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Species Distribution Model of *Shorea contorta* S. Vidal in the Philippines Using Maximum Entropy

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The existing forest policies pushed low supplies and high export of timber in the Philippines. This study projected the current and potential distribution of *Shorea contorta* (S. Vidal) in the Philippines using Maximum Entropy (MaxEnt) approach. The location of *Shorea contorta* in protected areas and future harvestable areas were also identified and its potential revenue for timber production was assumed. MaxEnt is a machine learning algorithm that estimates a selected species probability distribution of occurrence. The occurrence data (presence-absence) and environmental variables were used as inputs in running the model. Two models were generated, Full Model and Final Model. Principal component analysis (PCA) tool was used in decreasing the number and selecting the environmental variables. The full model had an ROC of 0.755 area under the curve (AUC), whereas the final model showed a value of 0.772 AUC value and land cover having the highest contribution on the distribution of *S. contorta*. Unlike the full model which utilized all variables, the final model only included suitable variables, excluding variables that were highly correlated to prevent overestimation of the results. Areas appropriate for the species were approximately 7.1 million ha, whereas unsuitable areas were 20 million ha. The highest potential harvesting area for the species was in Agusan del Sur, which covered 518,570.42 ha. *S. contorta* grows slowly when planted in stressful conditions such as damaged soils. This improves when maize is intercropped and fertilized. The species' financial performance was found to be poor, and it is the least likely to be financially viable due to its longer rotation duration when compared to traditionally cultivated exotics. This can reduce the internal rate of return and net present values, even if the price of timber rises.

Keywords: dipterocarp, MaxEnt, modeling, stumpage value, white lauan, wood

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INTRODUCTION

The Philippines hosts a rich biodiversity of unique flora and fauna species. It ranks 5th in plant species quantity and keeps an approximate number of about 10,000– 14,000 plant species (Barcelona *et al*. 2013; Zapanta *et al*. 2019), accounting for 5% of the world's flora. Numerous of these species are trees that dominate the country's forested areas, which are also considered economically valuable for the timber industry (Salvaña and Gruezo 2018; Zapanta *et al*. 2019). In the lowland forest with an approximate elevation of less than 800 m above sea level, dipterocarp species are widely distributed and abundant (Utsugi *et al*. 2009). When logging was prevalent in Southeast Asia, particularly in the Philippines, dipterocarps contributed the majority of the logs and volume to the world's timber resources. One of the known species in this family is *Shorea contorta* S. Vidal, which is Philippine endemic and is locally known as "white lauan." As to the updated Department Administrative Order, the country's official list of threatened plants – *Shorea contorta* S. Vidal – is categorized as a vulnerable species (DENR 2017). However, from the International Union for Conservation of Nature (IUCN) 2019 Red list, the species was assessed as "least concern" because its number are still more than 10,000 despite the observed decline due to timber extraction and illegal logging activities (EDC 2020).

Although the IUCN Red List categorized *Shorea contorta* S. Vidal as "least concern," the continuous presence of illegal logging activities, conversion of forests to agricultural areas or plantations of other fast-growing species (Utsugi *et al*. 2009), climate change, and other anthropogenic activities pose a threat for this species to disappear at an alarming rate (DENR-ERDB 2012). This scenario is not isolated to white lauan alone but also to other dipterocarp species. Because of anthropogenic activities that lead to the decrease of the rich biodiversity resources, the Philippines is also regarded as a biodiversity hotspot (Garcia *et al*. 2013). While there are initiatives being done to minimize cutting of trees in the Philippines such as the logging ban and other reforestation activities, the assessment of the results of these endeavors are limited (Langenberger 2006).

Nevertheless, continuous efforts are conducted to safeguard and conserve the residual dipterocarp species in the Philippines. In recent years, innovative approaches to better understand species occurrence's relationship to environmental conditions such as modeling tools are explored. One of the species distribution modeling tools is Maximum Entropy or MaxEnt, created by Phillips *et al.* in 2006. Various species distribution models using MaxEnt have already been conducted in the Philippines. It was employed to identify bioclimatic niches of selected endemic *Ixora* species (Banag *et al*. 2015) and future spatial distribution of *Shorea palosapis* (Blanco) Merr. and *Shorea polysperma* (Blanco) Merr (Torres *et al*. 2016). In this study, the authors aim to generate the species distribution model of *Shorea contorta* S. Vidal using MaxEnt. Specifically, the study seeks to [1] determine potential habitat of *Shorea contorta* for further propagation of the species in the future, [2] identify the distribution of *Shorea contorta* under protected areas and future potential harvestable areas, and [3] establish profit assumptions of *Shorea contorta* for potential timber production.

MATERIALS AND METHODS

Study Area

The Philippines is an archipelago with 7,641 islands and has an area of 30 million hectares. It is situated at the southeastern region of the world and bordered by various bodies of water – namely South China Sea, Celebes Sea, and Philippine Sea. In terms of its neighboring countries, the Philippines is situated at the south of Taiwan, north of Indonesia and Malaysia, east of Vietnam, and west of Palau Islands. Manila is regarded as the country's capital. The topography of the Philippines is generally rugged, with its highest point being Mount Apo having an elevation of 2,954 masl (Garcia *et al*. 2013).

Shorea contorta is a dipterocarp species commonly used in enrichment planting activities. This species is usually located at lowland dipterocarp forest in the Philippines and naturally occurs in elevations up to 700 masl (Villarin 2013). This dipterocarp species belongs to the "Philippine mahogany," the "light-red Philippine mahogany." This species is commonly used for house construction due to its heavy weight and durability. The distribution of *Shorea contorta* is endemic to the Philippines. de Guzman *et al*. (1986) identified that the species can be found within the island of Luzon from northern Cagayan to Sorsogon. It can also be found within Babuyan Islands, Polillo Islands, Masbate, and Marinduque. In the Visayas region, it is distributed in Samar, Leyte, Negros, and Sibuyan.

