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Predicting Species Occurrence of *Litsea leytensis* Merr. in the Provinces of Laguna and Quezon, Philippines

ABSTRACT

Litsea leytensis Merr. is an endemic and premium hardwood species in the Philippines used for wood carving. It is a threatened species that survival in the wild is impossible with persistent causal factors. The study estimated the species probability of occurrence in Laguna and Quezon based on local knowledge, published records of species distribution, and environmental variables using the Maximum Entropy (MaxEnt) model. Six pre-models were generated: one climatic model, four partial models of variable groups combined with climatic variables, and one full model with 31 original variables. The Final model had 19 highly correlated variables after variable selection and reduction using Jackknife and multi-collinearity tests. Analysis of variable importance revealed that L. leytensis' occurrence was mostly determined by climatic (62.0%), edaphic (21.76%), and anthropogenic variables (9.53%), while topographic (5.15%) and vegetation-related variables (1.34%) had lesser contributions. The Area Under the Receiver Operating Characteristic Curve (AUC) and True Skill Statistics (TSS) measured model accuracy; and the Final model performed best at AUC = 0.9489 and TSS = 0.7175. Modeling species probability of occurrence could help key sectors in Laguna and Quezon to formulate appropriate conservation strategies for L. leytensis as a reforestation and industrial tree plantation species.

Keywords: *endemic, occurrence, MaxEnt, modeling, conservation*

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INTRODUCTION

Litsea leytensis Merr. of the family Lauraceae is an endemic forest tree species and a premium hardwood species in the Philippines, growing in cold climates and in the lowland forests of Bataan, Quezon, Sorsogon, Negros, and Leyte, with limited distribution in Laguna and Pangasinan (*Pelser et al. 2011*). It is locally known as "Batikuling or Bitokling" referring to the wood as the main raw material used for carving in Paete, Laguna the Carving Capital of the Philippines and home of skilled wood carvers and sculptors.

The trade name of the species in Southeast Asia is "medang," with known distributions in the Indo-Malayan regions, Australia, and the Pacific Islands. It is listed as a near threatened species in the International Union for Conservation of Nature (IUCN) Red List as assessed by the *Energy Development Corporation* (*2020*). It is an endangered species in the Updated List of Threatened Philippine Plants and their Categories by the Department of Environment and Natural Resources (DENR) Administrative Order (DAO) No. 11 s. 2017, which means that survival in the wild is impossible with the persistence of various causal factors. Thus, the cutting, gathering, and utilization of *L. leytensis* is regulated in privately developed lands. Owners of the land are required to obtain a private land timber permit (*Forestry Development Center 2004*). In the natural and residual forests of public domain, moratorium on cutting trees include *L. leytensis* as per Executive Order No. 23 Declaring a Moratorium on the Cutting and Harvesting of Timber in the Natural and Residual Forests and Creating the Anti-Illegal Logging Task Force (2011).

L. leytensis was on the list of threatened trees without (0) off-site collections as assessed by *Fernando et al.* (*2008*) but was present in the taxonomic list of the 358 tree species recorded in Mt. Banahaw-San Cristobal Protected Landscape (*REECS 2011*). The first collected specimen was recorded in a forest of about 500 m altitude in Buenavista, Leyte, near Jaro, in

1914, which was verified as *L. leytensis* (*Merrill 1915*). The study aimed to estimate the probability of the occurrence of *L. leytensis* in Laguna and Quezon through species distribution modeling (SDM), specifically using Maximum Entropy (MaxEnt), to provide information about its potential geographic range, habitat, and ecology as needed in formulating appropriate species conservation measures. The species probability of occurrence generated from species presence only (PO) data, local knowledge, and biophysical and climate-related variables can provide information for the stakeholders of these provinces about the appropriate conservation measures that may influence future species distribution. The description of *L. leytensis* and its habitat could be relevant inputs in assessing the ecosystem services provided by the tree species when integrated into tree farms, forests, and other proposed areas for its preservation. Also, modeling potential niches and distributions of this economically important but increasingly threatened tree species would help key sectors formulate strategies for managing and sustaining the needed planting materials for reforestation in support of the nationwide greening of the country by virtue of Executive Order No. 26 (2011) and the establishment of industrial tree plantations for the production of wood for carving. The SDM of *L. leytensis* can contribute to determining the potential locations of vigorous mother trees that could lead to improved species selections for conservation and management programs that consider the ecology of the site, environmental data, and the socioeconomic desirability of tree species.

MATERIALS AND METHODS

The study was conducted from September 2021 to May 2022. It involved gathering of secondary information to identify data gaps before the collection of primary data.

Study Site

The geographical boundary of the research covered the provinces of Laguna and Quezon in the southern portion of Luzon in in the Philippines, where Litsea leytensis Merr. naturally thrives at low to medium altitudes (400 to 500 masl) (**Figure 1**). The Global Biodiversity Information Facility recorded that the tree species occurs in Pangil (*Orrell and Informatics Office 2022*), Lumban, Paete, and Siniloan in Laguna province (*Bijmoer et al. 2022*) and in Tayabas (*MNHN and Chagnoux 2022*), now Quezon province.

Study Framework

At the initial stage of the study, local knowledge on the history of species occurrence and presence-only (PO) species information were important inputs in predicting the species occurrence of *L. leytensis* Merr. in Laguna and Quezon provinces. The additional inputs that influence the characteristics and description of the species' growing conditions are climatic, anthropogenic, edaphic, vegetation-related, and topographic variables. Model development of *L. leytensis* used a list of species obtained from the PO data and environmental predictors across a defined landscape (**Figure 2**). Maximum Entropy (MaxEnt) was considered a Poisson model where the number of counts is a function of biophysical and bioclimatic variables (*Merow et al. 2013*). The pixels of the study area form the space on which the MaxEnt probability distribution is defined when applied to PO species distribution modeling, pixels with known species occurrence records are the sample points; and the features are environmental variables; and their functions (*Phillips et al. 2006*). It is more likely that groups of environmental variables, act together to influence species occurrence (*Garcia et al. 2013*). Climate-related variables, such as mean annual temperature and rainfall as well as the conditions of topography and soil may affect the distribution range of species. This is because species populations are influenced by biophysical factors, especially if the species are left alone to follow natural processes. Latitude or elevation are also connected with variables that have a biophysical impact on the species but vary in their spatial and temporal relationships (*Phillips et al. 2006*). Putting the data on the biophysical conditions with the anthropogenic factors such as human population and distance variables (built-up, river, and road) may pose threats to species occurrence or loss. Land cover change, including human activities, will also have a major effect on species' present and future distributions (*Torres et al. 2016*).

The integration of environmental components and known locations of *L. leytensis* would indicate the suitable locations corresponding to its current distribution. Thus, a model can be developed using MaxEnt with climatic and biophysical variables as inputs to describe and project the future distribution of *L. leytensis* throughout Laguna and Quezon provinces (**Figure 2**).

Collection of Species Presence-Only (PO) Data

Secondary data of species presence-only (PO) information or species occurrence points (SOPs) in the provinces of Laguna and Quezon were sourced from the biodiversity surveys of Southern Luzon State University (SLSU), technical reports from the Department of Environment and Natural Resource-Ecosystems

