Mapping of Potential Sites of Bamboo Plantation in Agusan del Norte, Philippines using Species Distribution Modelling

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Abstract: *The Philippines is focusing on cultivating a high-value bamboo species for global markets, particularly in paper production and construction materials, with Agusan del Norte identified as a key plantation area. The study aims to find potential area for bamboo species plantation using MaxEnt modeling. The methods involve gathering presence data, environmental and other data, correlation of this data, and running the MaxEnt modeling. A 0.802 mean AUC was generated indicating a good modeling, with BIO 7 as the most influential variable. A 1 km x 1 km bamboo suitability map was generated using the model. As predicted in the suitability map modeling Buenavista, Nasipit, and Carmen presented a pronounce suitability points (i.e., highly suitable area).*

Keywords: Bamboo species; MaxEnt modeling; area under curve (AUC); suitability

1. INTRODUCTION

Ensuring the responsible utilization of natural resources and the mitigation of climate change have become critical concerns on a global scale. One such resource with immense potential is bamboo, a versatile and rapidly growing plant known for its numerous ecological, economic, and health benefits. In recent years, there has been increasing interest in the plantation of bamboo specie due to its remarkable growth rate, carbon sequestration capabilities, and its potential to provide renewable resources for various industries [1]. The Gramineae family's tallest perennial grass is bamboo. Bamboo is a flexible material for a number of commercial purposes, including handcraft and home furnishings, farm equipment, fishing pens, cages, and other vessels for fishing, banana materials, musical instruments, pulp and paper, and home building. Aside from these, new branches from some species are edible. There are 60 documented bamboo species in the Philippines, and the number is growing as plant collectors and bamboo enthusiasts introduce new species. The demand for bamboo in the Philippines is rapidly expanding. However, demand is not currently being satisfied. As a result, bamboo cultivation has the potential to provide revenue for agroforestry farmers [2]. Bamboo also provides ecological advantages, since it reduces soil erosion and stabilizes riverbanks. Bamboo thrives in a variety of site circumstances, making it an ideal replanting species for environmental conservation. Bamboo is an important economic and cultural resource in Southeast Asia, utilized for construction materials, food, and as a flexible raw material. Certain bamboo species may grow 36 inches in 24 hours, averaging 1.6 inches per hour [2].

Land suitability analysis is a method of land evaluation, which allows identifying the main limiting factors of a particular crop production [3]. At the same time, it enables decision makers to develop a crop management system for increasing land productivity [4]. Agusan del Norte has diverse ecosystems and natural resources. With its tropical climate and abundant rainfall, the region possesses favorable conditions for bamboo cultivation. However, systematically establishing a bamboo species plantation requires careful organization and a deep comprehension of the land's suitability, which can be achieved by integrating system techniques [5]. Agusan del Norte, where both the main and auxillary campus of Caraga State University are situated. [6, 7]. Conducted several studies involving suitability mapping for trees [8], employing MaxEnt modeling [8] approach. There has been study of susceptibility mapping for Pityokteines curvidens that uses MaxEnt at the same time [9]. That study focuses in the area of Turkey and employed the technique of finding the susceptibility of the species [9]. The MaxEnt model is a machine-learning approach that solely uses presence data [10]. This model is more extensively used than other species distribution models because of various advantages, such as improved accuracy and ease of use [11]. MaxEnt has shown to outperform other SDMs in several studies [12, 13, 14]. One essential assumption of MaxEnt is that the presence-data are an independent sample from the species' unknown probability distribution of occurrence over the study area [10]. MaxEnt provides a unique opportunity to predict the potential distribution of species suitable habitats, which is conducive to identifying potential threat areas of biodiversity and formulating positive response strategies for biodiversity conservation [15]. MaxEnt is a reasonably common model for precisely forecasting species distribution that operates on the premise of estimating the distribution of probabilities, such as the geographic distribution of the species that tends to be widely dispersed, subject to restrictions such as the species' known observations. MaxEnt employs entropy to generalize individual observations of a species' presence, and it doesn't need or even include absence points in its theoretical framework. Presence points are the species' global positioning system (GPS) locations, although absence points are rarely documented. The MaxEnt model has several distinguishing qualities, including the requirement of simply presence data, the ability to handle both continuous and categorical data, and efficient deterministic methods. Furthermore, the result is continuous and generative, and it also works well with minimal data [10].