Species Occurrence Records Data

The occurrence data of *Shorea contorta* were collected from multiple sources – including field survey, Global Biodiversity Index Facility (GBIF 2023), and journal articles. There were 137 records of *Shorea contorta*. This species was chosen from the 2020 IUCN Red List. IUCN changed the conservation status of the species from critically endangered to least concerned (EDC 2020). The reason for this change was the large extent of occurrence (EOO), the high number of individuals present and its presence in different locations (EDC 2020).

Shorea contorta belongs to the family of Dipterocarpaceae. Tumaneng *et al*. (2019) stated that a great number and volume of these species were severely diminished because of widescale deforestation in the country during the early 1960s. Reasons for harvesting these species were due to economic crisis and infrastructure damage after the war and logging companies' exploitations. This species was chosen for species distribution modeling since it is classified as premium species for its wood (EDC 2020), serves as a habitat for floral and faunal species (Mendoza *et al.* 2016), and is socio-culturally significant.

Environmental Layers Used in the Study

Twenty-six (26) environmental variables were used in this research paper shown in Appendix Table I. Out of the 26 environmental variables, 19 are climatic variables from WorldClim 2 (Fick and Hijmans 2017), and seven are biophysical variables (slope, elevation, aspect, land cover 2020, NDVI, soil class, and distance to roads). ArcGIS 10.5 was used to resample all variables to a pixel resolution of 1 km by 1 km. The data were masked to cover the boundaries of the Philippines. The variables were reprojected to WGS 1984 UTM Zone 51N. Additionally, the layers of the bioclimatic and biophysical variables were changed to the same extent and were converted to Raster ASCII grids (.asc) format for it to be utilized in the MaxEnt software. Lastly, the variables were divided into five groups: climatic for the bio1 to bio19 variables, topographic for elevation, slope, and aspect, vegetation-related for land cover and NDVI, edaphic for soil class, and anthropogenic for distance to roads. Information and sources of these data are shown in Appendix Table I.

Multi-collinearity Test

To determine relations between the 26 variables, all of the variables underwent a test of multi-collinearity using the Pearson correlation coefficient. The principal component analysis (PCA) tool was used to reduce and choose the variables. This method was exhibited by Garcia *et al*. (2013), Torres *et al*. (2016), and Tumaneng *et al*. (2019).

Multi-collinearity test was used to prevent collinearity of the variables, which could have an effect on the final model run in MaxEnt. A cautious analysis is necessary in choosing the most suitable variable among every group of variables showing strong correlation. From the results of the run of the full model, only a single variable was chosen to be incorporated in the final model from the variables exhibiting high correlation. The outcome of the collinearity test indicated that there are a few (6) variables that exhibited high correlation among the variables.

The 26 environmental variables were grouped based on their count of collinearity ($r \geq \pm 0.70$) among other variables. The variables were ranked and selected based on the percentage contribution on the distribution of *Shorea contorta*. Variables that show no contribution and high correlation from the groups were removed.

Species Distribution Model

The MaxEnt modeling software v3.4.4 was used for this study. Occurrence records of *Shorea contorta* were used as the dependent variable and the environmental variables served as the independent variable. MaxEnt was used as the method for this study among other SDMs (Pearson *et al.* 2007; Garcia *et al*. 2013) due to the following advantages that it has as stated by Trisurat *et al*. (2011): [a] even with limited records it still performs best, requiring presence-only data and environmental data (Wisz *et al*. 2008); [b] can be applied using continuous and categorical variables; and [c] effective deterministic algorithms were developed that are guaranteed to congregate to the optimal probability distribution (Phillips *et al*. 2006). During modeling, the records were divided into two parts – training data were composed of 75% of the records that were randomly selected to develop the models, whereas the test data were 25% of the records and also randomly selected as to determine model fitness (Torres *et al*. 2016; Tumaneng *et al*. 2019). A bias file was also created to improve model performance (Kramer-Schadt *et al*. 2013), and the settings used in MaxEnt were derived from ENMeval tool using R software. 10,000 background points were used with 10 replicates and a regularization multiplier of 3. The maximum number of iterations was 500 with a convergence threshold of 1×10^{-5}.

This research employed a logistic output format of probability. This format type designates a probability value for each pixel from 0–1. The values assigned to a single pixel obtained are equal to all the possible values that the pixel has, and all pixels with equal or lower probability values were expressed as a percentage (Phillips *et al*. 2006). The probability values given by MaxEnt were classified into 10, with 0–0.5 showing lower suitability values and 0.5–1.0 showing higher suitability values (Torres *et al*. 2016). Values obtained from pairwise correlation were used for decreasing and choosing the variables and to avoid repetition among independent variables (Torres *et al*. 2016). The PCA tool was utilized for this purpose. Using PCA allows simplification of data and prevents overlapping and redundancy of the variables (Huang *et al*. 2024). Following this test, the variables were reduced to only 12 shown in Appendix Table II. These remaining variables are mutually independent of each other.

Stumpage Value of *Shorea contorta*

The economic potential of *Shorea contorta* was measured through the revenue from timber production using stumpage valuation. Stumpage valuation was defined as the procedure of determining the value of trees or standing timber with valuation of revenue, collecting taxes, and as a basis for trading timber as the objectives. The value of timber at rotation age was obtained if the timber yield (m^3/ha) and stumpage value (PHP/m^3) are known. The timber yield is the volume of the trees at rotation age, whereas stumpage refers to standing timber in its unprocessed form as it was found in the woods (DENR 1988). The equations for stumpage value and value of timber at rotation age were shown in Appendix Equations 1 and 2.