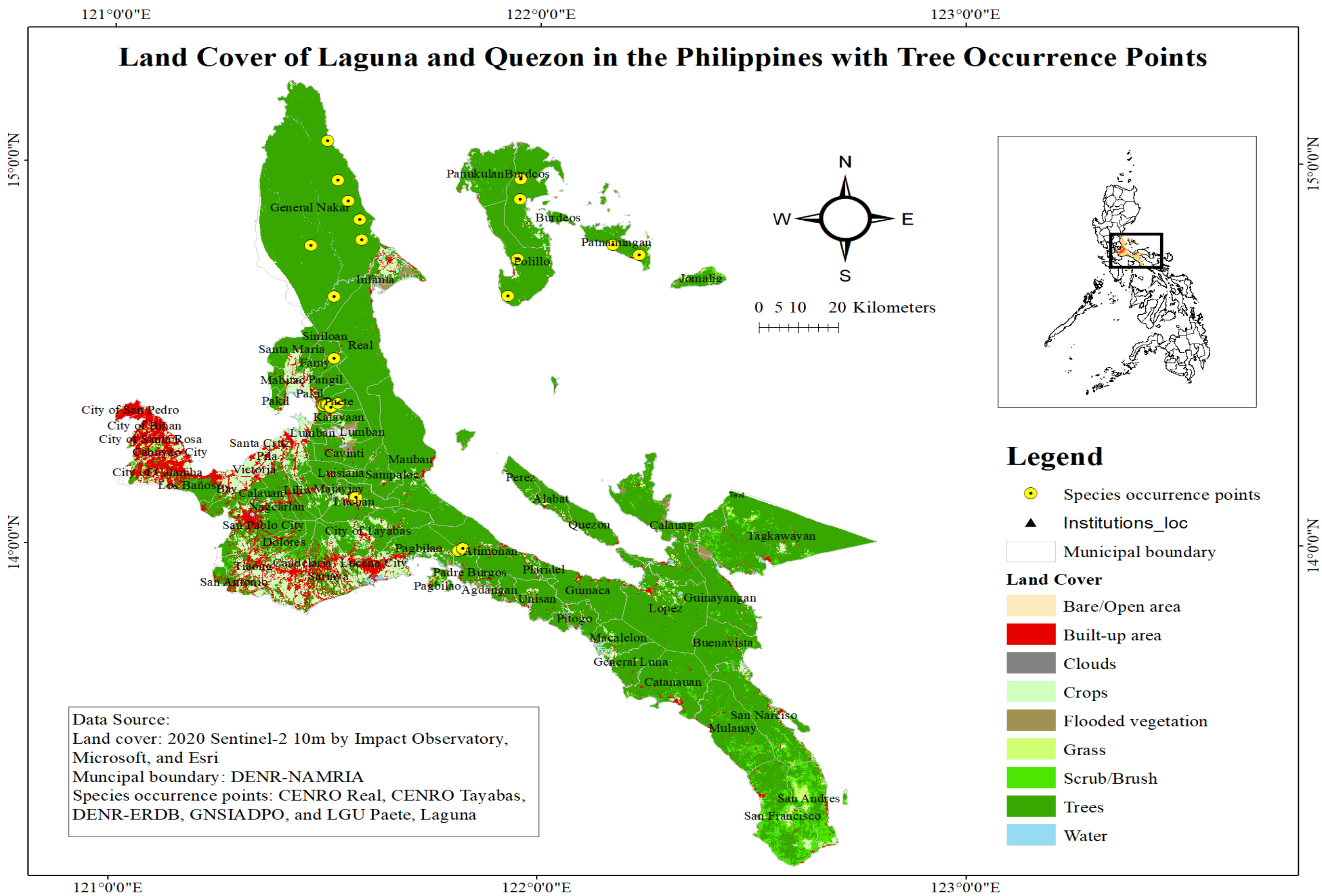

Figure 1. Land cover map of the provinces of Laguna and Quezon in 2020 including the species occurrence points of *Litsea leytensis* Merr.

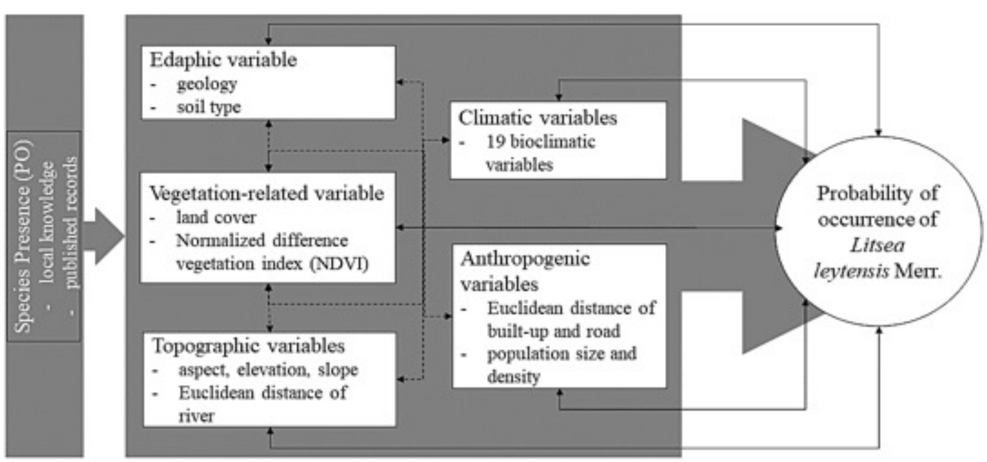

Figure 2. The conceptual framework used in the stud

Research and Development Bureau (DENR-ERDB), and Biodiversity Monitoring System (BMS) reports of the DENR-Community Environment and Natural Resources Office (CENRO) Tayabas, Quezon and DENR-CENRO Real, Quezon. The SOPs were validated through online interviews with focal persons from the government agencies. Primary data for the geographic coordinates of *L. leytensis* trees in Paete, Laguna were obtained using a Global Positioning System (GPS) device. The PO data in General Nakar and Pollilo Islands, Quezon were generated by creating a polygon centroid of the trees observed at the barangays based on reports and local knowledge using the data management tools in ArcGIS. The coordinates (longitude and latitude) used were encoded following the required format for the input samples in MaxEnt.

The description of the habitat of *L. leytensis* where the SOPs were obtained, was documented from key informant interviews (KIIs) recorded with the staff of the University of the Philippines Land Grant Management Office in Siniloan, Laguna; the National Power Corporation Caliraya-Lumot Watershed Area Team and Haribon Foundation Buhay Punlaan in Lumban, Laguna; the General Nakar Sustainable Integrated Area Development Project Office in General Nakar, Quezon; and the Municipal Environment and Natural Resources Officers of the local governments of Paete, Laguna; and Lucban and Tayabas, Quezon. They provided the biophysical characteristics of sites where the trees have occurred, the growth of regenerants, and other environmental factors that influence the potential future distribution of the species in Laguna and Quezon.

Climatic, Biophysical and Anthropogenic Variables

The environmental variables including data on climatic, topographic, vegetation-related, edaphic, and anthropogenic variables were considered potential predictors of the occurrence of *L. leytensis* in Laguna and Quezon. Data on rainfall and temperature (bioclimatic variables) with a spatial resolution of 30 s (~1 km^2) were obtained from the WorldClim version 2.1 climate data which was averaged for the years 1970-2000 and released in January 2020. These climatic variables were often used in species distribution modeling obtained from the monthly temperature and rainfall values to create more biologically meaningful variables that represent annual trends, seasonality, and extreme or limiting environmental factors (*Fick and Hijmans 2017*) (**Table 1**).

Topographic data were obtained from the National Mapping and Resource Information Authority (NAMRIA) of DENR, including edaphic information from the Bureau of Soils and Water Management (BSWM) of the Department of Agriculture (DA), which was downloaded in the NAMRIA geoportal. For the vegetation-related variable, the Sentinel-2 10 m land cover of 2020 this was produced by *Esri, Impact Observatory, and Microsoft* (*2022*) with class definitions: water, trees, flooded vegetation, crops, built area, bare ground, rangeland, and clouds, among others (*Karra et al. 2021*) under a Creative Commons by Attribution (CC BY 4.0) license. To improve and neutralize the vegetation cover with more generalized classes, a 250 m resolution normalized difference vegetation index (NDVI) was used. The 2020 NDVI data generated from the Moderate Resolution Imaging Spectroradiometer (MODIS) version 6 was accessed in the U.S. Geological Survey Earth Explorer. The NDVI values range between -1 to +1 where higher values correspond to forest canopy (*Perez and Comiso 2014*); low values refer to agricultural areas, grasslands, or bare soil; and negative values relate to water surfaces or clouds (*Perez et al. 2020*). Variables pertaining to distance from roads, rivers, and buildings were generated using the spatial analyst tool of Euclidean distance.

Anthropogenic variables included the 2020 population size and density of Laguna and Quezon at the barangay level. These data were obtained from the from the *Philippine Statistics Authority* (*2021*). All data were projected and masked to the administrative boundaries of Laguna and Quezon.

Data Preparation for Environmental Layers

The preparation of data for anthropogenic, climatic, edaphic, vegetation-related, and topographic variables followed the tutorial guide for users by *Young et al.* (*2011*) in formatting data prior to the MaxEnt model run. The environmental layers also were modified so that all the spatial data have the same geographic bounds and cell size (**Table 1**). All the environmental layers were converted from raster format to ASCII (American Standard Code for Information Interchange) grid format (.asc) with the exact same cell size, extent, and projection system (e.g., geographic or UTM) before model execution.

Model-building, Evaluation and Validation

Presence-only (PO) data or known occurrence records were used to estimate the species probability of occurrence of *L. leytensis* Merr. in Laguna and Quezon. The species occurrence points (SOPs) were filtered using the species distribution modeling (SDM) tool extension to spatially rarefy occurrence data and avoid the bias of clustered SOPs (*Tumaneng et al. 2019*), ensuring there was only one record of the species per 100 m x 100 m pixel. According to *Elith et al.* (*2011*), let y = 1 mean presence, y = 0 refer to absence, z represent a vector of environmental variables, and background be defined as all locations within L (or a random sample thereof). So, the probability of species' presence, conditioned on the environment, is based on (*Elith et al. 2011*): Pr(y = 1|z), which was initially presented by (*Phillips and Dudik 2008*) as P(y =1|x) by applying Bayes' Rule, where x is a site, rather than a vector of environmental conditions.

