

MaxEnt-Simulated Site Suitability Model for Adlai (*Coix lacryma-jobi* L.) in Bukidnon, Philippines

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ABSTRACT

To create a baseline and projected site suitability models for Adlai and assess the effects of climate change on the distribution of the species, 52 species occurrence points (SOPs) and 14 bioclimatic variables were used. Subsequently, purposive sampling was adopted to collect SOPs, while bioclimatic variables were obtained from a credible online source. The results showed that 245,980 hectares in the province are suitable for species based on the model. To determine the impact of climate change, the projected suitability modeled over 30 years was used, showing an increase from 245,980 hectares to 391,872, an increase of 145,892 hectares. Most of the projected suitable areas are in the southern part where some towns have almost 100% suitability coverage. The prediction accuracy of the model was excellent at 92% based on the Receiver Operating Characteristic-Area Under Curve (ROC-AUC). The bioclimatic variable with the most important contribution is AP12 (annual precipitation) which obtained 24.74%. The information generated in this research is essential for interested sectors in planning, targeting, and prioritizing strategic areas for Adlai investment programs.

Keywords: Adlai; climate change; climate suitability; Maxent

INTRODUCTION

The site suitability and distribution of a plant species are affected by both climatic and non-climatic factors (Paquit et al., 2018). On a broader geographic scale, climatic factors exert a greater influence in regulating species distribution (Hulshof & Spasojevic, 2020). Climatic factors directly affect a species' ecophysiology and can therefore affect its distribution to varying degrees. The effect of climate should be highlighted by the dangers caused by changes. Additionally, changes in species distribution, reproduction timings, and

growing season, length of plants, as well as induced temperature increases, are expected to affect species and ecosystems (Xu et al., 2017). The projected frequent occurrences of drought and typhoons are expected to affect the productivity of the agricultural sector (Israel & Briones, 2012). At the micro level, limiting factors such as elevation, slope, aspect, soil properties, and several biological and non-biological barriers also contribute substantially as they affect the local adaptation of the species (Akinci et al., 2013).

Adlai or Job's tear, scientifically named *Coix lacryma-jobi* L is a staple food of many upland

communities. It is a rain-fed crop like maize and survives in a variety of soils. Furthermore, it belongs to Poaceae grass family, which also includes crops such as rice, corn, and wheat. Adlai is cultivated as a cereal crop in tropics and subtropical regions, such as India, China, South Korea, the Philippines, Thailand, and Malaysia as well as presently being propagated as a staple food in some parts of Mindanao. In Bukidnon, it is propagated mainly by members of the indigenous communities in mountainous regions. In terms of distribution, Adlai is only known to thrive at high elevations where rice and corn do not grow well, thereby making the crop an important alternative food source in some areas. The plant potential as a commercial cash crop is continually being studied. However, there is still a lack of data on potentially suitable areas for cultivation. Essentially, this research will attempt to answer questions relating to spatial suitability as influenced by biophysical conditions through a modeling approach. The results can guide Local Government Units (LGUs) and other stakeholders in prioritization and targeting areas for Adlai-related projects.

This research involved the use of the Maximum Entropy Model (MaxEnt) (Phillips et al., 2006) to determine the suitability of Adlai using different climatic and non-climatic factors. Subsequently, MaxEnt is a species distribution model (SDM) used to determine relationships between species and their environments. In combination with Geographic Information System (GIS) technology, it has become very useful in ecology (Paquit & Rojo, 2018). This research, therefore, takes advantage of the use of Maxent and Geospatial technologies (QGIS ver. 3.4 and Garmin etrex 20x GPS device) to analyze and map the actual species

occurrences as the baseline as well as projected climatic suitability for Adlai to enhance the effectiveness of the model to predict suitable sites considering biophysical heterogeneity and climate change. Although the MaxEnt model was originally developed for wildlife and biodiversity monitoring, this research will inspire agricultural examiners to use this tool by showing its capacity to guide precision agriculture.

MATERIALS AND METHODS

Research Area

This research was conducted in Bukidnon, Philippines (Figure 1). The province of Bukidnon extends geographically from 7°20' – 8°40' N to 124°30' – 125°30' E, with a land area of 910, 046 hectares (calculated in GIS) representing 2.76% of the country's total land area (Paquit & Rama, 2018) the alarming spread of these plants has been documented. Knowing that climate exerts a dominant control over the distribution of plant species, predictions can therefore be made to determine which areas the species would likely spread under a climate change scenario and that is what this study aims to tackle. In the current study, a total of 211 species occurrence points were used to model the current and projected suitability of *Piper aduncum* in Bukidnon, Philippines using Maxent. Results revealed that the suitability of the species was determined primarily by climatic factors with Bio 18 (precipitation of the warmest quarter). Along its boundary are large mountain ranges from which the tributaries of the rivers originate. The central part consists mainly of grasslands and plains areas suitable for agricultural production.

