FORUM GEOGRAFI
Indonesian Journal of Spatial and Regional Analysis

Species Distribution of Styrax sumatrana in North Sumatra Using Maxent Modelling Approach

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Abstract. *Styrax sumatrana* is the prestigious tree from North Sumatra. The resin which is a product from this tree has high demand and take a role as the primary income for farmer around the forest. However, the climate change along with the land conversion, threatens the species distribution . This paper aims to analyse the variable that contributes to *Styrax sumatrana* distribution and predict the potential distribution area of the species in North Sumatra Province . Several variables, such as elevation, slope, aspect, climate condition and land use land cover (LULC), were used to analyse the contribution for *Styrax sumatrana* distribution. The analysis uses the Maximum entropy model to examine the variable contribution for species distribution. The result shows that the mean temperature of the coldest quarter has a higher contribution for species distribution followed by elevation and LULC. The climate condition has a great impact by 28.5% than the other variable. The potential area that is suitable for *Styrax sumatrana* distribution was 8.91% or around 663,221.94 ha from a total of region.

Keywords: Climate Change, Species Distribution Models, Styrax Sumatrana, Maximum entropy.

Abstrak. *Styrax sumatrana* merupakan jenis pohon andalan di Sumatera Utara. Kemenyan yang merupakan produk dari resin *Styrax sumatrana* bernilai tinggi dan menjadi sumber pendapatan utama bagi para petani kemenyan di sekitar hutan. Namun, perubahan iklim dan konversi lahan menjadi tantangan bagi sebaran species ini. Tulisan ini bertujuan untuk menganalisa variabel yang berperan dalam penyebaran kemenyan di Sumatera Utara dan memprediksi luasan area yang berpotensi untuk penyebaran jenis ini. Beebrapa variabel dikumpulkan untuk analisa. Variabel tersebut antara lain ketinggian, kelerengan, arah lereng, kondisi iklim dan tutupan lahan. Maximum entropy (Maxent) model digunakan untuk menganalisa variabel yang penting dalam sebaran jenis kemenyan. Hasil menunjukkan suhu rata-rata pada kuarter musim dingin berperan penting pada sebaran jenis kemenyan, diikuti oleh ketinggian dan tutupan lahan. Perubahan iklim berdampak lebih besar dengan nilai 28,5% dibandingkan variabel lainnya. Jumlah area yang berpotensi untuk sebaran kemenyan adalah 8,91% atau sekitar 66.221,94 hektar dari total area Sumatera Utara.

Kata kunci: Perubahan iklim, Species Distribution Models, Kemenyan, Maximum entropy.

1. Introduction

Styrax sumatrana as one of the non-timber product trees in North Sumatra is the source of Sumatra benzoin. Sumatra benzoin is the resin produced from the bark of *Styrax sumatrana*. The resin is used in many types

of products, such as pharmacy, food, industry and also in a traditional ceremony (García-Fernández, Casado, & Ruiz Pérez, 2003; Jayusman, 2014; Silalahi & Sunandar, 2017). This species is distributed along the North Sumatra mostly around Lake Toba Catchment Area (LTCA) (Sunandar, 2012). It is common to see the species as a garden plant in North Sumatra Province. Having this species in a garden is valuable and important since it can become an additional income for farmers around the forest. Moreover, the gardens could support the biodiversity in the forest area that protects the forest from the disturbances (García-Fernández *et al.*, 2003).

Recently, the distribution of this species has threatened by the land use changes and the change in the climate condition. The changes might shift the distribution of the species in the future as well as the reducing the quality of its gum (Anas & Kholibrina, 2017a, 2018; Kholibrina, Anas, & Susilowati, 2018). Furthermore, the area may be changes into more valuable land use such as crop, industrial or residential (Gaol & Simangunsong, 2012). The threat from valuable crop plantation may convert the Styrax garden and reduced the population (García-Fernández *et al.*, 2003).