The Maximum Entropy Species Distribution Modeling (MaxEnt) version 3.4.4 software (*Phillips et al. n.d.*) was used in this study. The probability distribution of MaxEnt $\hat{\pi}$ is exactly equal to the Gibbs probability distribution $q\lambda$ that maximizes the likelihood of the *m* sample

Table 1. Description of climatic and biophysical variables used in predicting the occurrence of *Litsea leytensis* Merr., Laguna and Quezon, Philippines.

Variable	Code	Data Source
Climatic		
Annual Mean Temperature	Bio1	WorldClim
Mean Diurnal Range (Mean of monthly (max temp - min temp))	Bio2	(*Fick and Hijmans 2017*)
Isothermality (BIO2/BIO7) (×100)	Bio3	
Temperature Seasonality (standard deviation ×100)	Bio4	
Max Temperature of Warmest Month	Bio5	
Min Temperature of Coldest Month	Bio6	
Temperature Annual Range (BIO5-BIO6)	Bio7	
Mean Temperature of Wettest Quarter	Bio8	
Mean Temperature of Driest Quarter	Bio9	
Mean Temperature of Warmest Quarter	Bio10	
Mean Temperature of Coldest Quarter	Bio11	
Annual Precipitation	Bio12	
Precipitation of Wettest Month	Bio13	
Precipitation of Driest Month	Bio14	
Precipitation Seasonality (Coefficient of Variation)	Bio15	
Precipitation of Wettest Quarter	Bio16	
Precipitation of Driest Quarter	Bio17	
Precipitation of Warmest Quarter	Bio18	
Precipitation of Coldest Quarter	Bio19	
Edaphic		
Geology	geology	DA-BSWM
Soil type classification	soil type	
Vegetation-related		
Sentinel-2 10 m land cover of 2020	land cover	*Esri et al.* (*2022*)
Normalized Difference Vegetation Index (-1 to 1) with 250 m resolution	NDVI	*U.S. Geological Survey* (*2020*)
Topographic		
Aspect (generated from digital elevation model: DEM)	aspect	DENR-NAMRIA
Elevation in meters (derived from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) with 30 m resolution)	elevation	
Slope in % (generated from digital elevation model: DEM)	slope	
Distance to rivers (Euclidean distance in meters)	eucdist_river	
Anthropogenic		
Distance to built-up areas (Euclidean distance in meters)	eucdist_built-up	DENR-NAMRIA
Distance to roads (Euclidean distance in meters)	eucdist_road	
Population size in 2020 at the barangay level	population_size	*Philippine Statistics Authority* (*2021*)
Population density in 2020 at the barangay level	population_density	

points (*Phillips et al. 2006*) which was presented by (*Garcia et al. 2013*) as:

$$p(x) = \frac{\exp\left(c1{*}f1{*}(x) + c2{*}f2{*}(x) + c3{*}f3(x)\ldots\right)}{Z} \quad (1)$$

where c_1, c_2,.cm are constants; f_1, f_2,.m are the features; and Z is the scaling constant that ensures that P sums to 1 over all grid cells (*Garcia et al. 2013*). Consistently, it reduces the negative log likelihood of the sample locations $\tilde{\pi}$ [−ln(qλ)], termed the log loss (*Phillips et al. 2006*). The MaxEnt distribution can be shown as the Gibbs (*Garcia et al. 2013*) (Equation 2):

$$\frac{\tilde{\pi}\,[-\ln(q\lambda)] + \Sigma\, \beta j|\lambda j|}{j} \quad (2)$$

The data were proportioned for the purpose of model training and model testing (the random test percentage was 25) while other values were kept in their default settings. The default auto features used were linear, quadratic, and hinge features. The creation of response curves, pictures of predictions, and Jackknife to measure variable importance was allowed in the software. The number of runs was set at 15 using the Sub-sample replicated run type. The maximum number of background points for the sampling technique was 10,000 and the maximum number of iterations was at 5,000 that allowed the model to have adequate time for convergence with 1×10^{-5} convergence threshold. The regularization multiplier was kept at its default setting (Equation 1). To represent sampling effort while reducing the sampling bias, a bias file was included in the run that defined where MaxEnt selects the background points. The output format was logistic with a .asc output file type.

A total of seven models, including the Final model for *L. leytensis* were created. Six preliminary models were developed for *L. leytensis* as: Full model; Climatic only model; Climatic + Anthropogenic model; Climatic + Edaphic model; Climatic + Vegetation-related model; and Climatic + Topographic model.

The Full model utilized all 31 variables which included 19 climatic variables and 12 biophysical variables. The Climatic model used the 19 climatic variables only, while the Climatic + Anthropogenic model involved the distance variables of built-up and roads, population size, and population density in addition to the 19 bioclimatic variables. With 19 climatic variables, the Climatic + Edaphic model used the geology and soil type variables, while the Climatic + Vegetation-related model used the land cover map and NDVI. The Climatic + Topographic variables utilized aspect, elevation, slope, and Euclidean distance of the river in addition to the 19 climatic variables. During the pre-modeling stage, 75% of species occurrence records served as training points, while 25% were used to assess the accuracy of the model. The output of the pre-model runs wasthe basis for selecting and reducing variables that were incorporated in the Final model.

Analyses were performed to verify which variables tend to reduce model reliability when omitted. During the model building, the Jackknife procedure was adapted to compare the six preliminary models with a combination of the parameters. The Jackknife tests of variable importance helped identify those with important individual effects (*Elith et al. 2011*). A multi-collinearity test through spatial autocorrelation was also applied for the 31 variables using the Pearson correlation coefficient (r) in the SDM toolbox of the ArcGIS desktop. The selected cross-correlation value as a cut-off threshold was $r \geq 0.80$ to remove strongly correlated predictors. Only one climatic variable was included in the Final Model from a set of highly cross-correlated climatic variables. The combination of variable groups considered in the selection of the model was based on the Jackknife test during the pre-modeling runs and the multi-collinearity test of variables to select the most appropriate variable for each group of highly correlated variables.

The accuracy of the models was measured using the area under the Receiver Operating Characteristic (ROC) curve (AUC) and the True Skill Statistic (TSS). The ROC curve was introduced by *Swets* (*1988*) and has been used by several authors to evaluate model performance. The Area Under ROC Curve (AUC) provides a single measure of model performance, independent of any choice of threshold (*Phillips et al. 2006*). The AUC values range from 0.5 to 1 with increasing model accuracy and a value of 0.5 represents that the model estimate was not better than random (*Torres et al. 2016*). AUC is explained as the likelihood that a randomly chosen presence location is ranked higher than a randomly chosen background point (*Merow et al. 2013*). The TSS is an intuitive method of measuring the performance of species distribution models, also referred to as the Hanssen-Kuipers Discriminant. The projections are expressed as presence–absence maps showing significant correlation with those of the threshold-independent AUC statistic (*Shabani et al. 2018*).

RESULTS AND DISCUSSION

Preliminary Models for *Litsea leytensis* Merr.

Six preliminary models were generated during the initial modeling runs using the combination of climatic data with the biophysical variable groups. The models were: Climatic model with the 19 bioclimatic variables only; Climatic + Anthropogenic model; Climatic + Edaphic model; Climatic + Vegetation-related model; Climatic + Topographic model; and Full Model with the 31 original variables. These models were summarized with significant variables and AUC values (**Table 2**).

Among the 19 climatic variables of the Climatic Model in terms of percent variable contribution, Bio11 (mean temperature of the coldest quarter) had the highest contribution (53.39%) followed by Bio2 (mean diurnal range) with 23.22% then Bio18 (precipitation of warmest quarter) with 13.35% while Bio5, Bio9, Bio10, Bio12, Bio14 were not included in **Table 2** because they have no (zero) contribution to the climatic model (**Table 2**). With this, it is difficult to interpret the

Table 2. Summary of preliminary models and the area under the receiver operating characteristic curve (AUC) values for predicting the occurrence of *Litsea leytensis* Merr. with the significant variables and their percent contribution, Laguna and Quezon, Philippines.