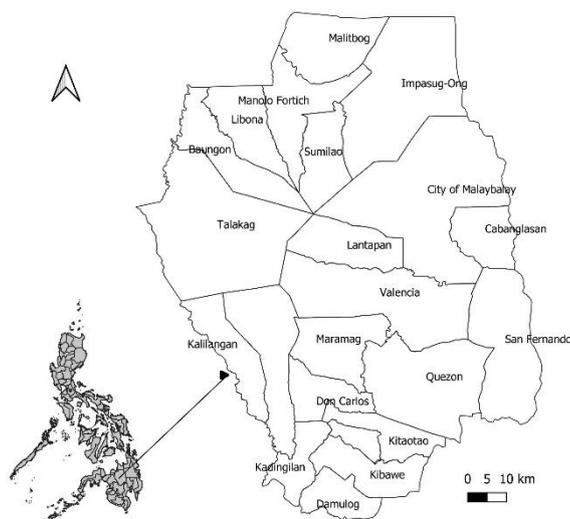


Figure 1. Map of Bukidnon Province

Regarding the climate, the Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA) reported that the northern and southern part of the province has type 3 and 4, respectively. The dry season lasts from November to April, and the remaining months of the year are wet. This climate condition is distinguished by a weak seasonal variability (Parlucha et al., 2017). The average annual rainfall is 2800 mm and temperatures vary with elevation in areas that lie lower than 500 meters above sea level having a recorded temperature range of 20-34°C. The variety of soils includes lowland agricultural soils as well as undifferentiated mountain soils. Inceptisol, ultisol, and alfisol are three of the dominant soil orders in the region, and they are primarily derived from volcanic parent materials. (Calalang & Colinet, 2014). This type of soil is advantageously high in organic matter, cation exchange capacity (CEC) values, low bulk density, and excellent water retention but characteristically stony, with low pH, high phosphorus retention, and aluminum toxicity (Calalang & Colinet, 2014).

Gathering of Species Occurrence Points (SOP’s)

Collection of SOPs was done through ground survey of farm sites in the Province of Bukidnon cultivated with Adlai. The sampling method was a combination of opportunistic and convenience, which aims at collecting SOPs that are essential input for generating the suitability map. A handheld Garmin eTrex 20x global navigation satellite receiver (GNSS) with enabled wide area augmentation system (WAAS) was used to mark the coordinates of SOP’s.

Site Biophysical Features

It is well recognized that using different combinations of environmental variables to create a species’ suitability model will provide a variety of results (Peterson & Nakazawa, 2008). The selection of relevant environmental data must be made with a sense of proportion. To create a final set of environmental data for modeling, a review of the literature was conducted. Considering that this research was conducted across an entire province, only bioclimatic parameters were employed to model the species’ suitability. Additionally, 19 bioclimatic variables obtained from WorldClim.org (Hijmans et al., 2005) were initially considered but were later subjected to spatial autocorrelation analysis using environmental niche model (ENM) tools to remove duplication. The analysis was carried out independently and outside of the GIS software by the ENM tool using ASCII raster data. To determine if two or more data sets are similar, spatial autocorrelation analysis, a measure of similarity, was frequently used in spatial statistics. Table 1 shows the result of the correlation analysis wherein 14 variables were kept for modelling.

In the ENM analysis, similar bioclimatic variables were grouped and spatial autocorrelation within each group was determined. The analysis was no longer necessary for AT1, DR2, and AP12 variables as well as other unique variables in group 8. If the variables in a subgroup are positively correlated, only one is retained aside. In contrast, if the variables have negative or no correlation, all are retained. This analysis ensures that the environmental variables used in MaxEnt are

Table 1. Result of correlation analysis using ENM tools (Paquit & Rama, 2018)