This study aims to identify suitable areas for bamboo species plantation in Agusan del Norte, Philippines using

Species Distribution Modelling. Bamboo's ecological, economic, and health benefits have gained prominence with the global emphasis on sustainable resource management and climate change mitigation. Agusan del Norte's favorable climate and ecosystems provide a suitable setting for bamboo plantations, but systematic planning is essential. MaxEnt modeling allow for mapping, the research seeks to identify suitable areas for bamboo species based on modeling.

2. MATERIALS AND METHODS

2.1 Study Area

Agusan del Norte is a province strategically located in the northeastern part of Mindanao Island, within the Caraga Region of the Philippines. With its geographical coordinates approximately at 8.9456° N latitude and 125.5319° E longitude, the province enjoys a unique position that contributes to its distinct ecological and environmental landscape. The region's topography is varied, featuring rolling hills, expansive plains, and lush river valleys which foster diverse ecosystems. There is a growing demand for bamboo in the province for furniture production, and several companies have shown interest in establishing operations locally to fulfill this need.

The province's climate is typically tropical hot and humid with abundant rainfall, which not only supports its dense forests and rich biodiversity but also makes it ideal for agriculture and aquaculture. Agusan del Norte is drained by several river systems, with the Agusan River being the most significant. This river system plays a vital role in irrigation, transportation, and as a source of water for domestic and industrial use. The natural landscapes of Agusan del Norte, from its rivers to its mountainous areas, are integral to its identity and offer opportunities for ecotourism and environmental studies, making it an important area for geographical and environmental research in the region.

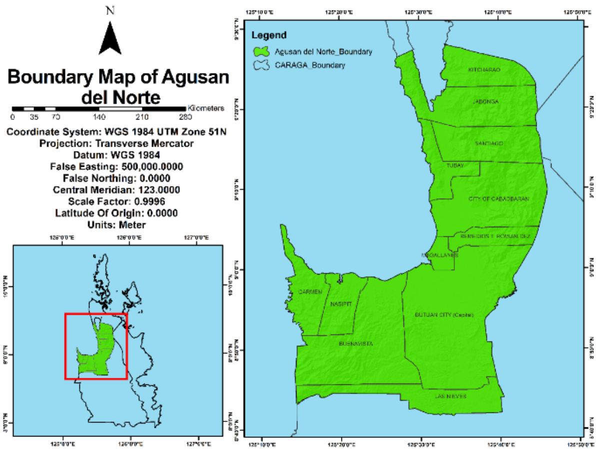

Fig. 1. Location map of Agusan del Norte, Caraga Region, Mindanao.

2.2 Bamboo Prescence Data

The presence of bamboo data was sourced from the local government unit of Agusan del Norte. The data they provided was meticulously geotagged to specific locations within the municipalities situated in Agusan del Norte. Subsequently, we input this information into an Excel spreadsheet and converted it into a CSV file. The coordinates inputted were then transformed into geographic coordinates for further analysis and visualization.

2.3 Environmental Factors

An overall number of 23 environmental factors were determined for analysis, encompassing the 19 bioclimatic variables, topographic variables (elevation and slope), soil type, and land use/land cover type (refer to Table 1). These variables are crucial as they interact and contribute to the optimal growth conditions and geographic distribution of bamboo cultivation across the surroundings. The bioclimatic variables (BIO1-BIO19), with a spatial resolution of approximately 1 km and available in GeoTIFF file format, were derived from the World Climate v.2.1 spanning 1970-2000. These data were sourced via WorldClim website (https://www.worldclim.org/data/worldclim21.html). To generate topographic layers, a Digital Elevation Model (DEM) was derived from Copernicus with their Sentinel 2 data dated from September – December 2023. Subsequently, the DEM was resampled to a 1 km resolution to maintain consistency with the bioclimatic variables. The soil and land-cover type layers, available in shapefile format, were obtained from Center for Resource Assessment Analytics and Emerging Technologies (CReATe) and ESRI Sentinel - 2 Land Cover Explorer, respectively. These layers were converted into 1 km rasters for compatibility with other data layers. To ensure uniformity in geospatial resolution (1 km), coverage, and raster dimensions, all data layers were layer-stacked using ArcGIS 10.8 software. Subsequently, each of the layers was converted to ASCII (*.asc) format in preparation for MaxEnt modeling.