The effort to protect the Styrax sumatrana habitat needs the support from the species distribution information (Miller, 2010). The environmental requirement for the species to survive need to be known as well as the spatial location for the species to distributed. The variable also needs the existing location of the species (Prasad *et al.*, 2016). This action will lead the conservation strategies to determine the potential location for Styrax sumatrana. Species Distribution Models (SDMs) are models that predict the geographical maps of species suitability in the area by calculating the correlation of known between occurrence records and the environmental condition at the area (Gomes *et al.*, 2018). SDMs use to analyze the variable that gives the contribution for Styrax sumatrana distribution and provide the

information of suitable area for it to spread. SDMs use three components: an ecological model, a data collection model, and statistical model which is the algorithm in modelling approach to classifying the probability of species distribution as a function of a set of environmental variables (Austin, 2007). Several approaches that used for SDMs are Maxent (Phillips *et al.*, 2004), Generalized Linier Models (GLM) (Hudjimartsu *et al.*, 2017), CLIMEX (Byeon *et al.*, 2018), and BIOCLIM (Booth *et al.*, 2014). The essential information in SDMs is depend on the presence and absence data occurs during the observation. However, in many conditions not all presence and absence data reliable to achieved during the incomplete data specifically for endangered species (Gomes *et al.*, 2018)

One of the models that only require the presence of species current location is Maximum entropy (Maxent) (Gomes *et al.*, 2018; Phillips & Dudík, 2008). Maxent programs use present-only data and collect the information related to the environment condition at the exact point where the location of sample exist (Phillips *et al.*, 2004). This model is broadly used for species distribution analyse in every aspect such as impacts of climate change on forest tree species (Deb *et al.*, 2017; Rodrigues *et al.*, 2015; Sohel *et al.*, 2017). Moreover, Maxent is used to analyze the influences of land-use changes (Benítez-Badillo *et al.*, 2018), species distribution assessment (Nimasow *et al.*, 2016; Nursamsi *et al.*, 2018) and invasive species assessment (Dermawan *et al.*, 2018). Maxent has the advantages than other models due to presence data only for a requirement in the model, together with environmental information for the whole study area. It can utilize continuous and categorical data in the model. Furthermore, it can directly produce a map of the potential suitability area explicitly. Moreover, to evaluate the environmental variable which is considered to be important, it encompasses a jackknife test feature. Lastly, The occurrence data can be used to interpret

the environment information and easy to use as an interface program (Phillips *et al.*, 2008). This approach gives the huge information that reliable for the researchers to identify the potential distribution of species with additional information such as variable significant and the probability of occurrence map (Phillips *et al.*, 2006). Indonesia SDMs has been applied in many aspects. The model is used to estimated bird distribution (Nursamsi *et al.*, 2018) and predicted the endangered tree species distribution in Borneo (Singh, 2013). Moreover, alien invasive species in National Park using Maximum Entropy (Maxent) and Generalized Linear Model (GLM) (Dermawan *et al.*, 2018; Hudjimartsu *et al.*, 2017). Furthermore, the model used to analyze the threat in primate conservation. The prediction was calculated for anthropogenic risk from human intervenes (Thorn *et al.*, 2009) and the conservation strategy for proboscis monkey in Kalimantan (Meijaard & Nijman, 2000). However, the species distribution model still limited to know in Indonesia. Most of the research uses the SDM such as GLM, Maxent and survey analysis with a limited environmental variable. The research of SDM still limited for few species and region.

This study aims to predict the suitable area of Styrax sumatrana and analyse the environmental variable that contributed to the species distribution by applying the Maxent model in North Sumatra Region. The available of presence location and environmental data is essential for Maxent model. The information of species potential distribution of Styrax sumatrana is important as the input for the conservation strategies to protect it from the population degradation.

2.   Research Method

Several steps were applied to predict the species distribution of Styrax sumatrana; data collection from the second and primary data, preprocessing, Maxent modeling, and postprocessing. The tools that used is GIS for spatial analysis and Maximum Entropy for Species Distribution Modeling. A simple schematic of analysis was provided in Figure 1.
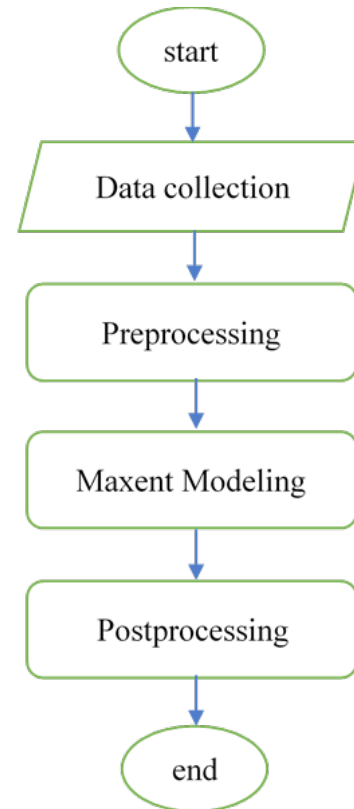

Figure 1. The Maximum Entropy model process.