Group	Variable description	Variable Code	Correlation (+, 0, -)	Variables kept
1	Mean Annual Temperature	MAT1	n/a	MAT1
2	Quarterly Temperature	QT8, QT9, QT10, QT11	+ (all) n/a	QT9
3	Monthly Temperature	MT5, MT6	+	MT5
4	Diurnal Range	DR2	n/a	DR2
5	Annual Precipitation	AP12	n/a	AP12
6	Quarterly Precipitation	QP16, QP17, QP18, QP19	+ (17 and19)	QP16, QP17, QP18
7	Monthly Precipitation	MP13, MP14	0	MP13, MP14
8	Unique Variables	UV3, UV4, UV7, UV15	0	UV3, UV4, UV7, UV15
Total		19		14

Note: Bioclimatic variables (recoded to initials) were the WorldClim version 2.1 climate data for 1997-2000 which was released in January 2020.

unique, therefore, the results are simpler and much easier to interpret.

Data Pre-Processing

SOPs were encoded in Microsoft excel with provided data on species names, latitudes, and longitude as fields. The geographic coordinates were all in decimal degrees (dd) format and were georeferenced under the World Geodetic System of 1984 (WGS 84). The standard reference system/datum for angular GPS readings was WGS 84. Finally, the excel document was saved in .csv format as required for MaxEnt. Furthermore, 75% of 50 SOPs were used for training, while 25% were used for testing. The training SOPs served as one of the most important inputs for generating the habitat distribution model, the other is the environmental variables. The resultant habitat distribution map depends on the number of SOPs, and therefore it is important, the more the SOPs collected, the better the results. However, it had been previously reported that MaxEnt produces credible models with minimal SOP input. The relatively strong performance of Maxent is due to its capacity to handle small sample sizes (Pearson, 2007). It can also generate good models with a sample size as low as five (5) SOP's (Garcia et al., 2013; Pearson, 2007)

Meanwhile, GIS layers of all environmental variables were prepared and converted to ASCII format, the required input format of the modeling software.

Data Analysis

In this research, the Maximum Entropy SDM algorithm "MaxEnt" version 3.3.3 (Phillips et al., 2006) downloaded from the American Museum of Natural History (https://biodiversityinformatics.amnh.org/open_source/maxent/) was used. Using the SOPs and 14 variables, 5 replicate runs were produced to obtain mean values from the models created. Maxent produces an output that can be interpreted as an estimate of the relative probability of species distribution in space (Elith et al., 2006). For the assessment of the model accuracy, the receiver operating characteristic - area under the curve (ROC-AUC) generated as one of the Maxent outputs was used (Franklin & Miller, 2009) resource management and conservation planning. These include biodiversity assessment, reserve design, habitat management and restoration, species and habitat conservation plans and predicting the effects of environmental change on species and ecosystems. The proliferation of methods and uncertainty regarding their effectiveness can be daunting to researchers, resource