Partial Models	Significant Variables	Contribution (%)	AUC Training Values
Climatic	Bio11	53.39	0.9497
	Bio2	23.22	
	Bio18	13.35	
Climatic+Anthropogenic	Bio11	31.38	0.9657
	population	19.52	
	distance from the road	14.51	
	Bio2	12.64	
Climatic+Edaphic	soil type	61.97	0.9822
	Bio11	21.01	
	geology	12.56	
Climatic+Vegetation-related	Bio11	51.60	0.9471
	Bio2	20.99	
	Bio18	11.64	
Climatic+Topographic	Bio11	31.08	0.9478
	Bio2	24.34	
	elevation	11.75	
Full Model	Soil type	43.48	0.9857
	Bio11	14.78	
	geology	12.55	

significance of each bioclimatic variable from this model based on percent contribution alone (*Tumaneng et al. 2019*) and without the biophysical variables. The Climatic Model in terms of the area under the AUC values, 0.9497 was obtained for the training data (**Table 2**). It was sensitive and descriptive, with a mean value of 0.9229 of the test AUC for the replicate runs and a standard deviation of 0.026 (**Figure 3**). The Jackknife test with the variable only revealed that the Bio8, Bio9 (mean temperature of driest quarter), and Bio11 variables made a higher AUC value but not all bioclimatic variables used were seen to be needed in this model for the occurrence of *L. leytensis*. Bio11 (mean temperature of the coldest quarter) was the environmental variable with the highest gain when used in isolation in this model, which appear to have the most useful information. Bio18 (precipitation of the warmest quarter) decreases the gain the most when omitted in the Climatic Model, which appear to have the most information that is not present in other bioclimatic variables.

The Climatic Model shows that temperature and rainfall contribute to the probability of occurrence of *L. leytensis*. The climatic conditions of Laguna and Quezon are favorable for *L. leytensis* to grow well. Laguna is characterized by a Type III climate with a short dry season and without a very pronounced maximum rain period. Quezon province has a Type II climate which is characterized by the absence of a dry season but has very pronounced maximum rain period from December to February (*DOST-PAGASA 2014*).

The anthropogenic variables including population and distance from the road of the Climatic+Anthropogenic Model had a greater contribution with 19.52% and 14.51%, respectively. The distance from built-up areas and population density had a lesser contribution (5.88% and 1.38%) when modeled with climatic variables for *L. leytensis*, while Bio11 had the highest contribution with

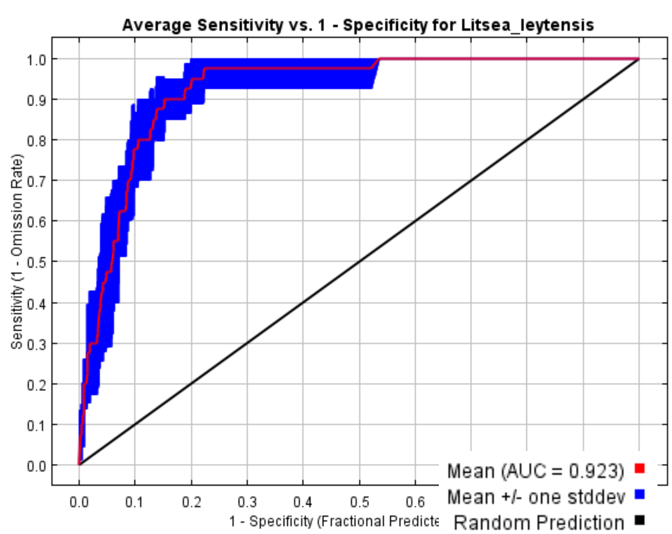

Figure 3. The receiver operating characteristic (ROC) curve of the climatic model for *Litsea leytensis* Merr. with an average test AUC of 0.923.

31.38% followed by Bio2 (12.64%) and Bio8 (6.32%). In terms of the AUC values of the Climatic + Anthropogenic Model, precise results were obtained with 0.9657 for the training data (**Table 2**). It was sensitive and descriptive, with an average test AUC of 0.9236 for the replicate runs and a standard deviation of 0.038 (**Figure 4**). The Jackknife test with the variable only revealed that the Bio8, Bio9, and Bio11 had higher AUC values but not all climatic and anthropogenic variables used in the model were essential for the occurrence of *L. leytensis*. Bio11 had the highest gain when used in isolation, which has the most useful information by itself, while the population variable decreases the gain the most when it is omitted in the Climatic + Anthropogenic Model. Bio11 had the most information that is not present in the other climatic and anthropogenic variables.

Although climatic variables have a higher contribution than anthropogenic variables in this model, the effect of population and distance from the road on the occurrence of *L. leytensis* is also critical. The wood of the species is an economically important raw material for carvers, and overexploitation may have decreased supply to a critical level (*Escobin et al. 2019*). Consequently, the species populations are also affected by the land use and cover changes of the human population.

Edaphic variables when combined with the 19 climatic variables in terms of percent variable contribution showed that the soil type had a greater contribution (61.97%) than geology (12.56%) to the model for *L. leytensis* of the Climatic + Edaphic Model. Of the climatic variables, Bio11 had the highest contribution (21.01%) followed by Bio8 with 2.11%. Bio5, Bio3 (isothermality), Bio7 (temperature annual range), Bio12 (annual precipitation), Bio13 (precipitation of the wettest month), Bio14, Bio16 (precipitation of the wettest quarter), and Bio19 had zero contribution to the model (**Table 2**). Precise results were obtained for the training data of the Climatic + Edaphic Model with an AUC value of 0.9822. The model was sensitive and descriptive, with an average test AUC of 0.9184 for the replicate runs and a standard deviation of 0.013 (**Figure 5**). The Jackknife test with the variable only revealed that the soil type, Bio11, and Bio8 had a higher AUC values but not all climatic variables used were necessary for the occurrence of *L. leytensis* in the Climatic + Edaphic Model. Soil type was the environmental variable with the highest gain when used in isolation and decreases the gain the most when it is omitted in the Climatic + Edaphic Model which has the most useful information by itself and appears to have the most information that is not present in the other climatic and edaphic variables.

The Climatic + Edaphic Model showed that the distribution of soil type and geology is not closely related to precipitation on a regional scale. The soil type variable in this model had a relatively higher influence on the probability of the occurrence of *L. leytensis*. This could be considered in seed technology, propagation, and nursery management of the species; thus, a continuous study on the best soil media to ensure high seed germination of *L. leytensis* is recommended (*Ecosystems Research and Development Bureau 2017*). Biofertilizers such as the mycorrhizal fungi would be helpful for the soil nutrition of the newly emerged seedlings of *L. leytensis*.

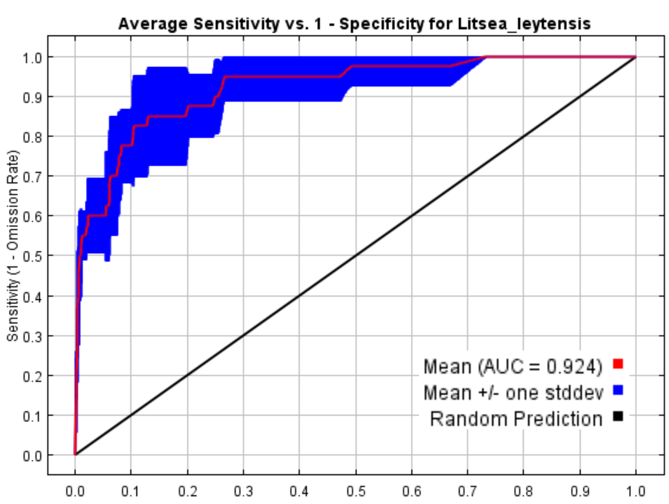

Figure 4. The receiver operating characteristic (ROC) curve of the Climatic + Anthropogenic model for *Litsea leytensis* Merr. with an average test AUC of 0.924, Laguna and Quezon, Philippines

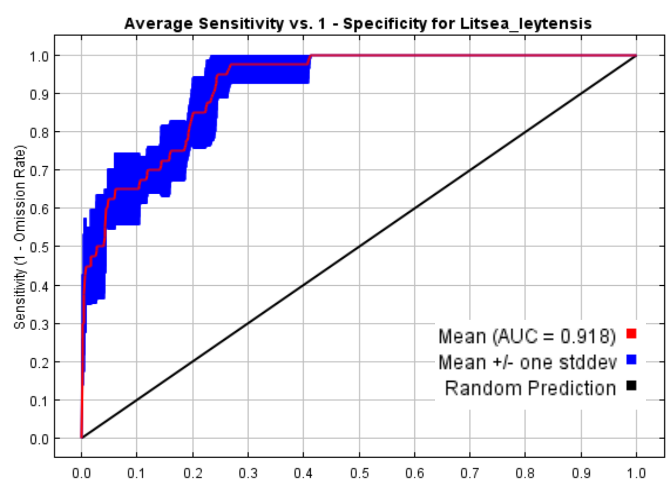

Figure 5. The receiver operating characteristic (ROC) curve of the Climatic + Edaphic model for Litsea leytensis Merr. with an average test AUC of 0.918, Laguna and Quezon, Philippines

Vegetation-related variables such as land cover and NDVI, when combined with the 19 climatic variables in the Climatic + Vegetation-related Model had a lesser contribution with 1.64% and 4.20%, respectively. Bio11had the highest contribution with 51.6% followed by Bio2 (20.99%) and Bio18 (11.64%). Accurate results were obtained for the training AUC of the Climatic + Vegetation-related Model with a value of 0.9471 (**Table 2**). The average test AUC for the replicate runs of 0.8939, and a standard deviation of 0.024 show that the model was sensitive and descriptive (**Figure 6**). The Jackknife test with the variable only revealed that the Bio2, Bio8, and Bio11 had relatively higher AUC values but not all the climate variables used in the model were seen to be necessary for the occurrence of *L. leytensis*. Bio11 when used in isolation, had the highest gain, which has the most useful information by itself, while Bio18 decreases the gain the most in the Climatic + Vegetation-related Model when it is omitted, which appears to have the most information that was not present in the other variables.