RESULTS

Analysis of Variable Significance

The high contribution of biophysical variables compared to the climatic variables does not necessarily translate that the former is more important than the latter, as these two variables are inherent, spatially, and temporally autocorrelated, hence the difficulty in defining the importance of each variable to the model individually (Schrag *et al*. 2008). As such, this indicates that groups of the biophysical variables coordinate together to have an effect on the occurrence of the presence and absence *Shorea contorta.*

Having inaccurately predicted distribution could prevent effective conservation or harvesting efforts and decision-making. Therefore, it is essential to have expertise regarding the environmental suitability of a desired species to identify the environmental variables that will be used adequately. It limits the number and selects the most appropriate variables for the species to increase the accuracy of predictions and maximize the performance of SDMs (Tumaneng *et al*. 2019).

From Figure 1, the predicted distribution of *Shorea contorta* has a high probability occurrence in Visayas – specifically in Samar, Leyte, and Panay Island. There is also a probable occurrence in the southeast portion of Bohol. In Luzon, high probability of occurrence can be observed in the northern region, Sierra Madre Mountain range, Region 4A and 4B, and southern portion of the Bicol Region. In Mindanao, a high probability of occurrence is located in the CARAGA region, Zamboanga Peninsula, and southwest portions of SOCCSKARGEN. Areas with a probability of occurrence of at least 50% were classified as a habitable zone for *Shorea contorta*, whereas areas less than 50% probability of occurrence were classified as non-habitable.

Based on the results, the distribution of *Shorea contorta* is highly determined by 87% of the biophysical variables (topographic, vegetation-related, edaphic, and anthropogenic factors) and 13% of the climatic variables (Bio 2, Bio 5, Bio 6, Bio 18, and Bio 19). From the result of the climatic variables, Bio 2 had the highest percent contribution (10.77%). The second was Bio 19, having a contribution of 1.08%. This means that the occurrence of *Shorea contorta* can be explained by these two climatic variables. Bio 5 had the least contribution with 0.02%.

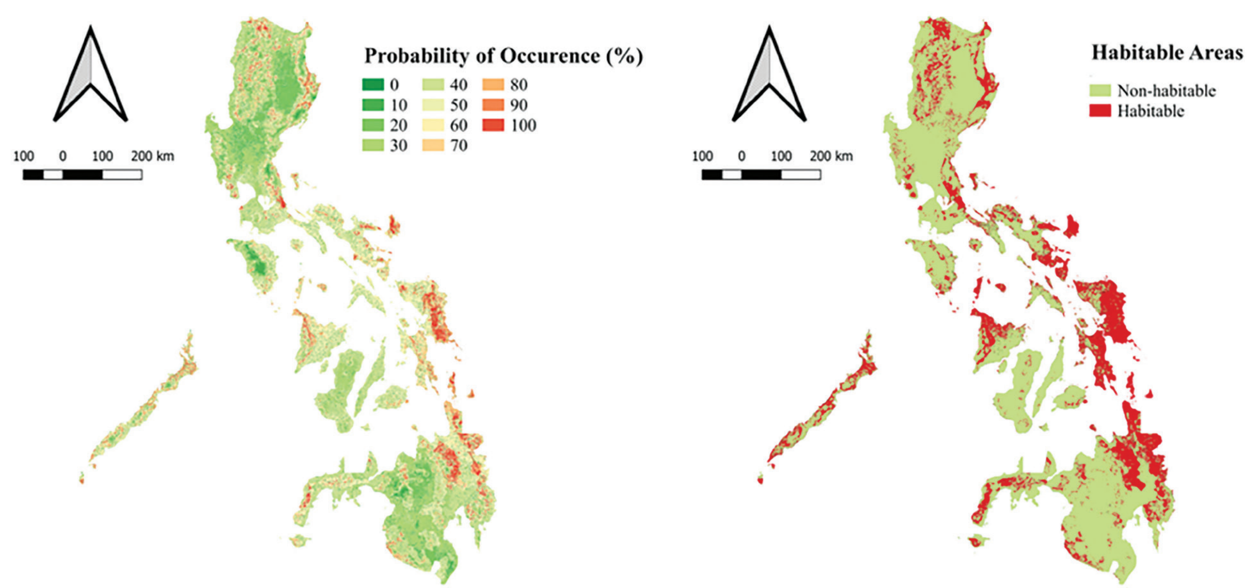

Figure 1. Predicted current suitable and non-suitable areas of *Shorea contorta* using base climate scenarios.

Bio 2 shows the monthly average of the difference of the highest and lowest temperatures within the day. It shows the variability of the temperature, which can have significant effects on the distribution of *Shorea contorta*. Bio 19 or the precipitation of coldest quarter falls in the months of December, January, and February in the Philippines.

Results from the biophysical variables showed that the most significant contribution was land cover with 55.32%, then by distance to roads with 14.95%. Therefore, this means that the occurrence of *Shorea contorta* can be explained by these two biophysical variables. On the other hand, aspect (0.04%) had the most minor overall effect.

Table 1 shows the areas that are suitable and unsuitable for *Shorea contorta*. Unsuitable areas were classified from 1–5, with their probability of occurrence ranging from 0–50%, whereas suitable areas were classified from 6–10, with their probability of occurrence ranging from 50% and above. The unsuitable areas were greater than the suitable areas, having a total area of 20,307,947.03 ha compared to only 7,177,822.83 ha suited for the species. This implies that the potential distribution of the species is limited due to its environmental requirements.