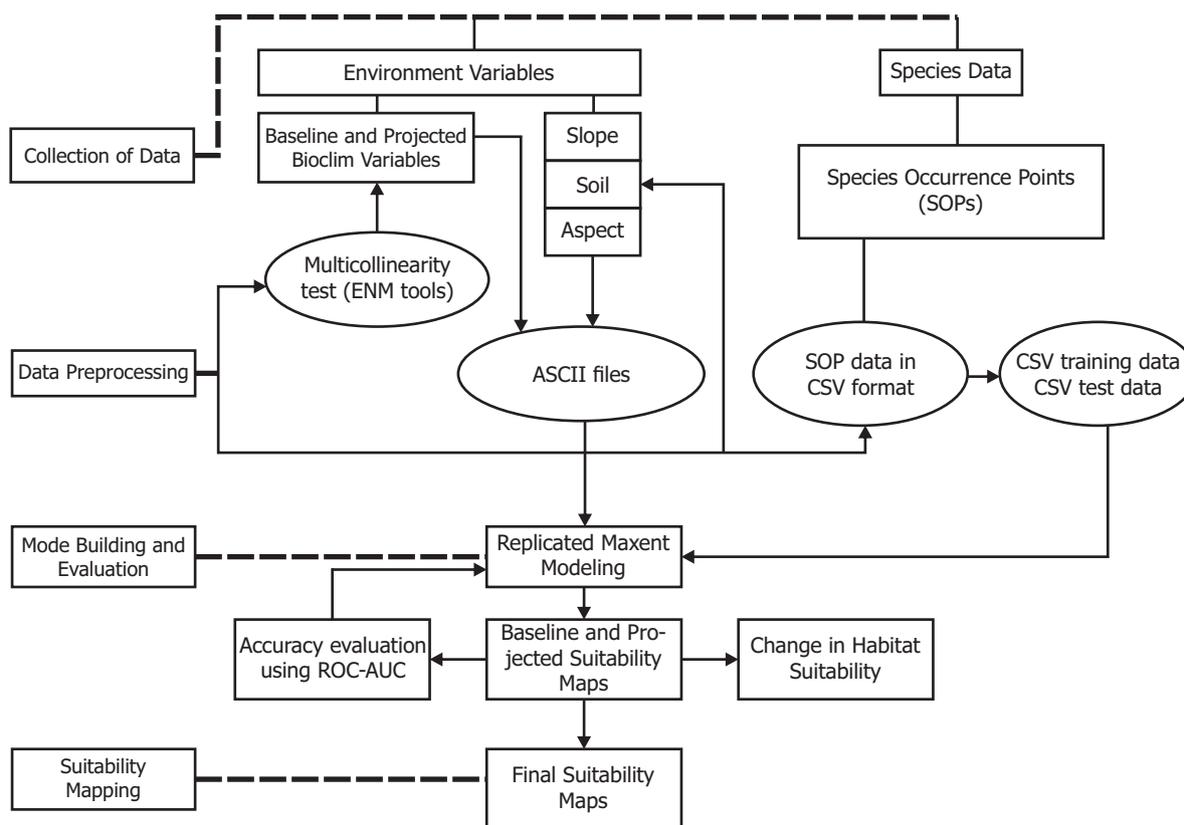


Figure 2. Conceptual summary of modeling method (Paquit & Rama, 2018)

managers and conservation planners alike. Franklin summarises the methods used in species distribution modeling (also called niche modeling. ROC-AUC is a threshold independent accuracy evaluation method that has been proven and tested in many similar research (Rebello & Jones, 2010) when data are scarce and usually collected with sampling biases. We modelled the potential distribution in Portugal of one of the rarest European bats *Barbastella barbastellus* and subsequently ground-validated predictions by using acoustic transects. We used ecological niche factor analysis (ENFA). The percentage influence of each environmental variable on the distribution of the species was determined using the jackknife test. The result of the test was automatically produced by Maxent (Figure 2). To account for crop sensitivity to climate change, the projected climate from the IPCC greenhouse gas concentration trajectory "Representative Concentration Pathway 8.5" (RCP 8.5) for 2050 (IPCC, 2007) was used. The sensitivity of the crop was analyzed by examining the change in suitable areas affected by climate change.

Post-Processing in GIS

Since Adlai is an agricultural crop, only agricultural areas were targeted for the final suitability map. As a result, all areas that are not used for agriculture, such as built-up regions, protected areas, and water bodies, were designated as restricted sites (Figure 3). All land uses were extracted from the 2015 land cover map of the National Mapping and Resource Information Authority (NAMRIA), the central mapping agency of the Philippines (www.namria.gov.ph). Hazard-prone areas

(www.mgb.gov.ph) were also included and classified under restricted sites.

Map Layouts and Statistical Analysis

All the maps were created using QGIS ver. 3.4 (Madeira), which was one of the most recent QGIS versions. MaxEnt is free software and QGIS complements it very well, both are open-source software. It has built-in algorithms for analyzing the percentage contribution of environmental variables to the model. This means that maxent is capable of producing statistical analysis inherently. The Sensitivity analysis was carried out using QGIS, and descriptive statistics were also employed.

RESULT AND DISCUSSION

Actual Locations of Adlai

As shown in Figure 4, most SOPs were recorded in the central part of the province, and there are also several points discovered in the northern part. Prior to fieldwork for data collection, experts from the academic community, local government agricultural technologists, and farmers with experience on both small- and large-scale existing farms were questioned. The sampling method was useful because locations were predetermined based on known occurrences. A total of 52 SOPs were collected from the field in several months of fieldwork. These points correspond to the actual occurrences of the species, whether growing naturally or cultivated. The lowest elevation at which the species has been observed was 214m asl in Quezon, Bukidnon while the highest was 1200 m as recorded in Lantapan,