2.1. Data collection

The data consists of species presence location and environmental condition. The presence location collected from primary and secondary data. Primary data was collected by direct observation in the field. While the secondary data was taken from several literatures (Anas & Kholibrina, 2017b; García-Fernández *et al.*, 2003; Sunandar, 2012). The number of samples is 63 individual trees with 34 primary and 29 secondary data. The data recorded the name and geographical latitude and longitude coordinate of the trees. The data for environmental variable consists of elevation, aspect, slope, land cover, climate and soil type shown in Table 1.

Table 1. All the data used in this research as a resume.

No	Data	Source	Type	Extraction Method
1	Elevation	www.earthexplorer.usgs.gov	.tif	Spatial Analysis
2	Aspect	spatial analysis from DEM data	.tif	Analysis of the aspect of the surface topography
3	Slope	spatial analysis from DEM data	.tif	Analysis of the slope of the surface topography
4	Land cover	www.appgis.dephut.go.id	.kml	Spatial Analysis
5	Climate	www.worldclime.org	.bil	Spatial Analysis
6	Soil Type	http://www.fao.org/soils-portal	.asc	Spatial Analysis

2.2. Preprocessing

Maxent required the raster format for the environmental layer that consist of elevation, slope, aspect, soil type, temperature and land cover with same resolution, extent and geographical coordinate system. The resolution is 30 meters and the extents for environmental layers are 4.30460808352 (top), 97.0590820307 (left), 100.424402031 (right), and -0.568441916477 (bottom). The environmental layer will extract into Action Script Communication (ASC) file to be applied in Maxent program. The format in Maxent program use the Comma Separated Value (CSV) format for presence location. Furthermore, the environmental data need to be collected and selected for North Sumatra region. Nineteen bioclimatic variables (Hijmans *et al.*, 2013 – Table. 1) with 30-second (1 km) spatial resolution were obtained from the WorldClim dataset (http://www.worldclim. The ArcGIS 10's used to derived these bioclimatic variables from global scale to North Sumatra region border. The data converted into raster map as Maxent requirement for analysis. Other variables are soil type, altitude, aspect and slope. Altitude was collected from the Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model (ASTER GDEM). The altitude data was interpreted from the ASTER GDEM V2 dataset. The format has a 30-m spatial resolution in the Geo TIFF image and WGS84 datum (ASTER, 2004). Spatial Analysis function in ArcGIS then used to help extract Slope (as degree of an angle) and aspect (as an eight-class categorical variable: N, NE, E, SE, S, SW, W, NW), from Geo TIFF to raster format. The Sumatra soil unit was define into 43 soil unit (FAO, 1974).

2.3. Maxent model

Maxent is machine learning method that use the presence location as the input for analysis. Maxent programs use presence-only data and collect the information related to the environment condition at the exact point where the location of sample exist (Phillips *et al.*, 2004). Maxent method is used to estimate a target probability distribution by finding the probability distribution of maximum entropy by considering a set of constraints that represent our incomplete information about the target distribution (Phillips *et al.*, 2006).

Maxent model rely on Baye's rule (Phillips & Dud*í*k, 2008)

$$P(y = 1|x) = \frac{P(x|y = 1)P(y=1)}{P(x)} \tag{1}$$

where:
$P(y=1 | x)$ is the probability that the species is present at the site x (y ranges from 0-1)
$P(x | y=1) = \pi(x)$ is the present observation or realized distribution at x area
$P(y=1)$ is the probability of presence
$P(x) = \frac{1}{|X|}$ is the all-area probability from the X site

Based on the Equation (1) The new formula become

$$P(y = 1|x) = \pi(x)P(y = 1)|X| \tag{2}$$

The formula used the presence and absence information as the basis. However, the presence-only data is used in MaxEnt. This mean, the model will be implemented even the absence data is not available. Based

on this condition, rather than estimating the Baye's estimation rule, MaxEnt use the Gibbs distribution from the sets of features f_1, ..., f_n and weights $_1$,.....,$_n$. This distribution calculated the realized distribution () from the Baye's rule. The formula defined by (Phillips & Dudík, 2008)100 mg/kg, i.v.

$$q\,\lambda(x) = \frac{exp\,(\sum_{j=1}^{n} \lambda jfj(x))}{Z\lambda} \qquad (3)$$

where:
$q\,\lambda(x)$ is Maxent distribution
$exp\,(\sum_{j=1}^{n} \lambda jfj(x))$ is an exponential distribution parameterized by a vector of feature (f) weights .
$Z\,\lambda$ is a normalization constant ensuring the q(x) sum to one over the area.

