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Species Abundance and Ecological Niche Modelling of *Mondia whitei* in Ntcheu, Malawi

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Abstract

Mondia whitei, a medicinal plant of significant cultural and economic importance in Malawi, faces increasing threats due to overharvesting, habitat degradation, and climate change. Despite its high demand in traditional medicine, limited research has been conducted on its abundance, distribution, and habitat suitability in Malawi. This study assessed the population dynamics of *Mondia whitei* in Lizulu and Zuze, Ntcheu, and modelled its ecological niche with MaxEnt to predict current and future distribution patterns under climatic change scenarios. Abundance and density were higher in Zuze than in Lizulu, suggesting that localized environmental conditions and, potentially, differing harvesting pressures are associated with the species' status at each site. The species distribution model (SDM) identified potential evapotranspiration (PET), isothermality (Bio3), and temperature seasonality (Bio4) as the variables contributing most to habitat suitability. Climate projections for 2055 under the HadGEM2-ES global climate model (RCP 4.5 and RCP 8.5) suggest an expansion of climatically suitable habitat, particularly in Dedza and Ntcheu, offering potential opportunities for conservation and sustainable harvesting, though this projection carries the limitations discussed below.

Subject Areas

Environmental Sciences

Keywords

Mondia whitei, Species Distribution Modeling, Climate Change, Habitat Suitability, Conservation

1. Introduction

Traditional and complementary medicine (TCM) plays a vital role in global healthcare systems, with the World Health Organization (WHO) recognizing its significance. In Africa, over 80% of the population relies on traditional plants to meet their fundamental medical needs [1]. Among these medicinal plants is *Mondia whitei*, locally known in Malawi as *Gondolosi*. This perennial climbing shrub, belonging to the Apocynaceae family, is endemic to Africa and has been an integral part of traditional medicine across the continent. *Mondia whitei* thrives in higher altitudes, in moist to wet forests, and even in swampy grasslands. Its natural range spans several African countries, including Guinea, Nigeria, Cameroon, Uganda, Sudan, Tanzania, Kenya, Zimbabwe, Malawi, Mozambique, South Africa, Swaziland, and Angola [2].

In South Africa, *M. whitei* is restricted to coastal and midland areas in KwaZulu-Natal and the Limpopo Province and is listed as endangered on the Red Data List of South African plants [3]. In Kenya, *M. whitei* is confined to remnant forest fragments such as Kakamega, Mukua, and Kariti, where overharvesting poses a significant threat [4]. In Malawi, *M. whitei* is predominantly found in regions like Ntcheu, Zomba, and Mulanje and holds substantial cultural and economic importance. It is sold in local markets and plays a significant role in the economic activities of rural communities, particularly in regions such as Lizulu and Zuze, where the plant has traditionally been abundant. On a global scale, *Mondia whitei* is recognized for its various medicinal properties, including its use as an aphrodisiac, treatment for digestive issues, and remedy for fatigue and sexual dysfunction [5]. The roots of this plant, which are the most commonly used part, are harvested, leading to plant destruction [6]. The global demand for *Mondia whitei* and other medicinal plants has led to increased pressure on wild populations, making conservation efforts more crucial than ever.

Despite its importance, *Mondia whitei* faces significant threats in Malawi [7]. Overharvesting, driven by local and international demand, coupled with habitat loss, has raised concerns about the long-term survival of the species in these areas. The conservation of *Mondia whitei* in Malawi is essential for several reasons. First, the plant is a vital component of the country's biodiversity, contributing to the ecological balance within its native ecosystems [8]. The loss of *Gondolosi* could have far-reaching effects, potentially disrupting the delicate balance of these ecosystems. Second, the cultural and medicinal value of *Mondia whitei* means that its decline would result in the loss of an important aspect of Malawian heritage. Third, for the rural communities that rely on the sale and use of *Gondolosi*, its scarcity could have severe economic consequences, especially in areas with limited alternative sources of income.

Previous studies on *M. whitei* have largely focused on pharmacological properties, with little emphasis on conservation and habitat preferences. The study, therefore, aims to assess the abundance and distribution of *M. whitei* in Lizulu and Zuze and compare population densities between the two sites. It will further develop a species distribution model for *M. whitei* to evaluate its habitat suitability and predict shifts in distribution due to climate change. Species Distribution Modeling (SDM) has emerged as a valuable tool in conservation planning by helping predict the current and future distribution of species under various climatic scenarios using occurrence data and environmental variables. Given the uncertainties posed by climate change, predicting how *M. whitei's* distribution may shift over time is vital for ensuring its sustainability.

2. Materials and Methods

2.1. Study Area

The study was conducted in Lizulu and Zuze areas in Ntcheu district, Malawi (Figure 1). Lizulu is a place in Ntcheu, Malawi, located at an elevation of 1492 meters above sea level. Its coordinates are −14.5167 and 34.4667 (decimal degrees). Zuze is a place in Ntcheu, Malawi, and is located at an elevation of 1062 meters above sea level. Its coordinates are −14.7481 and 34.6365 (decimal degrees).