The final model evaluation returned a measure of area under the curve (AUC) larger than 0.5. The area under the receiver operating characteristics curve was utilized to determine the quality of the model, as introduced by Swets (1988). This curve is a ranked approach, which is defined as the likelihood of the model to accurately distinguish between a present record and absent record in a random selection from a collection of presences and absences. AUC measure that is equal to 0.5 implies that the model fit is almost similar to that expected by random, whereas a large AUC value indicates that the model has the capacity to distinguish with accuracy in between areas where the species is absent or present. The proposed classification of AUC values by Swets (1988) was used to describe the AUC of the final model. Omission rate implies a proportion of test locations that are categorized into pixels not projected as fit for the species (Phillips *et al*. 2006). It is desirable to have an omission rate value that is low to indicate good model performance.

Table 1. Habitable and uninhabitable area of *Shorea contorta* in the Philippines.

Probability of occurrence	Classes[a]	Habitat description	Area (ha)
0–10	1	Extremely unsuitable	2,973,023.51
10–20	2	Very unsuitable	2,547,207.05
20–30	3	Moderately unsuitable	4,902,559.68
30–40	4	Fairly unsuitable	5,308,610.84
40–50	5	Unsuitable	4,576,545.95
50–60	6	Fairly suitable	2,744,423.80
60–70	7	Moderately suitable	1,440,058.21
70–80	8	Suitable	1,103,883.39
80–90	9	Very suitable	997,444.71
90–100	10	Extremely suitable	892,012.72

[a][1–5] unsuitable; [6–10] suitable

The AUC of the final model was 0.772 for the test data and 0.811 for the training data. The full model had an AUC of 0.755 for the test data and 0.810 for the training data. The AUC values were all larger than 0.5. This value translated that the full model outperforms a null model. The omission rate value for the final model was 0.

Jackknife Test of Variable Importance

MaxEnt provides a relative contribution graph for each variable used in the model. It calculates a "model gain" once a variable is utilized separately and the "mean gain" for the model uses every single one of the variables aside from one (Garcia *et al*. 2013; Phillips *et al*. 2006; Torres *et al*. 2016). Land cover displayed the greatest gain when used individually with a value of 0.228. This variable happened to be the most significant data on its own. It is then followed by soil type with a value of 0.1028. Land cover was also the variable with the highest reduction when excluded. with a value of 0.2634. This variable happened to contain the most information not found in the other variables. This was followed by soil type with a value of 0.333.

Future Potential Harvestable Areas of *Shorea contorta*

From the gathered data in suitable and non-suitable habitat of *Shorea contorta*, the occurring sites of the species were intersected to the determined protected area based on the National Integrated Protected Areas System (NIPAS) Act of 1992 to check which among the zones have the higher potential for species harvesting. Occurrence and habitat areas were analyzed and intersected to the conservation areas and protected areas of the country.

A total of 6,177,519.86 ha estimated land area was observed for potential harvesting. Out of 78 provinces, there were five highest land areas determined for projected extraction. Agusan del Sur, part of the CARAGA, boasts the largest land area for potential timber harvesting. As cited by Jurvelius (1997), the provinces with more than 100,000 ha of forest plantation in the region of Mindanao are Agusan del Sur and Surigao del Norte. This region, situated in the northeastern part of Mindanao, is home to the fourth largest timberland in the Philippines, covering 992,131 hectares (DENR-FMB 2020).

Moreover, Samar and Leyte – which are the provinces in Eastern Visayas with the largest total land area (DENR-FMB 2021) – have seen an increase in the use of native tree species like lauan by lumber dealers and timber processors, as noted in the study by Mangaoang *et al.* (2005). This increase had a later impact to the current program of National Greening Program, which has boosted the availability of native dipterocarps such as *Shorea contorta* and *Parashorea malaanonan* in nurseries (Dennis and Dirk 2014).

Stumpage Value of *Shorea contorta*

The computed total volume of production of *Shorea contorta* per province is shown in Table 2. Agusan del Sur has the highest estimated number of trees per harvestable area with a total volume of production of 10.37 million m^3, whereas Eastern Samar had the least with a total volume of production of 4.41 million m^3. The estimated total volume of production for all the provinces is 31.34 million m^3.

The computed total production cost of *Shorea contorta* per province is shown in Table 3. Agusan del Sur has the least production cost per tree of PHP 150.02 with a total production cost of PHP 1,613.70 million, whereas Eastern Samar had the greatest production cost per tree of PHP 352.27 and but the least total production cost of PHP 687.23 million. The total production cost for all the provinces was PHP 4,881.11 million.

The estimated revenue of *Shorea contorta* per province is shown in Table 4. Agusan del Sur had the highest estimated total revenue of PHP 10,889.97 million. This was followed by Leyte with PHP 8,062.91 million. Samar, Surigao del Sur, and Eastern Samar had estimated total revenues of PHP 4,678.21, 4,671.06, and 4,637.73 million, respectively. The estimated total revenue for all the provinces was PHP 32,939.88 million.

The estimated stumpage value of *Shorea contorta* shows that Agusan del Sur had the highest stumpage value of PHP 8,872.84 million. This was followed by Leyte with PHP 6,569.43 million. Samar, Surigao del Sur, and Eastern Samar had estimated total revenues of PHP3,811.67, 4,671.06, and 4,637.73 million, respectively. The total stumpage value of *Shorea contorta* for all the five provinces was PHP 26,838.48 million.

Table 2. Computed total volume of production of *Shorea contorta* per province.