2.4 Environmental Factors Selection Process

Collinearity between environmental factors is commonly measured such that only those variables that are not collinear (i.e., uncorrelated) with each other are employed in the SDM.. Collinearity "may cause over-adjustment problems and is expected to increase uncertainty and decrease the statistical power of the model" [16]. In order to facilitate the collinearity analysis, R tools are utilized to determine the Pearson's correlation coefficients between environmental variables. Pearson's correlation coefficients (r) between the variables were calculated; variables with a $r \geq 0.7$ are considered correlated, and only non-collinear variable are included in the MaxEnt model [16, 17]. As a result, only seven (7) of the 23 variables remained in the final model

Table 1. List of environmental variables. Highlighted variables are those included in the MaxEnt modeling.

BIO1	Annual Mean Temperature
BIO2	Mean Diurnal Range (Mean of monthly (max temp - min temp))
BIO3	Isothermality (BIO2/BIO7) (×100)
BIO4	Temperature Seasonality (standard deviation ×100)
BIO5	Max Temperature of Warmest Month
BIO6	Min Temperature of Coldest Month
BIO7	Temperature Annual Range (BIO5-BIO6)

BIO1	Annual Mean Temperature
BIO8	Mean Temperature of Wettest Quarter
BIO9	Mean Temperature of Driest Quarter
BIO10	Mean Temperature of Warmest Quarter
BIO11	Mean Temperature of Coldest Quarter
BIO12	Annual Precipitation
BIO13	Precipitation of Wettest Month
BIO14	Precipitation of Driest Month
BIO15	Precipitation Seasonality (Coefficient of Variation)
BIO16	Precipitation of Wettest Quarter
BIO17	Precipitation of Driest Quarter
BIO18	Precipitation of Warmest Quarter
BIO19	Precipitation of Coldest Quarter
LC	Land-cover type
SOIL	Soil type
ELEV	Elevation
SLP	Slope

2.5 MaxEnt Modeling

The MaxEnt v.3.4.1 was obtained from https://biodiversityinformatics.amnh.org/open_source/maxent/ and was used in this study. To provide for appropriate convergence time, the model run used 15 replicates with a maximum of 10,000 iterations each. Each cycle divides the presence data randomly into subsamples (70% for modeling, 30% for testing), with a convergence threshold of 0.00001 and a maximum of 10,000 background points. Random seeding and jackknife testing for varied significance were likewise allowed. The relevance of diverse environmental factors was assessed by the Jacknife test [18]. The model's accuracy was evaluated using the area under the receiver operating characteristic curve (AUC) [19]. The evaluation criteria are as follows: excellent (>0.9), good (0.8–0.9), accepted (0.7–0.8), poor (0.6–0.7), and unsatisfactory (<0.6) [16]. The model's prediction accuracy improved as the AUC value approached 1 [20]. The suitability maps were generated using Maxent's logistics output, which spans from 0 (lowest appropriateness) to 1 (best suitability). The prediction results were imported into ArcGIS 10.2 for visualization and further analysis, and the habitat suitability maps were divided into four levels: unsuitable habitat (0 - 0.35), poorly suitable habitat (0 - 0.55), moderately suitable habitat (0.55 - 0.75), and highly suitable habitat (0.75 - 1) [21]. The result of the model was then map using GIS. GIS has been employed to create service area maps [22]. Moreover, GIS was used to map and estimate road traffic emissions in the Caraga Region [23].