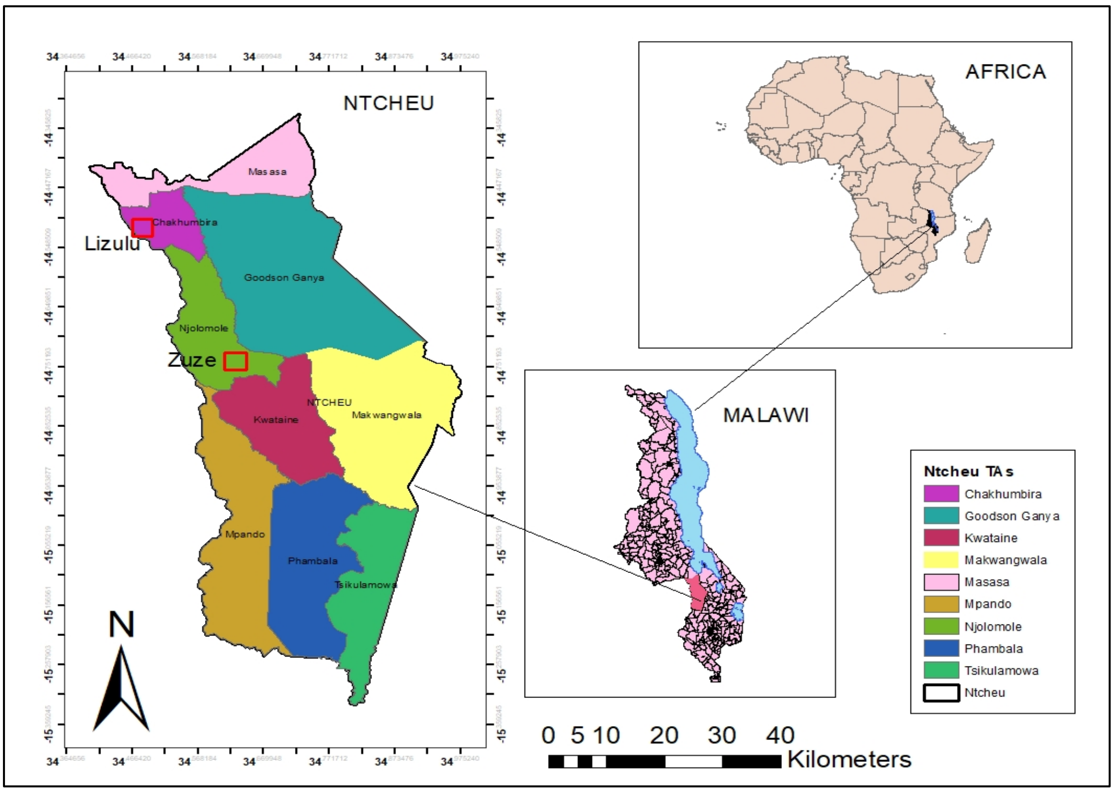

Figure 1. Study area location generated in ArcGIS Pro.

2.2. Data Collection

Belt transects were used to establish sampling plots, a highly effective method for assessing plant populations in diverse habitats [9], and allowed for a thorough and systematic sampling of the areas, reducing sampling bias and increasing the accuracy of the results [10]. In each area, 20 transects were drawn at a regular interval of 20 metres following the methods of [11], to ensure comprehensive coverage and representation of the vegetation. Each transect had a width of 1 metre and a length of 20 metres, resulting in a total sampled area of 400 square metres per area, sufficient to capture *Mondia whitei* populations [12]. The starting point of the first transect at each site was a randomly generated GPS waypoint located at the site boundary, with successive transects laid at the stated 20 m interval to reduce spatial bias and pseudo-replication.

Field sampling was carried out from 5 - 30 April 2023, which falls near the end of the rainy season in this part of Malawi. Because *Mondia whitei* detectability can vary seasonally (e.g., with foliage senescence or root dormancy).

Occurrence data for *M. whitei* were collected using a 1 m^2 quadrat, allowing for precise measurements of abundance, density, and frequency [13]. Quadrats were laid at a 4-meter interval along each 20-meter-long belt transect, following the recommendations of [14], to ensure adequate spatial resolution and detection of patterns in *Mondia whitei* distribution. This yields 4 quadrats per transect (20 transects × 4 quadrats), giving 80 quadrats sampled per site and 160 overall. The coordinate data for the species was recorded using a Garmin GPS. All collected data were recorded in a standardized data sheet and later entered into a Microsoft Excel spreadsheet, which was converted into a CSV format. Data were checked for errors and inconsistencies before analysis.

