various levels (Tiamiyu *et al*., 2021; Yan *et al*., 2022). Accurate forecasts of species diversity and composition are essential for formulating strategic management policies and conservation measures to prevent biodiversity decline and associated crises (Farooqi *et al*., 2022). In the past ten years, numerous forecasts have utilized this system to evaluate the influence of climate change on biodiversity across a variety of organisms (Weiskopf *et al*., 2020; Mkala *et al*., 2023).

In this study, we utilized Ecological Niche Modeling (ENM) to examine the impacts of climate change on the present and future distribution of *Macrolepiota procera* and *Pleurotus ostreatus* in Nigeria. The findings contribute additional evidence supporting previously documented climate-induced losses. Moreover, for the considered scenario, the average Area under the Curve (AUC) and True Skill Statistic (TSS) values were greater than 0.8 and 0.7, respectively, indicating a high level of confidence in the reliability of the models (Table 1).

Our results indicate that the model effectively characterizes the distribution of *Macrolepiota procera* and *Pleurotus ostreatus* within their established occurrence zones. This concurs with the documented distribution range of these species in Nigeria and other regions, as reported in previous research (Yaro *et al*., 2021; Tiamiyu *et al*., 2022; Chukwuma *et al*., 2023). The investigation further disclosed that the presence of species is intricately tied to both precipitation and temperature, in agreement with previous observations (Agwu *et al*., 2020; Yao *et al*., 2022). For instance, the geographic spread of *Fomitopsis pinicola*, *Mycena pura*, and *Hypholoma fasciculare* is primarily governed by precipitation, a key climatic factor (Rakić *et al*., 2022). Furthermore, the distribution of macrofungi in Bajaur, Pakistan, is significantly influenced by temperature and precipitation, contributing substantially to their geographic presence (Zeb *et al*., 2023).

Our future predictions indicate a threat to suitable habitats for distribution due to climate change. While some areas are currently deemed suitable, certain regions face reduced suitability under climate change scenarios. Specifically, projections suggest that 2050 under the RCP scenarios, environmental conditions favoring the two macrofungi will shift towards the Southern part of Nigeria, with diminished habitat suitability in the Northcentral zone. Furthermore, in 2055, the potential distribution of *Pleurotus ostreatus* is anticipated to increase in the western region (especially Oyo, Lagos, Ogun, and Ondo states) and some parts of Edo, Ebonyi, Cross River, and Imo states under RCP4.5. Nevertheless, in the RCP4.5 scenario 2055, the suitable habitats for *Macrolepiota procera* distribution are anticipated to decrease, with minimal increases in Delta, Imo, Abia, and Akwa-Ibom states. A study examining similar projections suggests that the principal driver of species losses will be the escalating climate instability and stress associated with drought due to climate change (Harrison, 2020).

CONCLUSIONS

Our research projected the potential distribution of *Macrolepiota procera* and *Pleurotus ostreatus* for the current and future (2055) based on climate change scenarios (RCP4.5). Southwest, recognized as one of the biodiversity hotspots, boasts a diverse and rich species population within the most suitable habitat. However, the decline in biodiversity is attributed to various factors induced by climate change. Our findings indicate that the potential distribution area of suitable habitats for *Pleurotus ostreatus* is expected to expand further with changing climate conditions in the future, while *Macrolepiota procera* will likely decrease, with only marginal increases in specific states. This research is distinctive in its identification of optimal growth regions for *Macrolepiota procera* and *Pleurotus ostreatus.* The generated maps serve as fundamental data for these key species. To preserve their current status and prevent potential extinction, a comprehensive conservation strategy is imperative. This approach would mandate collaboration among diverse stakeholders, including government agencies, research institutes, and the active participation of local communities.

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Conflicts of Interest: The authors declare that they have no competing interest.

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