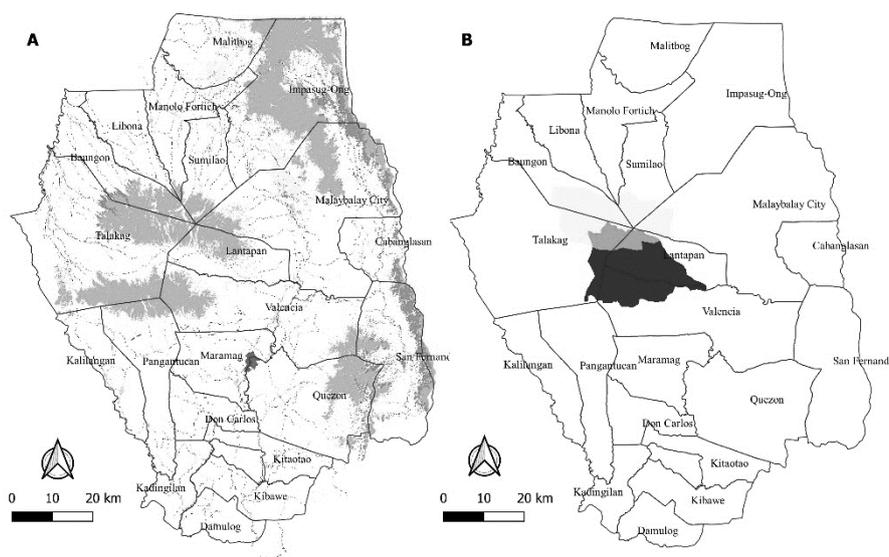


Figure 3. Map of the restriction zones

Bukidnon. This shows that the species adapted to a broader range of elevation. Climate factors change with spatially autocorrelated altitude, as elevation rises, the temperature falls, and more often, precipitation frequency and rate especially in forested mountains also increase.

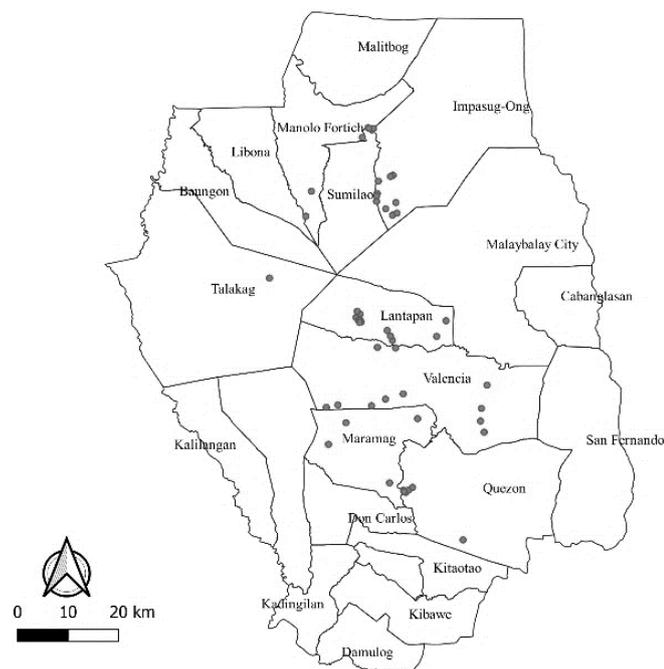


Figure 4. Actual locations of Adlai

The occurrence points indicate that there is a vast potential area in the province for the cultivation of the crop based on the validated observations carried out during field visits. Among the 8 towns with species records, the highest record was in Lantapan followed by Impasug-ong and Valencia City. These locations were prioritized for sampling based on information from experts. Additionally, Adlai is an important staple for some indigenous people (IP) in the province, particularly in Lantapan and Impasug-ong, where a prominent IP group resides. These groups of individuals are involved in the cultivation, and they make up this group. Members of the indigenous populations as well as local farmers grow Adlai in neighboring cities including Quezon and Maramag.

Baseline and Projected Suitability

The baseline and projected suitability maps are shown in Figure 5. Visual interpretation of the baseline suitability suggests that suitable areas have wide coverage. The rest of the cities have areas suitable for the species. The cities of Malaybalay and Valencia obtained the greatest area of suitable sites for the baseline suitability, and the least was obtained at San Fernando.

For the projected suitability, most of the southern part is predicted suitable. There are also substantial suitable areas along the northwestern region, comprising the municipalities of Manolo Fortich, Libona, Baungon, Talakag, Malitbog, Sumilao, and Impasugong. In the south, 5 municipalities almost obtained 100% coverage, namely, Damulog, Dangcagan, Don Carlos, Kadingilan, and Kibawe. This predicted change can be attributed to the interplay between various climatic variables largely influenced by the increase of annual mean temperatures in the highlands, where more baseline suitable sites are discovered and the increase in precipitation levels in the lowlands of Southern Bukidnon. Based on downscaled evaluations of WorldClim data (Daron et al., 2018), mean annual temperatures in the Philippines are projected to rise to ~ 2 °C with a corresponding increase in precipitation in 2050. Adlai is characterized as a short-day crop that requires high temperatures and abundant rainfall (Aradilla, 2016). The projected suitable sites are generally low altitude areas and therefore biophysically warmer with an optimal monthly rainfall yield that is projected to increase in the coming years.