The algorithm used to determine the ecological niche was MaxEnt, developed by Phillips and colleagues, and is freely available at https://biodiversityinformatics.amnh.org/open_source/maxent/. MaxEnt is a general-purpose machine learning program and has been widely used to predict species distributions [15]. It uses only presence data in combination with environmental data for the study area to derive a model and predict suitable conditions or ecological niches [15]. Data for nineteen bioclimatic variables were downloaded from http://www.worldclim.org [16]; these have a spatial resolution of 30 arc-seconds (ca. 1 km). Current climate data were obtained from the WorldClim database version 2.0. Two additional predictors were also included: potential evapotranspiration ("pet") and the Moisture Index of the Arid Quarter ("miaq"). For future climate change predictions, the nineteen bioclimatic variables (plus PET and miaq, where applicable) were obtained for RCP 4.5 and RCP 8.5 for the year 2055, downscaled from the HadGEM2-ES global climate model. Study area shapefiles were downloaded from the Malawi Spatial Data Platform (MASDAP). The study areas were then used as boundaries to clip out environmental data for these areas from the global dataset and then converted to an ASCII file format using RStudio (Version 2022.12.0+353 "Elsbeth Geranium").

2.3. Data Analysis

2.3.1. Abundance, Density, and Frequency

The data collected at each transect were used to compute and estimate the abundance, density, and frequency. The following equations were used.

Abundance = (Total no. of individuals of the species ÷ No. of quadrats in which they occur) × 100

Density = (Total no. of individuals of the species ÷ No. of quadrats studied) × 100

Frequency = (No. of units in which the species occurred ÷ Total no. of units studied) × 100

Table 1. Abundance and density of *Mondia whitei* by site.

Site	Total Individuals Recorded	Quadrats Where Species Occurred	Total Quadrats Sampled	Abundance (%)	Density
Lizulu	29	21	80	36	0.19
Zuze	55	32	80	69	0.33

The abundance, density, and frequency of *Mondia whitei* between the Lizulu and Zuze areas were compared using statistical tests (Table 1). A Welch two-sample t-test was used to compare the mean abundance and density of *Mondia whitei* between the two areas, as it is well suited to comparing means between two groups with a relatively small sample size [17]. An ANOVA was used to compare the frequency of *Mondia whitei* between the two areas, allowing for comparison of frequency data while accounting for potential variation within each area [9]. A Chi-squared test was used to compare presence/absence data between the two areas. All statistical analyses were performed using RStudio (Version 2022.12.0+353 "Elsbeth Geranium"); specifically, the vegan package, a widely used package for community ecology analysis, was employed for the abundance, density, and frequency data [18].

2.3.2. Species Distribution Model

The MaxEnt model requires point locations where the species is known to occur. Inputs to the model run were the predictor raster layers, matched in projection, extent, and resolution, and the species presence records. A three-column CSV was prepared with species scientific name, longitude, and latitude. Fifty replicates of the model were run, with MaxEnt randomly selecting 70% of occurrence localities in each run for training and reserving the remaining 30% for testing, using simple random partitioning. User-specified parameters were: regularization multiplier = 1, maximum iterations = 5000, convergence threshold = 0.0001, maximum background points = 10,000, replication = 50, using linear, quadratic, product, threshold, and hinge features. Model output was a predicted distribution map in ESRI raster grid format, with average, minimum, maximum, median, and standard deviation rasters; the average output was used for spatial analysis.

2.3.3. Sensitivity Analysis

A jackknife analysis was used to evaluate the relative importance of each predictor variable and its contribution to predicting the species' range. The jackknife calculates the training gain of each variable when the model is run in isolation and compares it to the training gain with all variables included, identifying which variable contributes most. A response curve was generated for each environmental variable, showing how each variable affects the MaxEnt prediction and indicating the values suitable for the species.

2.3.4. Model Evaluation

The receiver operating characteristics (ROC) curve was selected to measure the model's performance, and the other options were set by the model default. The model was repeated 50 times, and the group with the largest area under the curve (AUC) value was selected as the final prediction result.

The application of subject work characteristics (ROC) and the AUC were used to evaluate the model's prediction accuracy. An AUC value closer to 1 indicates that the model prediction effect is better. In the output file, a maximum of 10 repetitions was selected as the study's prediction result. The result was based on the existence of the probability logic value (P) of the species to generate the ASCII grid graph layer. The P range was 0 - 1, and a larger P value indicated a greater likelihood of species being present. ArcGIS 10.8 software converted predictions into raster formats to grade and visualize the suitable areas. The natural discontinuous method divided the suitable area into 3 grids: Low unsuitable < 0.5, medium suitability 0.5 - 0.75, and high suitability > 0.75.