Due to Maxent idea is to estimate the probability of presence by maximum entropy we include the formula that delivered from Information theory by Shanon (Phillips & Dudík, 2008)100 mg/kg, i.v.

$$H = \Sigma q\lambda(x)\ln(q\lambda(x)) \qquad (4)$$

where:
H is maximum entropy
$q\,\lambda(x)$ is a MaxEnt distribution from formula (3)

After obtaining an estimate of $q\lambda$, sufficient information is obtained to obtain the probability distribution P(y=1|x), as indicated (5).

$$P(y=1|x) = \frac{eHq\lambda(x)}{1+eHq\lambda(x)} \qquad (5)$$

Where:
$q\lambda$ is the estimated probability of presence with the maximum entropy of π
H is the entropy of $q\lambda$.

2.4. Postprocessing
The Maxent output presented as spatial information of probability distribution of species. Furthermore, the result was interpret using ArcGIS. The spatial data from Maxent was converted into raster data by divided into

categories. The categories used to identify the probability classification. The analysis converted the probability range from 0 to 1 into 5 categories referred to FAO land classification which presented the suitable area form crop plantation (Nguyen, 2008)ETM4 and ETM5 with panchromatic band. Using this output, available secondary data together with field data in order to perform a Maximum Likelihood supervised classification. Six classes of forestland were classified, namely dense forest, degraded forest, forest plantation, grass, shrub and barren land. The overall accuracy for this classification is 84.6 % and Kappa index of Agreement is 82 %. The suitability assessment for forestry use and each tree species was conducted using the method described in FAO guidelines for land evaluation for forestry (FAO, 1984. The 5 categories presented in Table 2.

Table 2. Suitable classification for Styrax sumatrana distribution with corresponding probability

Major Classification	Classification	Probability values
Suitable	Highly Suitable	0.8-1
	Moderately Suitable	0.6-0.79
	Marginally Suitable	0.4-0.59
Not Suitable	Currently Not Suitable	0.2-0.39
	Permanently Not Suitable	0-0.19

The result of Maxent output changed from ASC file into raster map that easier to interpret. The raster map will divide into five class according to Table 2. The total area converted from percentage into ha to estimate the land cover area that suitable for *Styrax sumatrana*. Besides the spatial result, Maxent provide the statistical analysis of variable contribution and jackknife analysis.

3. Results and Discussion
3.1. Variable Contribution
Maxent result show the variable contribution to the model. All the variable was

calculated and arranged from the higher to the lower contribution. The three top variable that contributed for the model provided in Table 3.

Table 3. The three top variable contribution of *Styrax sumatrana* distribution

Variable	Description	Percent contribution
bio 11_styrax	Mean temperature of coldest quarter	28.5
alt_styrax	Elevation	26.3
lulc_styarx	Land use and land cover	15.4

After analysing 13 environmental variable, the highest percent contribution for the model was noticed by bio 11 (the mean temperature of the coldest quarter). This variable has 28.5% contribution to predicting the potential area for Styrax sumatrana distribution in North Sumatra region. While 26.3% by elevation and 15.4% by LULC. The rest of the variables indicated a small amount of contribution for the model by least than 10%The percent contribution shows how the variable give the impact for the species to distributed among the area. The bio 11 has the highest contribution for Styrax sumatrana distribution which is important even if the other variable did not include in the analysis.

Species distribution of Styrax sumatrana is classified based on three higher variable contributions, which is (i) the mean temperature of coldest quarter, (ii) elevation and (iii) LULC. These three variables give the useful information for Species distribution among the other variable. The explanation for each variable presented below.