The predicted change in suitability is attributed to the influence of climate change. Projected climate (2050) based on the Relative Concentration Pathway 8.5 climate change scenario of the International Panel for Climate Change (IPCC) was used to generate future suitability scenarios (Table 2). Projections are an important aspect of species suitability distribution modelling because species survival and reproduction are affected mainly by environmental factors, particularly climate. The macroscale distribution of species appears to be influenced by the climate, because of this, only climate variables were taken into account in this research. Both baseline and projected suitability maps should be interpreted with caution. Further refinement can be made when the level of mapping becomes local. Soils, aspect, slope, and other important biophysical parameters will now come into the picture as these are important variables at the local level.

Model Accuracy

Seventy-five percent (75%) of the total SOPs (training data) were used to generate the MaxEnt simulated suitability model. The accuracy of the model was then tested using the remaining 25% (test data). The testing or validation process measures the percentage of test points on the suitable sites, and test points are considered actual occurrences. Therefore, greater model accuracy was achieved as more test points fell in suitable sites. As shown in the table, an excellent mean AUC of 92% was obtained. By carefully analyzing the AUC of the test data, it can be concluded

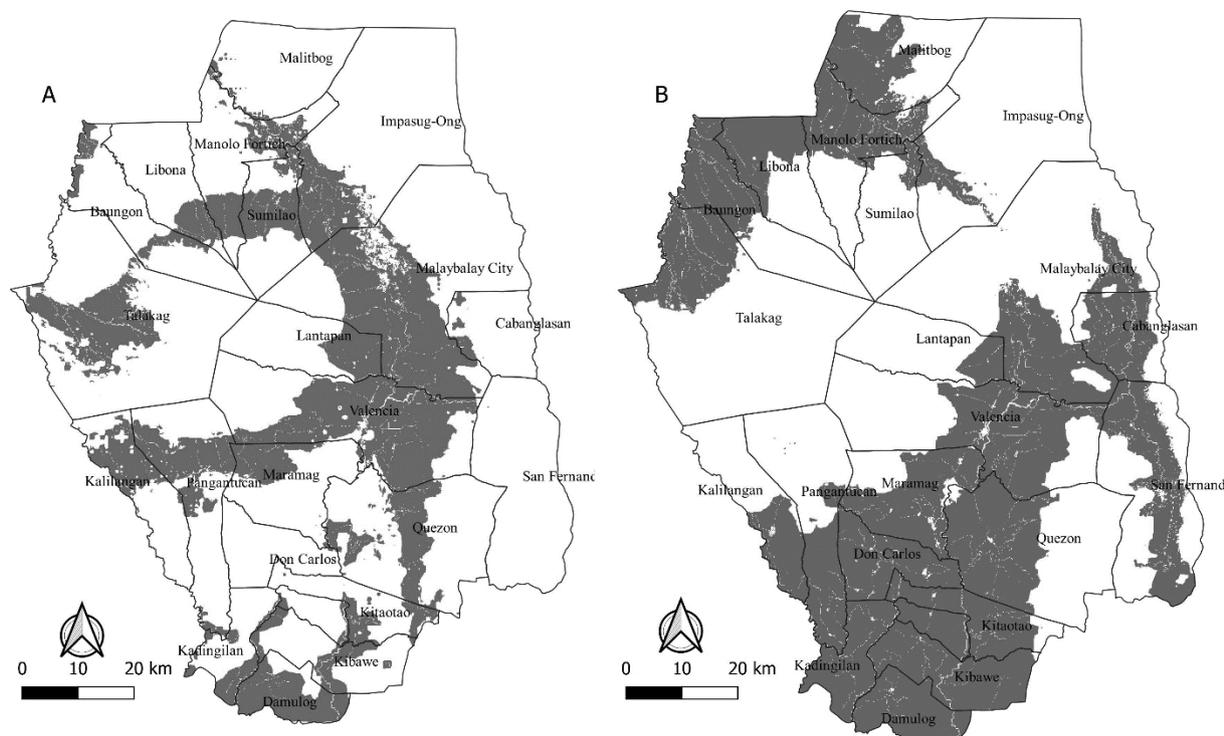


Figure 5. Map of baseline suitability (left), map of projected suitability (right)