3. Results

3.1. Abundance and Distribution of *Mondia whitei*

The total abundance of *Mondia whitei* recorded in the two-study sites demonstrated that Zuze village had a higher (69%) mean abundance than Lizulu (36%) (Figure 2), based on 55 individuals recorded across 32 of 80 sampled quadrats in Zuze and 29 individuals across 21 of 80 sampled quadrats in Lizulu (Table 1).

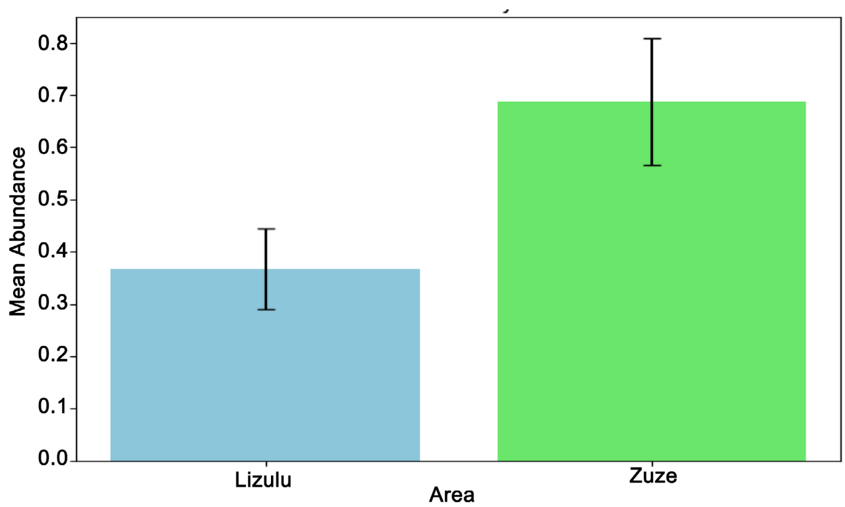

Figure 2. Bar chart showing the abundance of *Mondia whitei* for Lizulu and Zuze.

3.2. Density Analysis

Mean density (abundance normalised per quadrat) was 0.19 in Lizulu and 0.33 in Zuze. Density plots comparing *Mondia whitei* distribution between the two areas show that in Lizulu, the distribution of abundance is tightly clustered around lower values, with most quadrats having low or no abundance of *Mondia whitei*, while abundance in Zuze is more variable, with some quadrats notably higher (Figure 3). A Welch two-sample t-test revealed a statistically significant ($p < 0.05$) difference in the abundance of *Mondia whitei* between the two study areas.

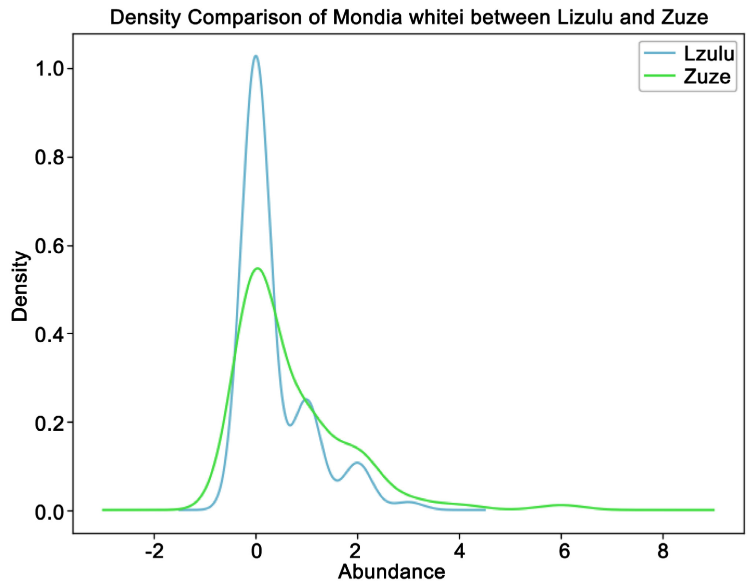

Figure 3. Density plot comparing *Mondia whitei* between Lizulu and Zuze.

3.3. Species Distribution Model Analysis

3.3.1. Jackknife Test of Important Variables

Average gains with and without each variable were calculated from the 50 replicate model runs. The environmental variable with the highest gain when used in isolation was pet, indicating it carries the most useful information on its own; bio3 (isothermality) was the second most important variable (Figure 4).