Vegetation-related variables of the Climatic + Vegetation-related Model had a low contribution to the occurrence of *L. leytensis* which may be due to the less varied or more generalized classes for land cover and NDVI. The advantage of using remotely-sensed data excluded highly altered habitats for the species for the purpose of conservation (*Phillips et al. 2006*). The climatic variables in the model are the major factors in determining the distribution of the species at a regional scale, while the vegetation-related variables may only provide a pathway for natural species migration. The study of *Castanopsis* (Fagaceae) by *Cheuk and Fischer* (*2021*) in the China and Indo-China region showed that most of the species distribution had no connection to the percentage of forest cover that is connected to the forest of current species ranges. At present, the continuous decrease of *L. leytensis* population is attributed to the forest cover losses within its range caused by logging and shifting cultivation (*Energy Development Corporation 2020*). In fact, the Global Forest Watch recorded continuous loss of tree cover in the Philippines during the National Greening Program in 2011 -2016 (expanding up to 2028), the largest area reforested by various sectors based on the Philippine Forest Statistics report of the DENR.

The topographic variables' elevation and distance from the river of the Climatic + Topographic Model had a greater contribution with 11.75% and 9.77%, respectively. Slope and aspect had lesser contributions (2.14% and 1.81%) when modeled for *L. leytensis* with climatic variables. Bio11 had the highest contribution with 31.08% followed by Bio2 (24.34%) and Bio18 (6.31%).

In terms of the AUC values, precise results were obtained for the training data of the Climatic + Topographic Model with 0.9478 (**Table 2**), and the average test AUC for the replicate runs was 0.8855, with a standard deviation of 0.058 (**Figure 7**). The Jackknife test with the variable only revealed that Bio1, Bio5, and Bio11 had relatively higher AUC values but not all the climatic and topographic variables used in the model were seen to be essential for the occurrence of *L. leytensis*. When used in isolation, Bio11 had the highest gain which has the most useful information by itself. Distance from the river decreases the gain the most in the model when it is absent, which appears to have the most information that is not present in the other variables.

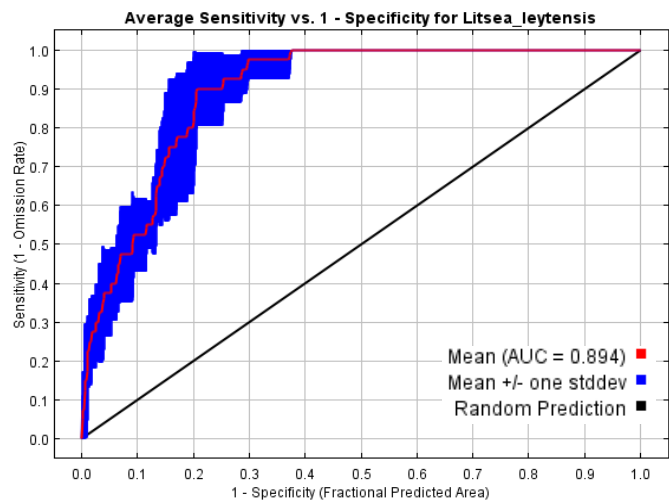

Figure 6. The receiver operating characteristic (ROC) curve of the Climatic + Vegetaion-related model for *Litsea leytensis* Merr.with an average test AUC of 0.894, Laguna and Quezon, Philippines

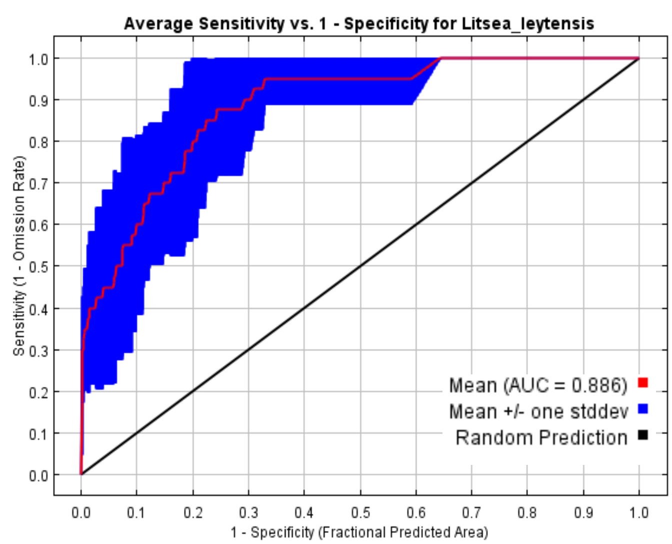

Figure 7. The receiver operating characteristic (ROC) curve of the Climatic + Topographic model for *Litsea leytensis* Merr.with an average test AUC of 0.886, Laguna and Quezon, Philippines

In this model, the climatic variables have a higher percentage of contribution with higher AUC values to the probability of the occurrence of *L. leytensis* thanthe topographic variables. Bioclimatic variables predicting species distribution areas do not necessarily indicate the importance of topography (*Çoban et al. 2020*). The natural habitat of the species is often described at low and medium altitudes in lowland forests in Luzon and Visayas (*Ecosystems Research and Development Bureau 2017*).

The Full Model for *Litsea leytensis* Merr. with all the 31 variables revealed that 13 out of 19 climatic variables contributed to the model while six climatic variables had zero contribution. Bio11 (mean temperature of the coldest quarter) had the highest contribution (14.87%) followed by Bio8 (mean temperature of the wettest quarter) with 2.39% then Bio2 (average of monthly maximum temperature - minimum temperature) with 1.40% (**Table 2**). Climatic variables without contribution were Bio1 (annual mean temperature), Bio5 (temperature seasonality), Bio10 (mean temperature of the warmest quarter), Bio14 (precipitation of the driest month), Bio16 (precipitation of the wettest quarter), and Bio19 (precipitation of the coldest quarter). Among the biophysical variables, the edaphic factors (soil type and geology) had the highest contribution with 43.48% and 12.55%, respectively, followed by population with 7.65% (**Table 2**). The least contributing biophysical variables were distance from river (0.31%), population density (0.37%), and land cover (0.94%). The area under the receiver operating characteristic (ROC) curve (AUC) values obtained precise results for the training data was 0.9857 (**Table 2**). The Full Model for *L. leytensis* was sensitive and descriptive, with a mean test AUC value of 0.9285 for the replicate runs and a standard deviation of 0.050 (**Figure 8**). The Jackknife test with the variable only revealed that soil type, Bio8, and Bio2 variables made a relatively higher AUC value. Among the edaphic variables, soil type had the highest gain when used in isolation and decreased the gain the most when it was omitted in the Full model, which appears to have the most information that were not present in the other variables.

Analysis of Variable Significance and Jackknife Procedure

The relative variable contribution of the six preliminary models of *Litsea leytensis* Merr. were averaged and ranked using the Jackknife test. The climatic variables were selected and reduced based on the percentage contribution from the pre-modeling runs and the Area Under ROC Curve (AUC) value with the only variable present, or the Jackknife of AUC for *L. leytensis.*

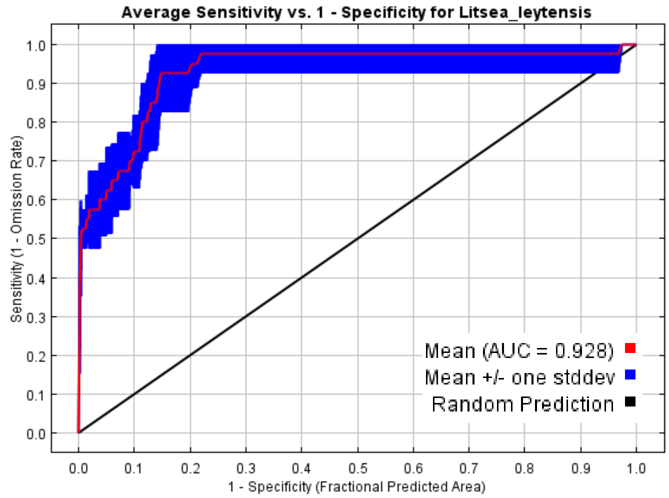

Figure 8. The receiver operating characteristic (ROC) curve of the Full model for Litsea leytensis Merr.with an average test AUC of 0.886 Laguna and Quezon, Philippines

Among the bioclimatic variables used in predicting the distribution of *L. leytensis*, Bio11 (mean temperature of the coldest quarter) had the highest contribution with 33.89%. This is followed by the mean diurnal range or mean of monthly maximum temperature - minimum temperature (Bio2) with 14.03%, while the maximum temperature of the warmest month (Bio5) had zero contribution (**Table 3**). Among the biophysical variables, soil type had the highest contribution with 17.58%. This is followed by population with 4.53%, while population density was recorded with the lowest contribution (0.29%). As revealed in the preliminary modeling, predicting the species occurrence of *L. leytensis* was largely determined by climatic (62.0%) and edaphic (21.76%) variables. Vegetation-related (1.34%) and topographic variables (5.15%) had relatively lesser contributions. In terms of AUC value with the variable only, soil type had the highest mean AUC (0.8804) followed by Bio8 (0.8358) and Bio14 had the lowest (0.5320) AUC value. The bioclimatic variables with a value <1% and/or < 0.60 AUC value were excluded in the Final model.