3. RESULTS AND DISCUSSIONS

3.1 Variance Inflation Factor (VIF)

Table 2 shows variance inflation factor of the remained variables for running the MaxEnt modeling. The selection of variables for the study was based on an assessment of multicollinearity using the Variance Inflation Factor (VIF) in R tools. The chosen variables demonstrated VIF values within an acceptable range, indicating that they each contribute unique information to the model without significant overlap or redundancy. This approach ensures the reliability and validity of the analysis by minimizing the risks associated with multicollinearity.

Table 2. Variance Interval Factor value of the selected environmental variables.

Variables	VIF
BIO_03	1.862672
BIO_04	3.897650
BIO_07	2.311733
BIO_12	3.168535
ELEV	4.049905
SLOPE	1.377055
LULC	1.228492

3.2 MaxEnt Model Results

The histogram in Figure 2 depicts the relative relevance of numerous environmental factors in predicting bamboo habitat suitability, using a Jackknife test in MaxEnt (Maximum Entropy Modeling). The Jackknife test evaluates each variable's contribution to the predictive model, with three bars representing different scenarios: without the variable, with only the variable, and with all variables. The results show that Temperature Annual Range (BIO7) and Annual Precipitation (BIO12) are the most critical factors, as they have the highest AUC values when used alone, indicating their strong individual contributions to the model. BIO7 measures temperature variation over a year, while BIO12 sums monthly precipitation values annually. Slope, on the other hand, has the least influence on the AUC, indicating that it plays only a tiny role in habitat appropriateness. Other factors, such as elevation, bio_03 (isothermality), bio_04 (temperature seasonality), and lulc (land use land cover), also have a role, albeit to varying degrees. This study emphasizes the importance of temperature and precipitation in ecological modeling and conservation planning for bamboo, highlighting the necessity to focus on these factors for optimal habitat preservation and management.

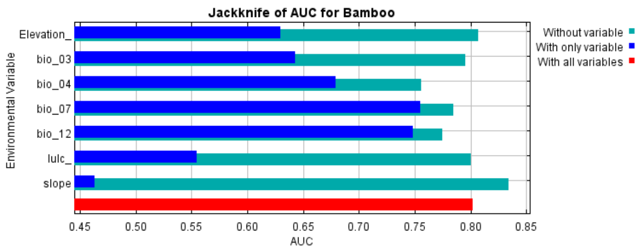

Fig. 2. Jackknife test results accumulated after running MaxEnt.

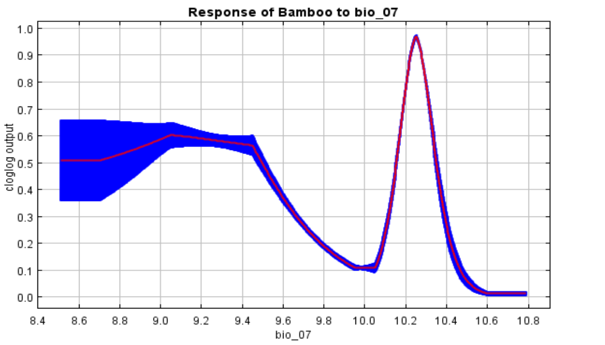

Fig. 3. Depicts the marginal response curve produced by MaxEnt modeling for Temperature Annual Range (BIO 7).

Figure 3 displays the marginal response curve for the temperature annual range (BIO7). This curve shows how changes in BIO7, which measures the difference between the maximum and minimum temperatures over a year, affect the probability of bamboo presence. The curve indicates that the highest probability of bamboo occurrence is around a temperature range of 10.2°C. This suggests that bamboo thrives best in environments with this specific temperature variation. The blue shaded area represents the variability in the model's predictions, providing a sense of the confidence intervals around the response curve. Figure 4 presents the response curve for annual precipitation (BIO12), demonstrating the relationship between bamboo habitat suitability and the amount of yearly rainfall. The model predicts the highest probability of bamboo presence when annual precipitation is between approximately 2900 mm and 3100 mm. This range indicates optimal conditions for bamboo growth, highlighting the importance of sufficient rainfall. The response curves in Figures 3 and 4 illustrate how bamboo habitat suitability responds to variations in specific environmental factors, based on MaxEnt modeling results. These response curves are critical for knowing which environmental conditions are most beneficial for bamboo. They aid in determining exact temperature ranges and precipitation amounts that best-fit bamboo habitats. This knowledge is crucial for conservation efforts because it enables focused interventions to protect bamboo ecosystems under ideal environmental conditions. By focusing on locations that fit these criteria, conservationists may improve the efficacy of their techniques and contribute to the sustainability of bamboo ecosystems.