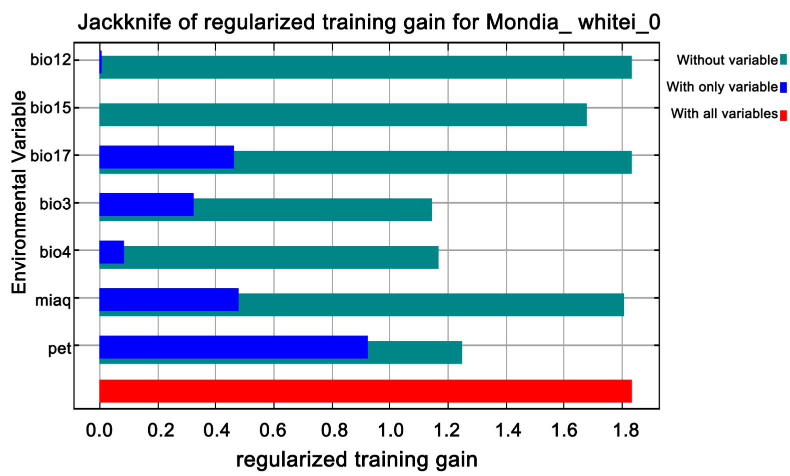

Figure 4. Jackknife test for evaluating the relative importance of environmental variables for *Mondia whitei*.

3.3.2. Percent Contribution of the Variables

The percentage contribution (Table 2) estimated that the pet plays a major role in determining suitable habitat for *M. whitei*. bio15 and bio12 have almost negligible contributions for *M. whitei*.

Table 2. Bioclimatic variables and their contribution.

Abb.	Bioclimatic Variable	Percent Contribution	Permutation Importance
pet	Potential evapotranspiration	51.4	18.7
bio3	Isothermality	15.4	33.7
bio4	Temperature seasonality	10.7	26
bio15	Precipitation seasonality	10.3	21
bio17	Precipitation of driest quarter	9.1	0
bio12	Annual precipitation	2.3	0
miaq	Soil moisture, air quality	0.7	0.7

3.3.3. Responsive Curves of the Predictor Variables

Figure 5 represents the response curve for the MaxEnt model created using only the corresponding variable of *Mondia whitei*.

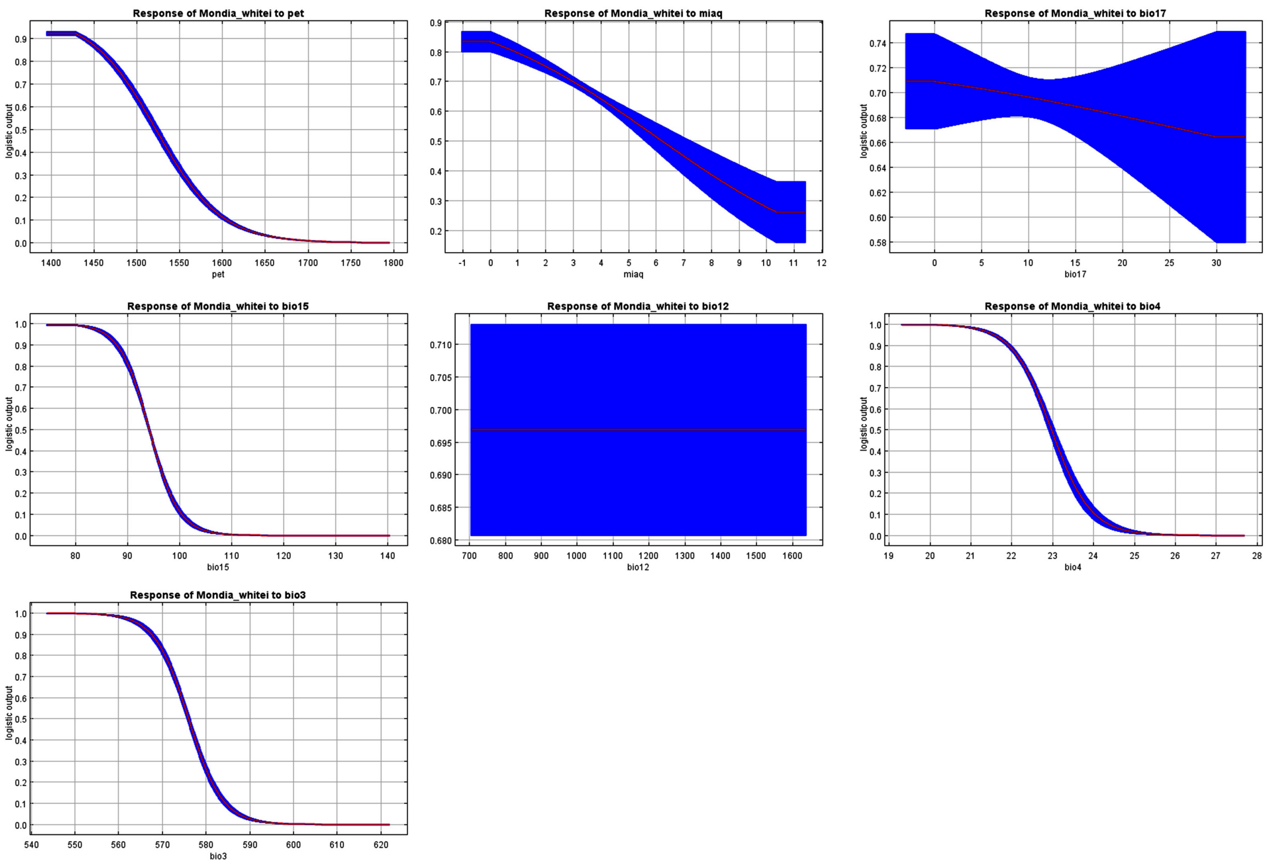

Figure 5. Responsive curves of the predictor variables.