Province	Potential harvestable area (ha)[a]	Recommended planting density (no. of trees/ha)[b]	Estimated no. of trees or potential harvestable area	Estimated total volume of production (in million m^3)
Agusan del Sur	518,570.42	250	2,074.28	10.37
Leyte	383,948.54	250	1,535.79	7.67
Samar	222,772.15	250	891.09	4.45
Surigao del Sur	222,431.86	250	889.73	4.44
Eastern Samar	220,844.67	250	883.38	4.41
			Total	31.34

[a]Based on the SDM projection
[b]Based on Nguyen *et al*. (2014)

Table 3. Computed total production cost of *Shorea contorta* per province.

Province	Production cost* (PHP/ha)	Production cost (PHP/tree)	Total production cost (in million pesos)
Agusan del Sur	311,184.00	150.02	1,613.70
Leyte	311,184.00	202.62	1,194.78
Samar	311,184.00	349.22	693.23
Surigao del Sur	311,184.00	349.75	692.17
Eastern Samar	311,184.00	352.27	687.23
		Total	4,881.11

*Based on DENR Memo Circular No. 2000-19 (prices were adjusted using 2021 inflation)

Table 4. Estimated revenue of *Shorea contorta* per province.

Province	Estimated volume of production (m^3/ha)[a]	Estimated total volume of production (m^3)[b]	Price of log (PHP/m^3)[c]	Estimated total revenue (PHP)[b]
Agusan del Sur	200.00	103.71	10,500.00	10,889.97
Leyte	200.00	76.78	10,500.00	8,062.91
Samar	200.00	44.55	10,500.00	4,678.21
Surigao del Sur	200.00	44.48	10,500.00	4,671.06
Eastern Samar	200.00	44.16	10,500.00	4,637.73
			Total	32,939.88

[a]Based from Tamesis and Aguilar (1953)
[b]Figures are expressed in millions
[c]Based on Philippine Forestry Statistics (DENR-FMB 2021)

DISCUSSION

Variables with Higher Contribution on the Occurrence of *Shorea contorta*

The high percent contribution of land cover (55.32%) on the occurrence of *Shorea contorta* suggests that the type of land cover has a critical significant role in determining the suitability of the species. The type of land cover from the occurrence data records used in this study showed that the species are most likely to be located at forests, which are the primary habitat of dipterocarps. This was followed by the distance to roads (14.95%). This species is mostly found in areas where there are limited anthropogenic disturbances. Encroachment and creation of roads mostly lead to destruction of the natural habitat, affecting the occurrence of the species. Aspect had the least value (0.04%). The occurrence of *Shorea contorta* is not limited to the orientation of the slope of its habitat. This indicates that the species has a broad habitat, which is supported by earlier discussion about land cover, and that aspect has an indirect effect on its occurrence.

Economic Potential of *Shorea contorta*

The contribution of the forestry sector to the country's regional development, employment, and foreign exchange was evident in the past particularly for two decades after 1960s (Tumaneng-Diete *et al*. 2005). According to the Department of Environment and Natural Resources (DENR) report in 1992, the forestry sector – together with the agriculture and fisheries sectors – was responsible for approximately 30% of the Philippines' gross domestic product from 1970 up to the late 1980s. However, due to inefficient management of forest resources and various social problems caused by anthropogenic activities, a decline in its contribution to the Philippine economy was eventually recorded (Asia-Pacific Forestry Commission 2001). The massive logging activities of timber products coupled with land conversion for agricultural cultivation has resulted in the decline of the country's forest cover from 70% during the first part of the 19th century, and during the 20th century, this was reduced to at most 17% (Lasco and Pulhin 2006).

In response to this, forest management in the country has shifted from purely economically oriented to a more holistic approach to include a range of social, environmental, and economic benefits, which started in the 1990s (Tumaneng-Diete *et al.* 2005). One of the earliest forest policies established in the country was the Forestry Act (FA) of 1904, with the intention to increase mindful utilization of forests by having a fitting regulatory environment, just imposition of taxes, and a well-established condition for agricultural conversion. In 1962, the Republic Act No. 3701 was established to counter excessive cutting of trees and massive conversion of forest lands. A few years later, several forestry-related programs leaned toward people-oriented forestry. FA 1904 was later revised into the Forestry Reform Code of 1974, which further evolved into Presidential Decree No. 705 or Revised Forestry Code of 1975. Another strategy was the implementation of the timber license agreement (TLA). This agreement aimed to regulate commercial timber businesses and strengthen the implementation against illegal loggers. Over the years, the number of licenses has dwindled in observation of the logging moratorium, as stated in Executive Order 23 of 2011. As a result, log production from TLAs significantly decreased from 2.1 million cubic meters in 1990 to around 3,666 cubic meters in 2010 (Pulhin and Ramirez 2016).

Generally, the contents of these laws and regulations are geared toward a more sustainable forest resource utilization. However, although the diversion of goals is valid with respect to sustainable use of the forest resources, it poses a difficult challenge particularly in striking a balance between effective management of the resources and addressing multiple problems of unemployment, opportunities for the population, and generating income and revenue. This is true in the country, wherein the occurrence of resource degradation, population growth, and institutional constraints are apparent. With this situation, promotion of one aspect – for example, forest conservation – would mean a reduction in profits coming from the wood industry. As a result of this conflicting nature of policies implemented with regards to forest management, the Philippine forestry sector was affected. In the study conducted by Tumaneng-Diete *et al*. (2005), the simultaneous attainment of all the goals of forest management is deemed difficult. Furthermore, policies implemented in the country affecting the wood-based industry such as adding taxes on export of logs and lumber and on pulp importation, and log export ban has resulted to penalized production and aggregate welfare of the sector instead of maximizing its contribution to economic goals.