that the MaxEnt model was highly accurate as far as accuracy assessment using AUC is concerned. The uncertainties and limitations in the data used are recognized and interpretations of the AUC values reported in Table 3 must be carried out with caution. Research on the potential distribution of potatoes using the Maxent model yielded 85% AUC, suggesting the acceptability and robustness of the model (Khalil et al., 2021). An AUC value of 90% was also obtained when Maxent was used to model and predict the distribution of *Dipterocarpus alatus* (Kamyó & Asanok, 2020). Achieving an AUC value of 50% indicates poor prediction and 100% means optimum model accuracy (Kamyó & Asanok, 2020).

Variable Contributions

The percentage contribution of the variables in MaxEnt depicts the importance of each variable to the model. AP12 (annual precipitation) gained the strongest contribution with a mean of 22.1% (Table 4). The mentioned variable received consistent contributions across 5 replicates, while MAT1 (mean annual temperature) achieved 10.16% and was ranked fourth. Adlai is a tropical plant species, which prefers an optimal wet and warm climate to grow and survive. Importantly, the climate is a driver of species distribution, as illustrated by the variables that contributed most, and

it is the primary factor regulating species distribution (Paquit et al., 2017).

Elevation was not included in this research, as well as other topographic factors slope, and aspect. The elevation is correlated with the climate, which explains why it was excluded. In many ecosystems, regional variation in slope and aspect plays a substantial role in determining vegetation pattern, species distribution, and ecosystem processes, however, the geographical scale of modeling is too wide for these parameters to have a meaningful role. The effects of topographic factors can be widely observed when modeling at a smaller spatial scale. The slope and aspect of a vegetated surface strongly influence the amount of solar radiation intercepted by that surface (Bennie et al., 2008) including near-surface temperatures, evaporative demand and soil moisture content. It also determines the exposure of vegetation to photosynthetically active and ultra-violet wavelengths. Spatial variation in slope and aspect is therefore a key determinant of vegetation pattern, species distribution and ecosystem processes in many environments. Slope and aspect angle may vary considerably over distances of a few metres, and fine-scale species' distribution patterns frequently follow these topographic patterns. The availability of suitable microclimate at such scales may be critical for the response of species distributions to climatic change

Table 2. Projected change (Gain or Loss) of suitable areas per town

Town	Baseline Suitability (BS)				Projected Suitability (PS, 2050)			Change Gain (+) / loss (-) (ha.)
	Area (ha.)	Suitable (ha.)	Unsuitable (ha.)	% Suitable	Suitable (ha.)	Unsuitable (ha.)	% Suitable	
Baungon	33,188	5,044	28,144	15	16,496	16,692	50	11,452
Cabanglasan	22,320	1,750	20,570	8	15,783	6,537	71	14,033
Damulog	17,287	13,837	3,450	80	16,880	407	98	3,043
Dangcagan	7,358	1,098	6,260	15	7,195	163	98	6,097
Don Carlos	20,373	90	20,283	0	19,824	549	97	19,734
Impasug-ong	85,463	14,471	70,992	17	5,018	80,445	6	-9,453
Kadingilan	17,316	4,886	12,430	28	16,852	464	97	11,966
Kalilangan	26,874	9,315	17,559	35	10,889	15,985	41	1,574
Kibawe	25,774	6,545	19,229	25	25,169	605	98	18,624
Kitaotao	18,930	5,438	13,492	29	16,460	2,470	87	11,022
Lantapan	29,082	7,802	21,280	27	4,904	24,178	17	-2,898
Libona	28,223	4,678	23,545	17	14,489	13,734	51	9,811
Malaybalay City	111,598	44,915	66,683	40	29,998	81,600	27	-14,917
Malitbog	35,959	1,059	34,900	3	18,479	17,480	51	17,420
Manolo Fortich	35,015	10,122	24,893	29	19,672	15,343	56	9,550
Maramag	32,388	8,209	24,179	25	23,841	8,547	74	15,632
Pangantucan	43,281	15,503	27,778	36	15,214	28,067	35	-289
Quezon	64,125	15,887	48,238	25	31,238	32,887	49	15,351
San Fernando	56,045	14	56,031	0	25,826	30,219	46	25,812
Sumilao	25,926	10,242	15,684	40	2,493	23,433	10	-7,749
Talakag	101,325	21,745	79,580	21	21,838	79,487	22	93
Valencia	72,607	43,330	29,277	60	33,314	39,293	46	-10,016
Total	910,457	245,980	664,477		391,872	518,585		145,892