3.3.4. Model Output for Special Distribution

Model 1 was chosen for *Mondia whitei*. The output gives the Area Under the ROC curve (AUC) for the training data, averaged over the replicates run. The specificity is defined using predicted area, rather than true commission [19]. The sensitivity measures the proportion of presence correctly predicted (**Figure 6**).

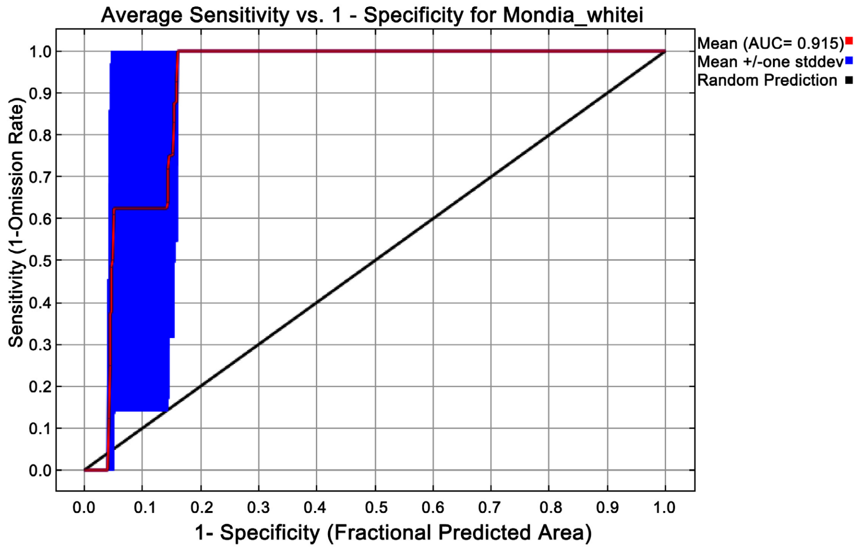

Figure 6. Area under the receiver operating curve (ROC) for training data of *Mondia whitei*.

The above Area Under the Receiver Operating Curve (ROC) for training data of *Mondia whitei* indicates the validity and performance of the model. An AUC of 0.5 indicates that the performance of the model is no longer better than random, while values closer to 1 indicate better model performance. The Area under the ROC (AUC) for *M. whitei* is 0.915, which indicates that the model has 91.5% discrimination performance.

3.3.5. Current Potential Suitability of *Mondia whitei* Species

The maxent predicted potential region for *Mondia whitei*. Model 1 obtained for the present distribution of *Mondia whitei* performed well with an average AUC value of 0.915. **Figures 7-9** were produced from an average of 50 random replicates of the species. Suitability for *Mondia whitei*, mainly in small patches, especially towards the southern part of the map (Ntcheu, Dedza). Most of the current habitat is marked as low suitability, with only a few pockets of medium suitability.

3.3.6. Future Potential Suitability Map of *Mondia whitei* Species

The future potential suitability of the model was based on the scenario for the year 2055. The observations indicate that under the assumption of model 1, the current potential distribution for *Mondia whitei* will change. For instance, under RCP 4.5, a moderate climate change mitigation with high-suitability regions predicted to expand, especially around Dedza and Ntcheu, compared to the current distribution.

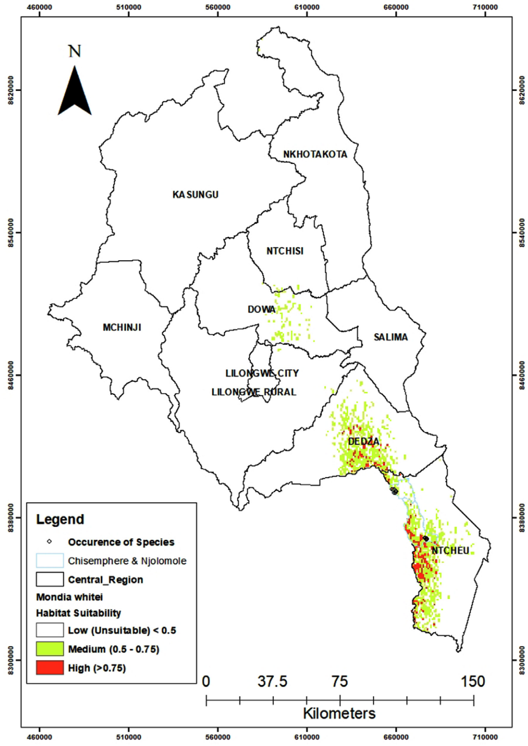

Figure 7. Current potential suitability map of *Mondia whitei* species in the central region of Malawi using MaxEnt software and ArcGIS Pro.