According to the Forest Management Bureau (FMB), the Philippines need about 6 million cubic meters of wood annually to sustain the wood processing industries. However, the wood industry has been on the decline for many years, despite it being a crucial downstream activity in the forestry sector for giving added value to log (Israel and Bunao 2017). Currently, the national demand for timber comes from local sources (25%) and imported logs (75%). Based on the 2020 Philippine forestry statistics report, the top five regions with the greater number of wood processing plants are Regions 10, 13, 11, 12, and 9 – which are from Mindanao.

The most important source of timber in the country due to its high quality is the dipterocarp species (Rebugio *et al*. 2007). Its value is widely recognized in both domestic and international markets (Tumaneng-Diete *et al*. 2005). The materials obtained from dipterocarp are in great demand both for residential and commercial development (Pito *et al*. 2019). One of the dipterocarp species is *Shorea contorta*, which is endemic in the Philippines and has also been a commercially important source of timber (EDC 2020). Its timber is a source material for various purposes such as plywood, pulp, paper making, *etc.* (DENR-ERDB 2013).

However, the study of Harrison *et al*. (2005) showed that timber production from *Shorea contorta* resulted in a negative net present value (–32,930) and land expectation value (–28,851) and failed to produce a 15% return (internal rate of return = 7%). This suggested that plantation using *Shorea contorta* is least likely to be financially feasible. Furthermore, in many countries, indigenous species offer good wood qualities that are greater than non-native species; however, the rotation period is longer, higher silvicultural needs, and planting material is not readily available. Moreover, in plantations composed of native species, there are often minimal experience cultivations, resulting in an insufficiency of knowledge regarding location and silvicultural needs, as well as growth performance (Harrison *et al*. 2005).

CONCLUSION

Using different collection methods to determine the occurrence data of *Shorea contorta* produced accurate results in predicting the distribution of the species. This study identified that *Shorea contorta* is suitable in large plantation areas and as a future harvestable timber. Biophysical variables mainly affect the distribution of *Shorea contorta* by 87%, whereas the bioclimatic variables only affect the distribution by 13%. The values obtained do not mean that biophysical variables are of greater significance when compared to the bioclimatic variables since both variables are essential and spatiotemporally autocorrelated. It can be stated that the spread of these species results from the combination of environmental factors, and a combination of these factors results in an optimal distribution of the species. The habitat and the occurrence of existing *Shorea contorta* are essential in determining the available land areas where the species thrive. However, since not all lands are recommendable for extraction, protected areas through NIPAS were eliminated. There was a total of 78 probable provinces for extraction. Among the provinces with high land area in terms of hectares in the Philippines, Agusan del Sur – having 518,570.42 ha of available land – is the best spot for a potential harvesting site. Most provinces with the highest land area are from CARAGA and Eastern Visayas.

There is limited literature about market efficiency specific to *Shorea contorta*, indicating a gap that has yet to be explored. However, the authors' attempt to compute the stumpage value of the provinces' *Shorea contorta* with potential harvestable area obtained from the model showed potential for timber production using the latest log price and adjusted cost standard for DENR plantation.

STATEMENT ON CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

NOTES ON APPENDICES

The complete appendices section of the study is accessible at https://philjournsci.dost.gov.ph

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APPENDICES

Table I. Descriptive outline of environmental variables utilized.

Variable	**Variable (unit)**	**Description**
Climatic factors		
Definition derived from USGS data series 691, 2012		
Bio 1	Annual mean temperature (°C)	The average of all the monthly mean temperatures; the annual average temperatures estimate total energy input of the ecosystem.
Bio 2	Mean diurnal temperature range [mean period max-min (°C)]	The average of the monthly temperature ranges (peak temperature of the month minus least temperature of the month); provides information on the significance of varying temperatures on species
Bio 3	Isothermality (BIO2/BIO7) (×100)	Ratio of the mean diurnal temperature range and temperature annual range expressed in percent
Bio 4	Temperature seasonality (standard deviation × 100)	The variation of temperatures in a given year; derived from the standard deviation of monthly temperature ranges; expressed in degrees Celsius (°C).
Bio 5	Max temperature of warmest month	The highest monthly recorded temperature of all months in a given year
Bio 6	Min temperature of coldest month	The lowest monthly recorded temperature of all months in a given year
Bio 7	Temperature annual range (BIO5-BIO6)	The difference between the highest monthly recorded temperature of the hottest month and the lowest monthly recorded temperature of the coolest month
Bio 8	Mean temperature of wettest quarter	The average temperature during the wettest three consecutive months of the year
Bio 9	Mean temperature of driest quarter	The average temperature during the driest three consecutive months of the year
Bio 10	Mean temperature of warmest quarter	The average temperature during the warmest three consecutive months of the year
Bio 11	Mean temperature of coldest quarter	The average temperature during the coldest three consecutive months of the year
Bio 12	Annual precipitation	The total of the monthly precipitation values in a year
Bio 13	Precipitation of wettest month	Amount of precipitation during the wettest month in a year
Bio 14	Precipitation of driest month	Amount of precipitation during the driest month in a year
Bio 15	Precipitation seasonality (coefficient of variation)	A measure of variation in the monthly total precipitation values expressed in percent
Bio 16	Precipitation of wettest quarter	The quantity of precipitation during the wettest three consecutive months of the year
Bio 17	Precipitation of driest quarter	The quantity of precipitation during the driest three consecutive months of the year
Bio 18	Precipitation of warmest quarter	The quantity of precipitation during the warmest three consecutive months of the year
Bio 19	Precipitation of coldest quarter	The quantity of precipitation during the coldest three consecutive months of the year.
Topographic factors		
Elevation	Digital elevation model	SRTM
Slope	Slope (%)	SRTM
Aspect	Aspect (degrees)	SRTM
Vegetation-related factors		
Land cover	Land cover classification (2020)	National Mapping Resources Information Authority
NDVI	Normalized difference vegetation index (–1 to 1)	Sentinel-2 MSI: MultiSpectral Instrument, Level-2A/Google Earth Engine
Edaphic factor		
Soil class	Soil type classification	Bureau of Soils and Water Management–Department of Agriculture
Anthropogenic factor		
Dist_roads	Euclidean distance (meters)	www.geofabrik.de

Table II. Variables used in the final model.