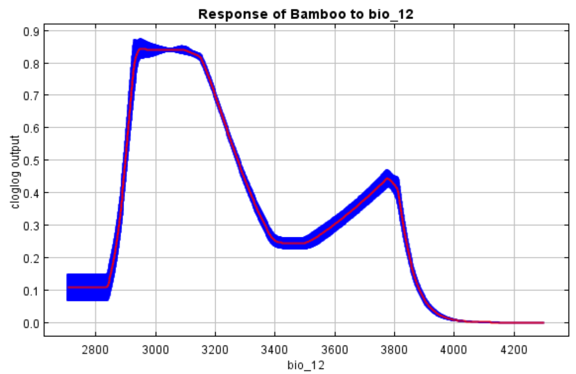

Figure 4. Marginal response curve generated by the MaxEnt for Annual Precipitation (BIO12).

3.3 MaxEnt Modeling Map

This map depicts the suitability of different areas within the Agusan del Norte region for growing bamboo plants. The map uses a color-coding system to indicate the environmental conditions and their appropriateness for bamboo cultivation. The red-shaded regions are labeled as "Highly Suitable", meaning these locations have the ideal soil, climate, and other factors that allow bamboo to thrive and reach its full potential. The yellow areas are considered "Moderately Suitable", where bamboo can still grow but perhaps not as robustly as in the optimal red zones. In contrast, the green sections are marked as "Poorly Suitable", suggesting the environmental characteristics in those areas are not as well-suited for successful bamboo growth. Based on the suitability map, the northern and southwestern parts of Agusan del Norte appear to be the best places for cultivating bamboo crops. This type of detailed modeling and visualization can be extremely valuable for farmers, foresters, and land use planners, enabling them to make more informed decisions about where to focus their bamboo planting and harvesting efforts in order to maximize productivity and sustainability.

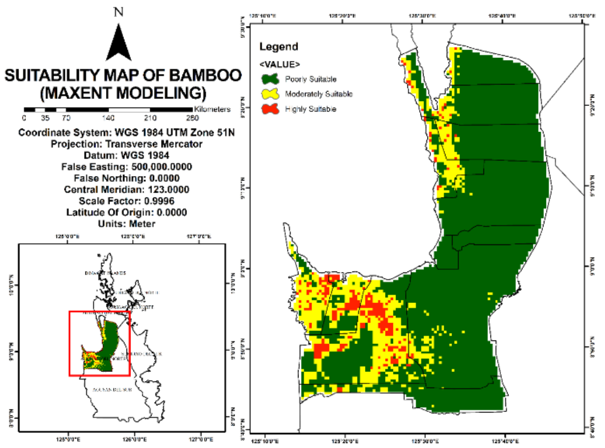

Fig. 5. Suitability Map of Bamboo using MaxEnt Model.

4. CONCLUSION

The MaxEnt model demonstrated high prediction accuracy with an area under the curve (AUC) of 0.802, highlighting its effectiveness in identifying suitable bamboo habitats. The model underscores the critical role of temperature and precipitation in bamboo distribution, revealing that temperature variations and annual precipitation are key factors, while slope has minimal impact. This indicates that bamboo is highly sensitive to environmental conditions, with its growth and establishment closely tied to appropriate temperature and precipitation levels. The model's identification of the northern and southwestern regions of Agusan del Norte as optimal for bamboo production provides clear targets for conservation and management efforts. To enhance the model's predictions, particularly in areas with water limitations and land use constraints, incorporating additional factors like proximity to water bodies and zoning information is recommended. This will offer a more comprehensive understanding of bamboo distribution and growth factors, leading to more effective and targeted plantation strategies.

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