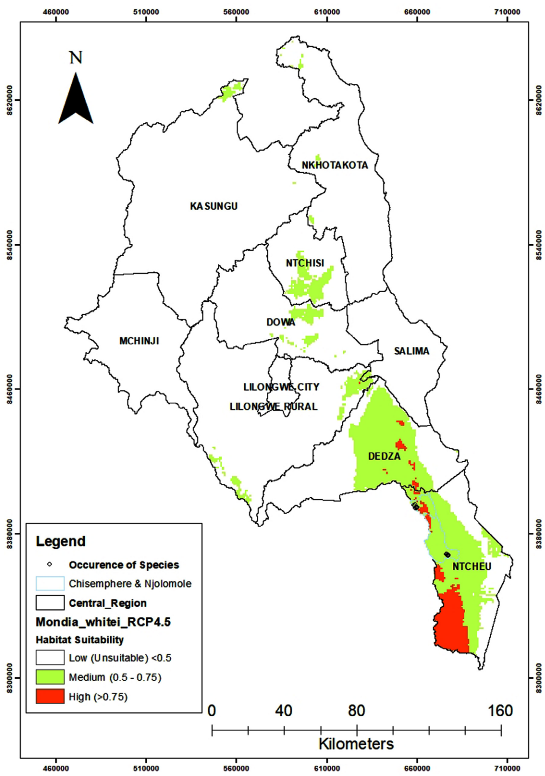

Figure 8. Future potential suitability map (RCP 4.5) of *Mondia whitei* species in the central region of Malawi using MaxEnt software and ArcGIS Pro.

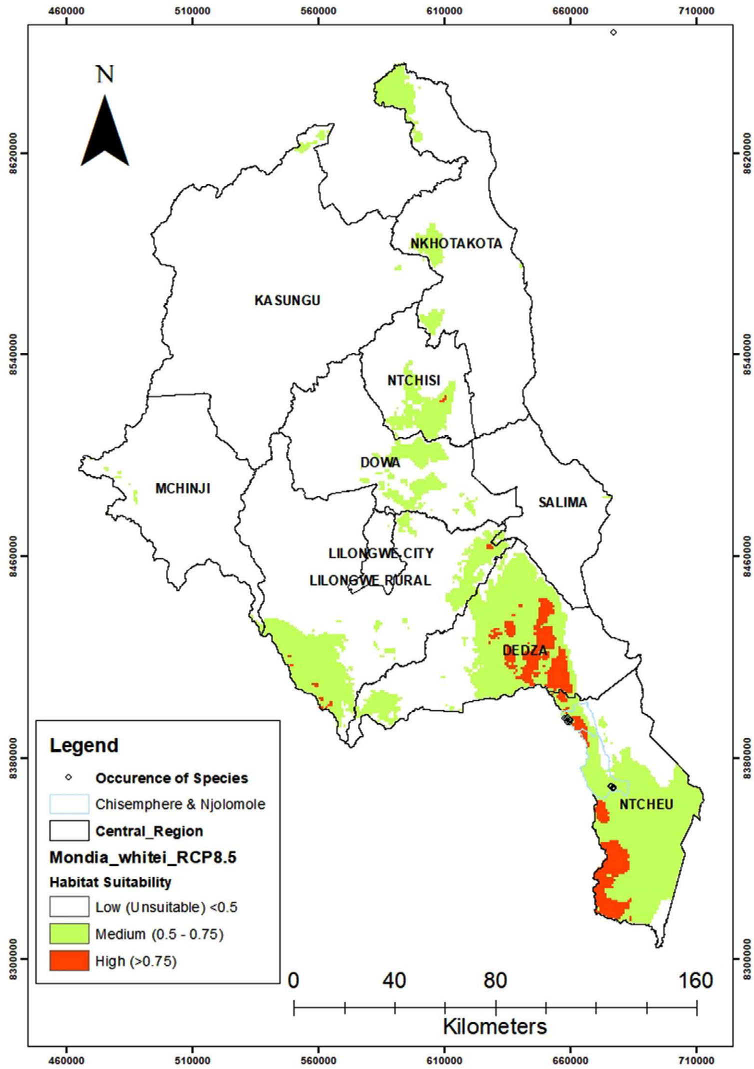

Figure 9. Future (year 2055) potential suitability map (RCP 8.5) of *Mondia whitei* species in the central region of Malawi using MaxEnt software and ArcGIS Pro.