During the pre-final modeling stage, bioclimatic variables with <1% and/or < 0.60 AUC values were removed, and the number went down from 19 to 14. The biophysical variables were retained for the multi-collinearity test with all the climatic variables. Prior to final species distribution modeling, variable reduction and selection methods reduce errors in the model, particularly those caused by spatial autocorrelation of the presence data, or the multi-collinearity of bioclimatic and biophysical variables used (*Torres et al. 2016*).

Table 3. Variables selected based on the mean area under the receiver operating characteristic (ROC) curve (AUC) value using the Jackknife Test and percent contribution in the pre-final modeling, Laguna and Quezon, Philippines.

Variable	AUC with the variable only (Jackknife of AUC)	Percent Contribution
Bio11	0.8325	33.89
Soil type	0.8804	17.58
Bio2	0.8225	14.03
Bio18	0.7043	6.18
Population	0.8203	4.53
Bio8	0.8358	4.27
Geology	0.7408	4.19
Distance from road	0.6433	3.40
Elevation	0.7858	2.36
Distance from river	0.7072	1.68
Distance from built-up	0.5389	1.31
Bio4	0.6091	1.03
NDVI	0.6551	0.91
Bio3	0.6993	0.59
Aspect	0.5775	0.58
Slope	0.5555	0.53
Land cover	0.5942	0.43
Bio7	0.6418	0.30
Population density	0.5890	0.29

Multi-collinearity Test

One way to minimize problems caused by the multicollinearity of environmental variables was to examine the cross-correlations among variables (*Torres et al. 2016*). Thus, only one variable ($r \geq 0.80$) from a set of highly cross-correlated predictors was included in the final modeling. Among the 31 original variables, 16 were highly correlated with at least two variables. Of the 16 variables, seven variables had the highest counts of highly correlated variables (counts= six). The annual mean temperature (Bio1) was correlated to six climatic variables (Bio5, Bio6, Bio8, Bio9, Bio10, and Bio11); the annual precipitation (Bio12) was correlated with Bio13 and Bio16; and the precipitation of the driest month (Bio14) was correlated with Bio17 and Bio19. Distance from built-up areas was correlated with the distance variables' road and river. There were five non-correlated climatic variables (Bio2, Bio3, Bio4, Bio7, and Bio15) and nine biophysical variables. Seven temperature variables (r values ranging from -0.88702 to -0.95992) and two precipitation variables (r= -0.15281and -0.12687) had negative linear correlations with elevation, which confirms that lower elevations have higher temperatures. In contrast, elevation had positive linear correlations with five other precipitation variables (r value ranges from 0.02272 to 0.35254), which confirms that the chance of rainfall is higher at higher elevations. The rainfall in Laguna and Quezon ranges from 2,000 to 3000 mm annually (*DOST-PAGASA 2014*).

The choice to eliminate and include one variable from a set of highly correlated variables was made based on the inherent environmental importance of *leytensis* and their comparative predictive capacity evaluated based on AUC with the variable only (Jackknife of AUC > 0.60). Based on the output of the initial modeling runs, the most appropriate variable from a set of highly cross-correlated variables was included, thus, only seven (Bio2, Bio3, Bio4, Bio7, Bio8, Bio18, and Bio11) out of the 19 bioclimatic variables and all 12 biophysical variables were kept for the Final model.

Model Evaluation using AUC Values

All AUC values were greater than 0.5 and based on the Area Under ROC Curve (AUC) classification by *Swets* (*1988*), it could be concluded that all seven probability models for *Litsea leytensis* Merr. showed better performance than a null model. The mean AUC values of all seven models were compared and ranked using the classification of AUC by *Swets* (*1988*), which were the same AUC values of test points used in the model analysis of Maxent studies conducted by *Garcia et al.* (*2013*), *Japitana and Macandog* (*2020*), *Paquit et al.* (*2017*), and *Torres et al.* (*2016*).

The level of accuracy of the seven probability models obtained from test points (dark bars) is quite lower when compared to the training points (light bars), and this difference may have occurred due to a small number of test points with a random distribution (**Figure 9**). The Final Model had the most excellent performance with an AUC value of 0.9489, while the Full Model ranked second with an AUC value of 0.9285. The Climatic model performed quite well (AUC=0.9229). Among the partial models, the Climatic + Anthropogenic model worked best (AUC=0.9236) while Climatic + Topographic model (AUC=0.8855) ranked last. Climatic + Edaphic and Climatic + Vegetation-related models had AUC values of 0.9184 and 0.8939, respectively. Higher AUC values suggest superiority and imply excellent model accuracy (*Pramanik et al. 2018*). Based on decreasing AUC values, the partial models are as follows: Climatic + Anthropogenic > Climatic + Edaphic > Climatic + Vegetation-related> Climatic + Topographic. The Final Model with only 19 variables performed better than the partial models and the Full Model with all 31 original variables.

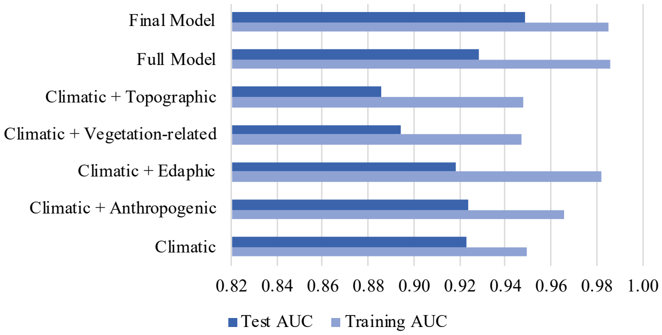

Figure 9. Area under the receiver operating characteristic (ROC) curve (AUC) of the seven models predicting the occurrence of *Litsea leytensis* Merr., Laguna and Quezon, Philippines

Model Evaluation using TSS Values

Since the SDM for *Litsea leytensis* Merr. will be used for its conservation, the evaluation accuracy of prediction was based on a selected specific threshold, different from the threshold-independent ROC curves; thus, the True Skill Statistics (TSS) was used (*Shabani et al. 2018*). The TSS values of the seven probability models were obtained from the sensitivity (true positive rate) and specificity (true negative rate) values of each model. Sensitivity is one minus the omission rate, and specificity is one minus the fractional predicted area (*Phillips et al. 2017*). Threshold selection for the computation of TSS was based on the maximum test sensitivity plus the specificity of the logistic threshold. TSS (sensitivity + specificity - 1) provides a reasonable viewpoint of the models performance through combining the capability of correctly predicting both presence and absence or background observations, taking into account both omission and commission errors (*Somodi et al. 2017*).

Average TSS values were computed with five replicates for the seven probability models and were ranked based on the TSS criteria used by *Garcia et al.* (*2013*) and *Torres et al.* (*2016*) (**Table 6**). Based on the TSS criteria, the Full Model and Final Model ranked second, and third of the seven probability models interpreted as good, with TSS values 0.7465 and 0.7175, respectively (**Table 4**). The Climatic + Topographic performed the least (TSS = 0.5456). However, TSS values between 0.4 and 0.8 is useful, and <0.4 is poor model performance (*Pramanik et al. 2018*). The predictive performances and TSS values of the partial models slightly decreased when combined with the climatic variables alone which suggests that a diversified set of variables, as shown by the Final and Full models is more appropriate.

Based on the TSS values, the rankings of all seven models were not comparable with the AUC-based criteria (**Table 4**). However, the values for the Final model with the Full model ranked on top, and this suggests that the relative predictive performance of a model improves as the number of variables increases, but only up to a certain extent (*Torres et al. 2016*).

Analysis of Variable Importance in the Final Model

Climatic and edaphic variables had the highest contribution in the Final model while vegetation-related and topographic variables had the least contribution with 4.31% and 3.30%, respectively (**Figure 10**). Soil type had the highest contribution (43.01%) among the biophysical variables. The availability of the fundamental basic resources of light, heat, water, and mineral nutrients is measured by bioclimatic and soil type (*Mackey and Lindenmayer 2001*) and their effect in one study area or time frame, should generalize to other situations in contrast to elevation, which will not generalize well (*Phillips et al. 2006*).