Variable group	Variables
Climatic factors	Bio 2 Bio 5 Bio 6 Bio 18 Bio 19
Topographic factors	Slope Aspect Elevation
Vegetation-related factors	Land cover NDVI
Edaphic factor	Soil class
Anthropogenic factor	Dist_roads

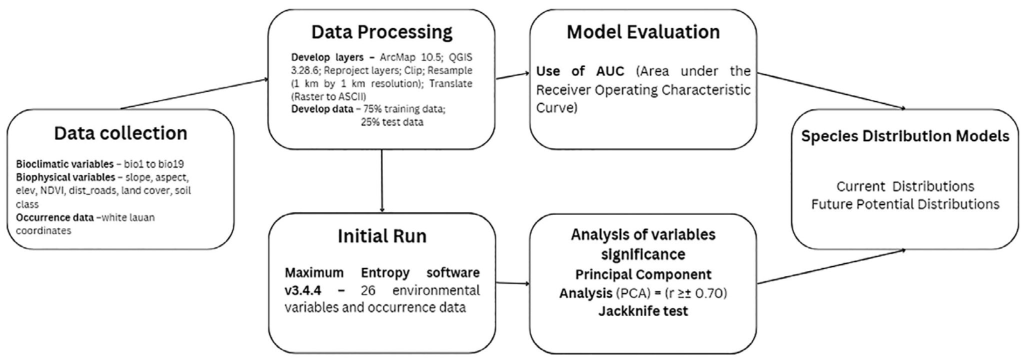

Figure I. Methodological framework employed in the study.

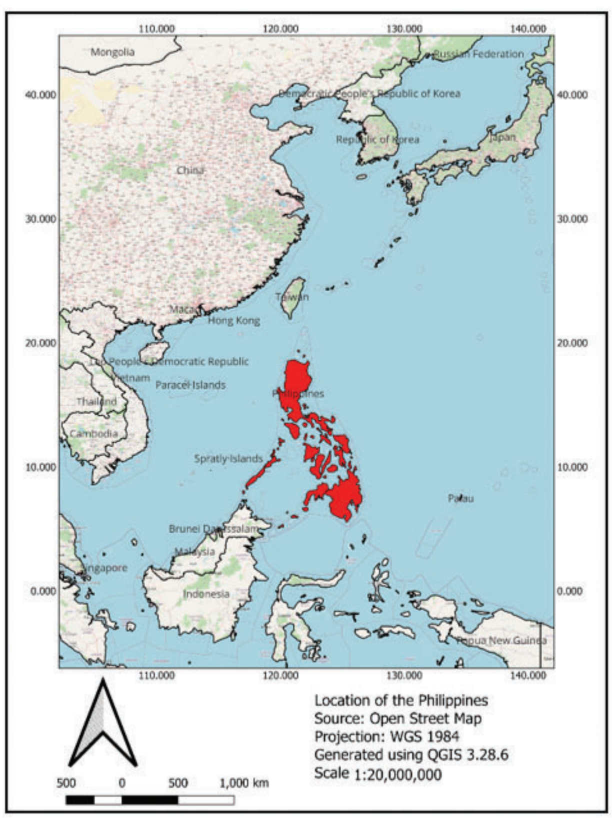

Figure II. Location of the study area.

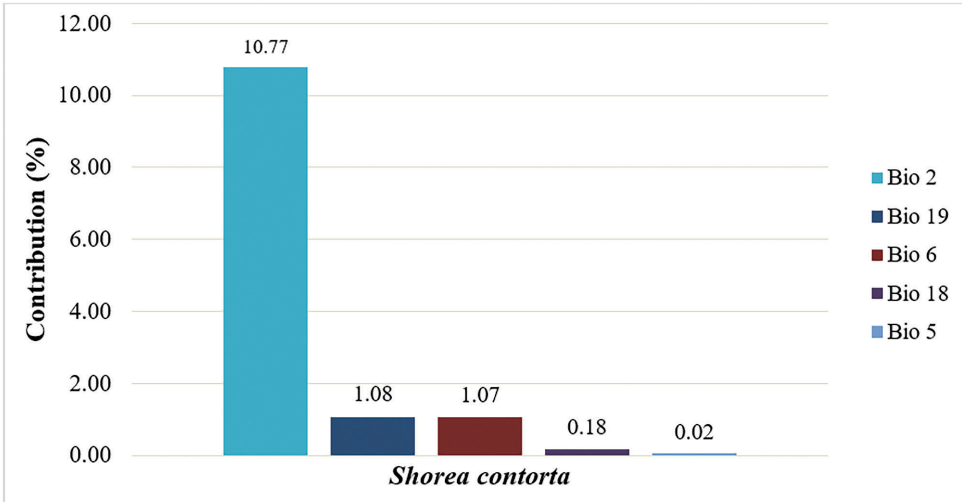

Figure III. Contribution of climatic variables extracted from maximum entropy model and its effect on the distribution of *Shorea contorta* in the Philippines.