4. Discussion

4.1. Abundance and Distribution of *M. whitei*

The total abundance of *M. whitei* in Zuze was higher (69%) compared to Lizulu (36%). This disparity suggests that environmental conditions and anthropogenic pressures may be influencing species abundance across the study sites. Lower levels of habitat disturbance and traditional knowledge in Zuze provide a favorable environment for *M. whitei*. Besides, Lizulu exhibits lower abundance due to more intensive exploitation of the species. Given that *M. whitei* is a slow-growing species, unsustainable harvesting in Lizulu has led to a lower regeneration rate and, hence, reduced abundance. These findings were further supported by the density analysis, where the mean density of *M. whitei* was 0.33, compared to 0.19 for Lizulu, suggesting that *M. whitei* populations in Zuze are not only abundant but also more evenly distributed across the sampled plots.

4.2. Climate Change on Species Suitability

The responsive curves singled out environmental variables such as potential evapotranspiration (PET), which were strongly correlated with the distribution of *M. whitei*. The jackknife further confirmed the dominance of PET as the variable with the highest predictive value for habitat suitability, with isothermality and temperature also having significant roles. This variable significance suggests that *M. whitei* is sensitive to climate variables that regulate temperature stability and water availability [20]. In Lizulu, fluctuations in isothermality disrupt the temperature stability required for seed germination, which leads to a lower regeneration rate. In this area, higher PET also increases the rate of moisture loss from the soil, thereby reducing growth rates and leading to lower abundance. This is different in Zuze, where the impact of isothermality is less severe due to adaptive cultivation practices that reduce the stress on plants from temperature variability.

M. whitei is not a narrow habitat specialist, occurring across swamp forest, riverine forest, disturbed forest, and woodland habitats generally [7], and its known elevational range (1000 - 1500 m, up to 1800 m) closely matches the elevation of both study sites and of the wider central Malawi plateau (e.g., Dedza District, 1200 - 1600 m; Kasungu, ~1000 m). Each fruit releases 180 - 320 wind-dispersed, comose seeds [7], giving the species a meaningful capacity for long-distance dispersal. On this basis, the wider central region is ecologically accessible to *M. whitei* over the timescales relevant to the 2055 projections, while noting that confirmed occurrence records for the region outside Ntcheu are currently lacking in available floristic databases.

From the maps (**Figures 7-9**), the RCP 4.5 (moderate climate change mitigation) predicts high-suitability regions expand around Dedza and Ntcheu (including Lizulu and Zuze), compared to the current distribution. It suggests an improvement in habitat suitability for *Mondia whitei*, with more extensive areas supporting the species by 2055. The RCP 8.5 suggests a more substantial increase in high-suitability areas. Despite the more extreme climate scenario in RCP 8.5, the habitat suitability for *Mondia whitei* appears to improve even more than in the RCP 4.5 scenario, with larger areas supporting the species.

The model suggests an increase in annual rainfall in the central region of Malawi by 5% - 10% under RCP 4.5 and up to 15% under RCP 8.5 in high-rainfall zones, while other areas will see reduced rainfall. Changes in precipitation patterns will affect the soil moisture content and water availability, supporting *Mondia whitei* growth [20]. Higher temperatures will expand the range of temperatures suitable for *Mondia whitei*. The warming will reduce temperature-related growth limitations, leading to improved survival rates in expanded regions and allowing it to expand into previously unsuitable areas. The Zuze and Lizulu areas will expand their favorable conditions for *Mondia whitei* as the changing climate will reduce competition from other species, freeing up more habitat for *Mondia whitei* [21]. For instance, plants that require cooler or drier conditions may retreat, while *Mondia whitei* thrives with a mixture of warmth and moisture. Changes in regional hydrology, including groundwater availability, have a positive impact on soil moisture retention [22]. However, the low impact of climate change on the area suitable for the species should not necessarily imply that *M. whitei* can easily survive in Zuze and Lizulu, as human-induced factors are also important in shaping the species' distribution.

5. Conclusions

The findings confirm that *M. whitei* abundance varies significantly between the two study areas, with Zuze having higher population densities than Lizulu. This disparity suggests that environmental conditions, harvesting practices, and conservation awareness play a significant role in shaping species distribution.

The model's prediction shows that the potential suitable climate distribution for *Mondia whitei* will be expanded under all future climate scenarios, which means more suitable habitat areas will be available for both cultivated and wild *Mondia whitei* in the future.

In general, all these findings give the basis for a targeted approach in the light of the conservation policy, which not only focuses on ecological sustainability but also considers the socio-economic realities of the local communities. An increase in partnership, education, and allowing sustainable practices has the potential to provide long-term survival for *Mondia whitei* and the livelihoods and cultural heritage of those communities dependent on it.

Author Contributions

J.M.M. conceived the study and collected field data. T.M. and W.M. supervised the research and reviewed the manuscript. All authors read and approved of the final manuscript.

Ethical Considerations

The Malawi University of Science and Technology Research Ethics Committee (MUSTREC) granted me Ethics approval to conduct this research.

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Conflicts of Interest

The authors declare no conflicts of interest.

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