The seven bioclimatic variables selected in the Final model contributed 19.03% with the mean temperature of the coldest quarter (Bio11) having the highest contribution with 16.99%, followed by the precipitation of the warmest quarter (Bio18) with 0.65% (**Figure 10**). Bio3 (isothermality), Bio4 (temperature seasonality), and Bio7 (temperature annual range) had the least contribution among the bioclimatic variables selected.

Table 4. Comparison of area under the receiver operating characteristic curve (AUC) and true skill statistics (TSS) values for all seven models of *Litsea leytensis* Merr., Laguna and Quezon, Philippines

Partial Models	Test AUC	Rank	TSS Value	Rank
Climatic	0.9229	4	0.6996	4
Climatic + Anthropogenic	0.9236	3	0.6766	6
Climatic + Edaphic	0.9184	5	0.7598	1
Climatic + Vegetation-related	0.8939	6	0.6855	5
Climatic + Topographic	0.8855	7	0.5456	7
Full Model	0.9285	2	0.7465	2
Final Model	0.9489	1	0.7175	3

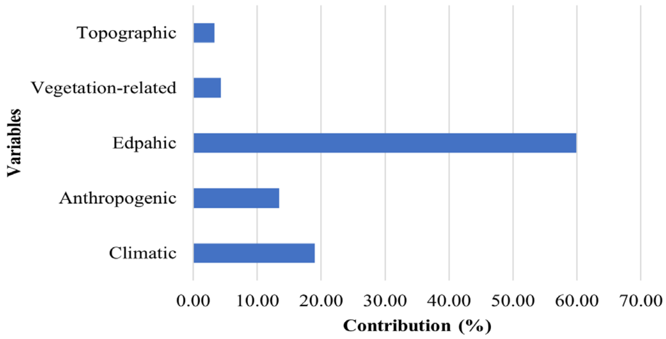

Figure 10. Percent contribution of variables in predicting the occurrence of *L. leytensis* in the Final Model, Laguna and Quezon, Philippines

Based on the Final model for *L. leytensis*, a similar trend was observed in models predicting habitat suitability of threatened Philippine native trees (*Garcia et al. 2013*) and Dipterocarp species (*Torres et al. 2016*) in which climatic variables had a lesser contribution compared with the biophysical variables (**Figure 10**).

Jackknife Test of Variable Importance in the Final Model

The environmental variable with the highest gain when used in isolation was soil type with a regularized training gain of 1.6121. This had the most useful information by itself based on the Final model, followed by Bio11 with a training gain of 0.6083. The temperature annual range (Bio7) decreased the gain the most in the Final model when it was omitted, as it had the most information that was absent in other variables, with a training gain of 2.6772. According to *Qin et al.* (*2017*), Jackknife analyses determine variables that reduce the reliability of a model when the variable(s) are excluded. refers to Jackknife analyses is also employed to measure the significance of the bioclimatic variables used in a model, and the results indicate the relative influence of these variables on the present distribution of plant species (*Pramanik et al. 2018*).

Probability of Occurrence of *Litsea leytensis* Merr. in the Provinces of Laguna and Quezon

The outputs of MaxEnt in logistic format of the probability of occurrence for *Litsea leytensis* Merr. were generated, wherein each pixel has a probability value ranging from 0 to 1 (*Phillips et al. 2006*). These values indicate an increasing level of suitability, which is helpful in presenting information if the tree species in a specific area is suitable or not. The default probability of occurrence of *L. leytensis* was classified into 10 classes of equal interval at 0.1. A value from 0 to 0.5 indicates unsuitable habitats for the tree species or is likely that the species is not found in those areas, while a value from 0.5 to 1.0 represents suitable habitats or the species is likely to be present in the area (**Figure 11**). Areas that have a darker blue color indicate a high probability of occurrence of *L. leytensis*, and as the color becomes

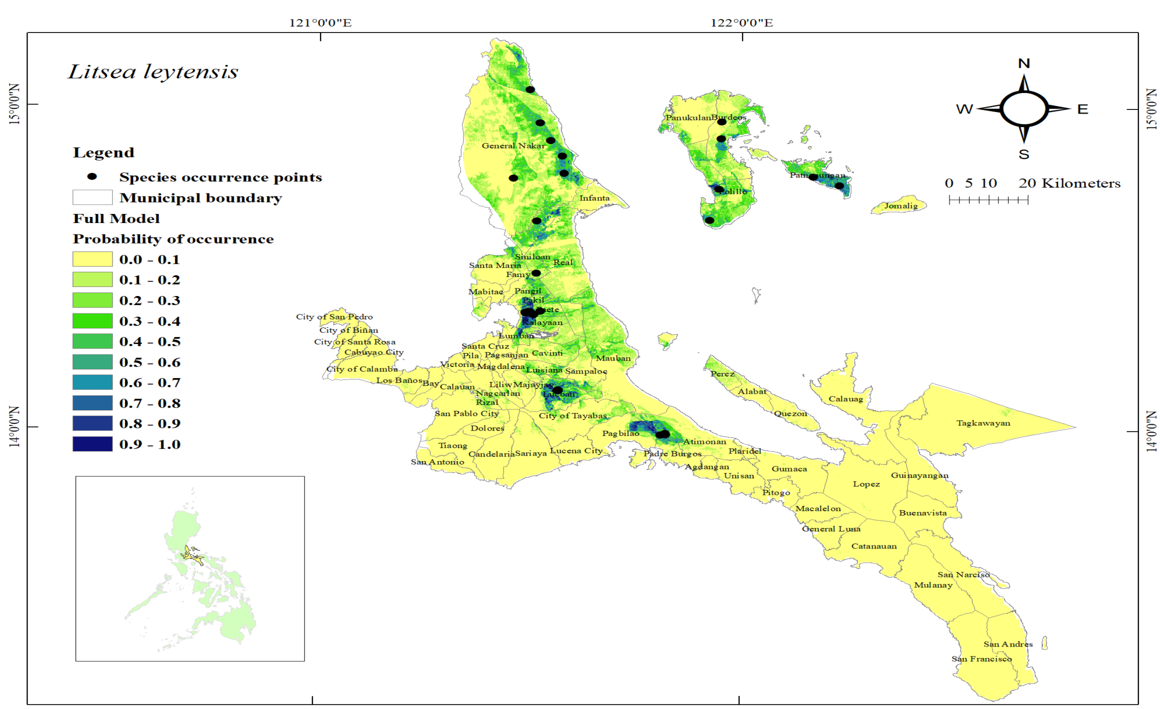

Figure 11. Full model of predicted suitable and unsuitable areas for *L. leytensis* (dark blue colors show areas with a high probability of occurrence), Laguna and Quezon, Philippines

lighter, the probability of its occurrence decreases.

Based on the Full Model, about 311,086,800 m^2 (**Figure 11**) are suitable for the tree species, with varying degrees of suitability. The Final Model has about 324,301,800 m^2 that covers the municipalities of Kalayaan, Lumban, Paete, Pakil Pangil, and Siniloan in Laguna province and the municipalities of Atimonan, Bordeos, General Nakar, Infanta, Lucban, Pagbilao, Patnanungan, Polillo, and Real in Quezon province (**Figure 12**). The distribution of the suitable areas for the Final Model of *L. leytensis* based on suitability is as follows: fairly suitable (38,688,600 m^2), moderately suitable (50,067,700 m^2), suitable (62,205,300 m^2), very suitable (78,818,700 m^2), and extremely suitable (96,721,600 m^2).

The Final model presents the potential large distribution of *L. leytensis* in the provinces of Laguna and Quezon, even with a limited number of presence-only (PO) locations. The species was recorded in 16 locations in the entire Philippines, with an estimated extent of occurrence (EOO) of 224,147 km² and a small area of occupancy (AOO) of 68 km² (*Energy Development Corporation 2020*). The results of the Final model could guide future documentation of the species in areas that were not previously covered by inventories. It will serve as a guide for a proper species management scheme to prevent it from being continuously threatened by habitat loss and overexploitation. Among the conservation efforts that have been done and are recommended to be sustained are the following: stem cutting propagation and DNA barcoding by the Southern Luzon State University in Lucban, Quezon; *ex-situ* conservation and domesticating of the species in UP Land Grant in Laguna and Quezon; and cultivating and planting by the local government in Paete, Laguna, the National Power Corporation, and the Haribon Foundation in Lumban, Laguna. The role of the DENR is crucial in managing protected areas where mature *L. leytensis* tree species were observed within the Umiray Watershed Forest Reserve, Mts. Banahaw-San Cristobal Protected Landscape, Quezon Protected Landscape, as well as the declared national park, wildlife sanctuary, and game reserve of the public domain situated in Laguna and Quezon (*Proclamation No. 1636 s. 1977*).