Table 3. Computed AUC values for training and test data

Replication	AUC	
	Training	Test
BS1PS1	0.949	0.932
BS2PS2	0.949	0.926
BS3PS3	0.953	0.930
BS4PS4	0.951	0.924
BS5PS5	0.961	0.887
Mean	0.952	0.919
SD*	0.004	0.018

*Standard deviation

at much larger spatial scales. However, quantifying the relevant microclimatic gradients is not straightforward, as the potential variation in solar radiation flux under clear-sky conditions is modified by local and regional variations in cloud cover, and interacts with long-wave radiation exchange, local meteorology and surface characteristics. We tested simple models of near-surface temperature and potential evapotranspiration driven by meteorological data with the incoming solar radiation flux adjusted for topography against measurements of temperature and soil moisture at two chalk grassland field sites in contrasting regional climates of the United Kingdom. We then estimated the cumulative distribution function of three key ecological variables (monthly

Table 4. Per variable contribution to the Maxent model in percent

Variable	BS1PS1	BS2PS2	BS3PS3	BS4PS4	BS5PS5	Mean
AP12	25.3	24.3	26.4	23.4	24.3	24.74
QP18	14.2	14.0	12.8	13.2	13.4	13.52
MT5	12.4	13.1	13.0	13.2	14.3	13.2
MAT1	10.1	10.2	10.3	10.1	10.1	10.16
MP14	9.60	10.8	9.00	9.40	7.00	9.16
QP17	8.60	7.20	8.00	7.60	9.40	8.16
UV15	7.40	8.40	8.10	8.00	7.70	7.92
MP13	6.30	6.50	7.70	8.00	7.00	7.10
QT9	2.60	1.90	1.10	4.10	0.80	2.10
UV4	1.40	1.40	1.40	1.40	1.40	1.40
QP16	0.90	1.30	1.00	0.30	1.20	0.94
UV7	0.20	0.30	0.70	0.80	2.60	0.92
UV3	0.50	0.20	0.30	0.30	0.50	0.36
DR2	0.50	0.40	0.20	0.20	0.30	0.32
Total	100	100	100	100	100	100

temperature sums above 5 and 30 °C, plus potential evapotranspiration. Correlation with solar radiation, slope, and aspect can greatly affect ecologically critical factors such as surface temperatures, evaporative demand, and soil moisture content (Paquit et al., 2017). Soil influences growth, however, the scale of modeling will affect the contribution of this variable, and therefore it was not included.

Important Implications

Food security as well as climate change mitigation and adaptation are among the important goals of the Philippine government. Substantial funding is being made available to support research and development projects that will in some way help in achieving these goals. The Department of Agriculture recently included Adlai in its main research and development program. Because of its potential in food security programs, research and development work on the commodity have been carried out to ensure the sustainability and promotion of the crop (Marin et al., 2020). In Bukidnon, Adlai is an important staple food for Indigenous people (IP), who are important targets and recipients of government programs on food security. The cultivation of this species must be sustained and improved not only for the preservation of the IP culture but also for the possible economic gains. The maps generated in this research can

serve as baseline information for the different sectors interested in Adlai to target and prioritize potential areas, and these maps are important inputs in planning the strategic sites for investments. The projected suitability map is also important considering climate change, which is also affecting the agriculture sector of the country. Therefore, in the longer term, appropriate areas in the projected maps for Adlai cultivation and other efforts should be targeted and prioritized.

CONCLUSION

This research demonstrated the effectiveness of utilizing MaxEnt model in combination with GIS technology to generate the suitability map of Adlai in Bukidnon, Philippines. Using the SOP’s collected across the province, Maxent simulated model generated a robust suitability map for Adlai with excellent accuracy of 92%. A total of 245,980 hectares (27%) in the province are suitable for the species and this was projected to increase to 391,872 hectares (43%) as predicted using bioclimatic parameters based on the Relative Concentration Pathway 8.5 climate change scenario of the IPCC. The bioclimatic variable with the greatest impact was bio 12 (annual precipitation), which had a 24.74% influence, suggesting that the species is sensitive to rainfall.

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CONFLICT OF INTEREST

This article was not published in any journal before and as such no conflict of interest.

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