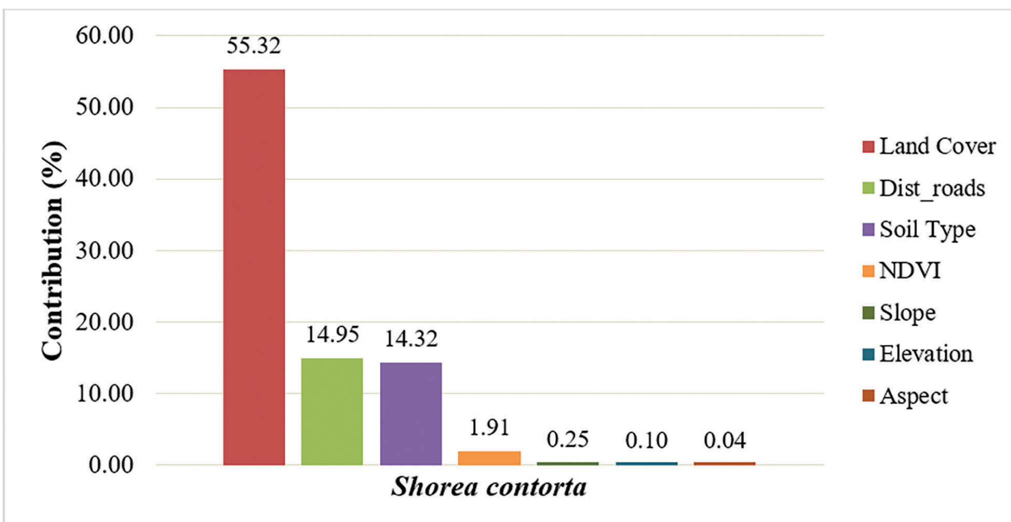

Figure IV. Contribution of biophysical variables extracted from maximum entropy model and its effect on the distribution of *Shorea contorta* in the Philippines.

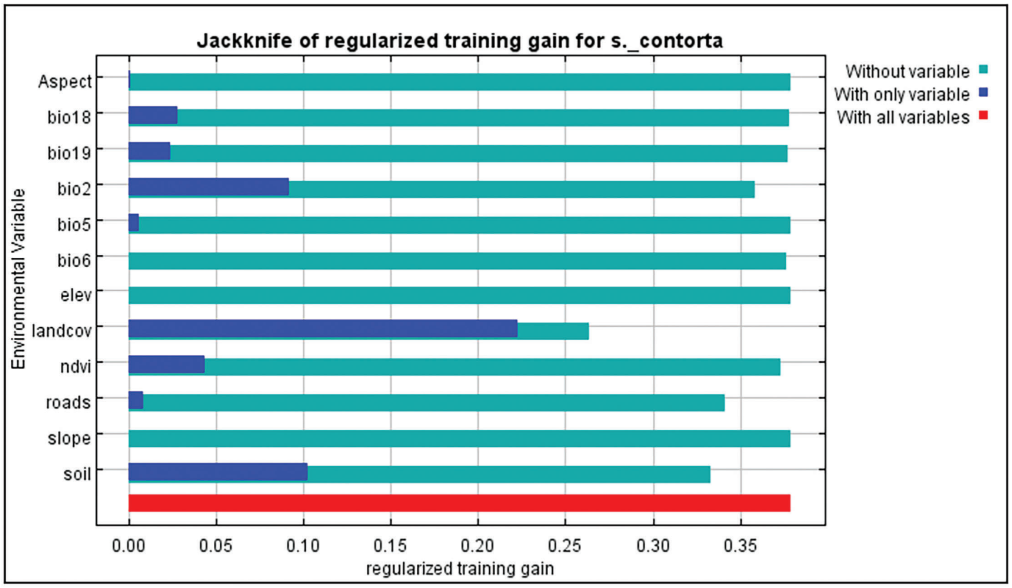

Figure V. Jackknife test result of regularized training gain for *Shorea contorta*.

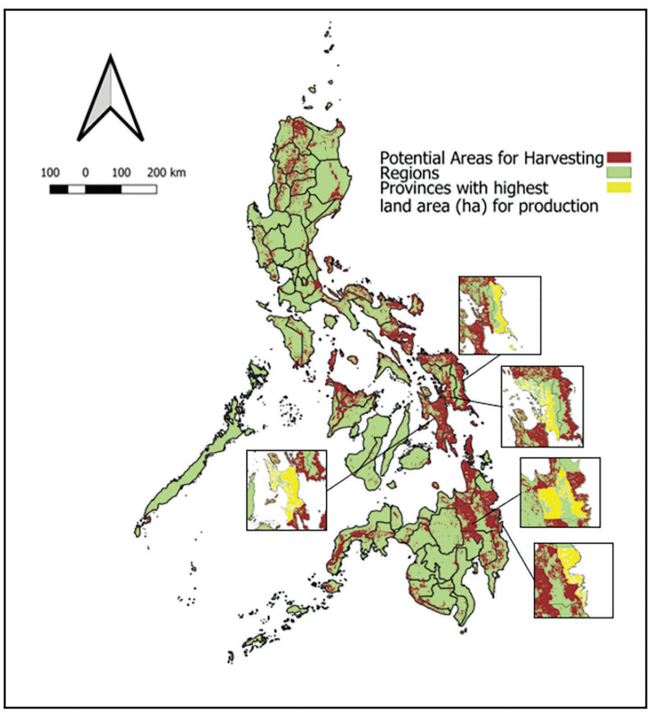

Figure VI. Land area of *Shorea contorta* having the highest potential area for harvesting or production.

Equation 1. Stumpage value.

$$SV = SP – (PC + mpr)$$

where:

SV is the stumpage value
SP is the selling price of log
PC is the production cost
mpr is the margin of profit and sink

Equation 2. Value of timber at rotation age:

Value of timber at rotation age = Y * SV

where:

Y is the timber yield in m^3/ha
SV is the stumpage value