In summary, the study presented the high probability of occurrence of *L. leytensis* and potential future species distributions in Laguna and Quezon through species distribution modeling using MaxEnt with climatic and biophysical variables (**Table 5**). Based on the results of the Final Model, 19 variables influence the species probability of occurrence in suitable areas for out planting seedlings of the species to ensure high growth and survival. The suitable areas could guide the DENR,

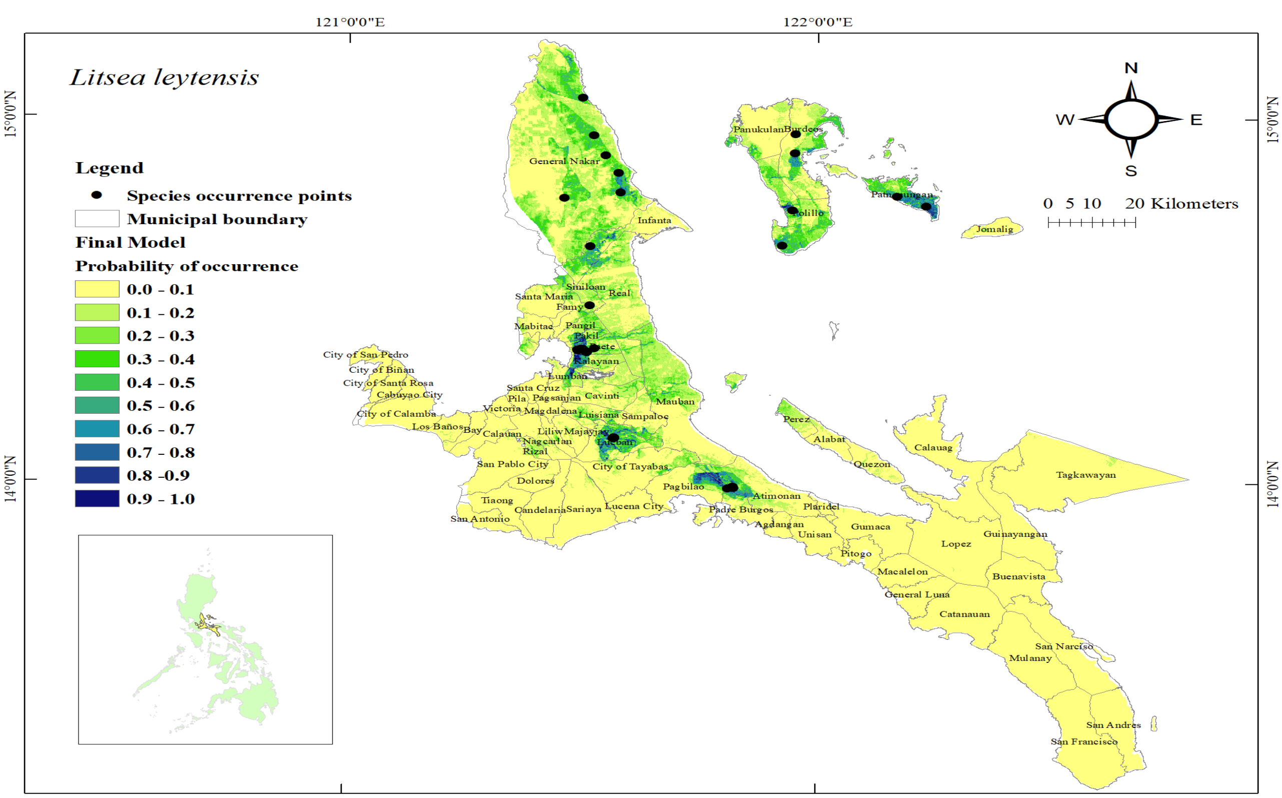

Figure 12. Final model of predicted suitable and unsuitable areas for *L. leytensis* (dark blue colors show areas with a high probability of occurrence), Laguna and Quezon, Philippines

Table 5. Suitable areas for *Litsea leytensis* Merr. in Laguna and Quezon, Philippines.

Suitability class	Area (m^2)	Municipalities	
		Laguna	Quezon
fairly suitable (0.5-0.6)	38,688,600	Famy, Los Baños, Liliw, Mabitac, Majayajay, Nagcarlan, Rizal, Santa Maria	Quezon, Sampaloc, Tayabas City
moderately suitable (0.6-0.7)	50,067,700	Cavinti, Kalayaan, Luisiana, Lumban, Paete, Pakil, Pangil, Siniloan	Burdeos, Infanta, General Nakar, Panukulan, Perez, Polillo, Real
suitable (0.7-0.8)	62,205,300	Kalayaan, Luisiana, Lumban, Paete, Pakil, Pangil, Siniloan	Atimonan, Burdeos, Infanta, General Nakar, Lucban, Mauban, Pagbilao, Polillo, Real
very suitable (0.8-0.9)	78,818,700	Kalayaan, Paete, Pakil, Siniloan	Atimonan, Lucban, Padre Burgos, Pagbilao, Patnanungan,
extremely suitable (0.9-0.1)	96,721,600	Kalayaan, Lumban, Paete, Pakil, Siniloan	Atimonan, Lucban, Pagbilao, Patnanungan

LGUs, NGAs, conservation practitioners, and other concerned sectors or agencies in locating mother trees of *L. leytensis* as seed sources in producing quality planting materials or the establishment of seedproduction area (SPA) necessary for reforestation initiatives and establishment of industrial tree plantations.

CONCLUSIONS AND RECOMMENDATIONS

The study estimated the probability of species occurrence of *Litsea leytensis* Merr. in the provinces of Laguna and Quezon using climatic and biophysical (edaphic, topographic, vegetation-related, and anthropogenic) factors as input variables. Seven probability models were generated using Maximum Entropy (MaxEnt). The analysis of variable contribution and the Jackknife of variable importance were used to evaluate model performance. The environmental variables with the highest contribution in the probability of occurrence of *L. leytensis* were determined based on the selected best performing model. The relative predictive performance of seven models was evaluated and compared based on Area Under ROC Curve (AUC) and true skill statistics (TSS) values. Using the proposed AUC classification by *Swets* (*1988*), all seven probability models for the species performed better than random, as indicated by the AUC values greater than 0.5. The Final model performed best for *L. leytensis* (AUC = 0.9489; TSS = 0.7175). The ranking of all seven models based on TSS values is not the same as the AUC-based index except that the Full Model and Final Model always rank on top, which indicates that a combination of climatic and biophysical variables improves the Full model's relative predictive performance when compared with the partial models. The Final model with only 19 variables performed better than the Full model with all 31 original variables as explained by the variable reduction method using the Jackknife test leading to the best performing model with few variables.

The analysis of the variable importance of the Final Model revealed that predicting the occurrence of the *L. leytensis* was mostly determined by edaphic variables (59.90 %) followed by climatic variables (19.03 %) and then anthropogenic variables (13.46 %). Vegetation-related and topographic variables had relatively lesser contribution with 4.31% and 3.30%, respectively. The top predictors with the highest contribution aside from geology and soil type are the mean temperature of the coldest quarter, human population size, and distance to the road. It is important to note that the distribution of forest tree species like *L. leytensis* or its species habitat requirement, is defined by the environmental variables where it occurs, and an optimal combination of these factors allows it to persist in areas (*Torres et al. 2016*). Based on the Final Model, there is high probability of occurrence of *L. leytensis* in Laguna and Quezon provinces despite the limited actual distribution or species occurrence records. Some possible reasons for the limited distribution of the species could be due to changes in species composition i.e., reduced seedling establishment of the species as affected changes in climate and other biophysical factors including anthropogenic activities. More studies are necessary to assess the sensitivity of *L. leytensis* using climatic and biophysical variables at the regional or provincial scale. The research used only 35 species occurrence points due to their very low presence based on local knowledge and published occurrence records. It would be necessary to obtain more presence data in future studies. Also, there is a need to include other variables that could influence the future distribution of *L. leytensis* in Laguna and Quezon, such as tree growth and development, phenological variables, and assisted regeneration, among others. This is to obtain a more significant and robust estimates on the suitability of habitat for the species.

The species probability of occurrence for *L. leytensis* generated from this study provides conservation practitioners with estimates of the habitat suitability of this economically important species in Laguna and Quezon. This will serve as a basis to protect, manage, and conserve the species, which is currently under threat. It could help the local government units in the provinces of Laguna and Quezon in collaboration with the national agencies and key sectors, to formulate policies for the proposed areas of conservation management for *L. leytensis*. This will also help in ensuring the sustainability of planting materials for reforestation initiatives to support biodiversity conservation efforts. Furthermore, it will also help in the development of tree plantations to sustain the raw material needs of the wood carving industry.

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