3.2. Species Distribution Based on Mean Temperature of Coldest Quarter

Based on mean temperature of coldest quarter the graphic of suitability is produced (Figure 2). The graphic shows that the suitable of species to distributed is increase from 13-19°C and then decrease. This result indicate that this species needs the wet season around

a year with the rainfall type A or B by the Schimt and Ferguson classification and the low temperature to distributed (Jayusman, 2014).
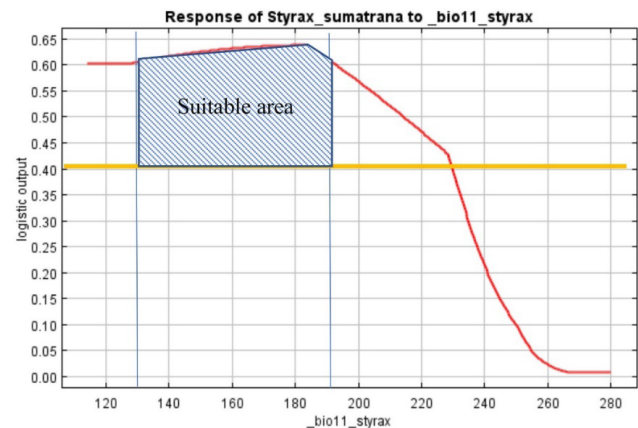

Figure 2. Response of Styrax sumatrana to mean temperature of the coldest quarter graph. The horizontal orange line in y axis indicates the suitable threshold classification by 0.4 and higher probability value. The temperature value in x axis multiple by 10 from the original value in Celcius degree. The red line presented the probability of species occurrence by the increment of mean temperature of the coldest quarter. While the shaded area shows the suitable condition for Styrax sumatrana to exist.

3.3. Species Distribution Based on Elevation

The elevation response curve shows the logistic probability of Styrax sumatrana increase from 0-1,400 meters (Figure 3). However, the suitable elevation for Styrax sumatrana distribution in North Sumatra is around 600-1,400 meters. Based on the result, the suitable area will decrease above 1,400 meters. This result relevant with the funding from other researcher where the most of Styrax garden in North Sumatra are located above 600 meters (García-Fernández *et al.*, 2003; Jayusman, 2014)Indonesia","title":"Mengenal Pohon Kemenyan (Styrax spp . . Moreover, the high altitude from 500 to 1,400 meters shows the good phenotype performance for Styrax sumatrana growth (Anas & Kholibrina, 2017b).

3.4. Species Distribution Based on LULC

In the response curves of the LULC, variables produce the high logistic probability in shrub (notated by number 10) and garden (notated by number 6) land classification followed by the forest (notated by number 2) (Figure 4). The probability of shrub and garden is more than 0.6 while the forest is low by around 0.45. The species is semi-tolerance type which needs small solar radiation from the sun to grow. Yet, the solar radiation requirement will increase following the increase of volume (Anas & Kholibrina, 2018). The shrub area was suitable for this condition. Furthermore, the competition of nutrient in shrub area was less rather than in forest.
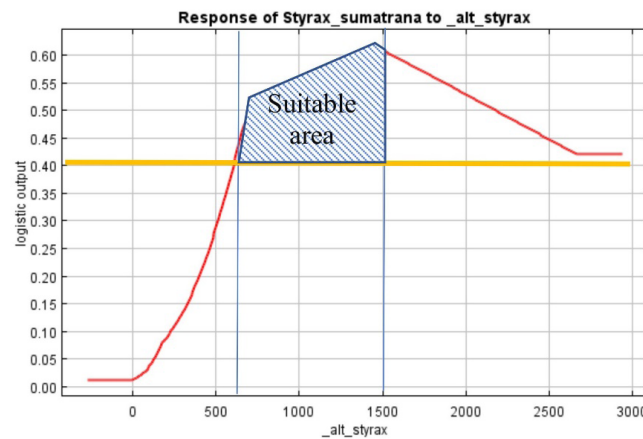

Figure 3. Response of Styrax sumatrana to altitude graph. The horizontal orange line in y axis indicates the suitable threshold classification by 0.4 and higher probability value. The altitude value in x axis presented the altitude in meter above sea level. The red line presented the probability of species occurrence by the increment of altitude. While the shaded area shows the suitable condition for Styrax sumatrana to exist.

Legend:
0. Airport
1. Crop
2. Forest
3. Lake
4. Mangrove
5. Open area
6. Garden
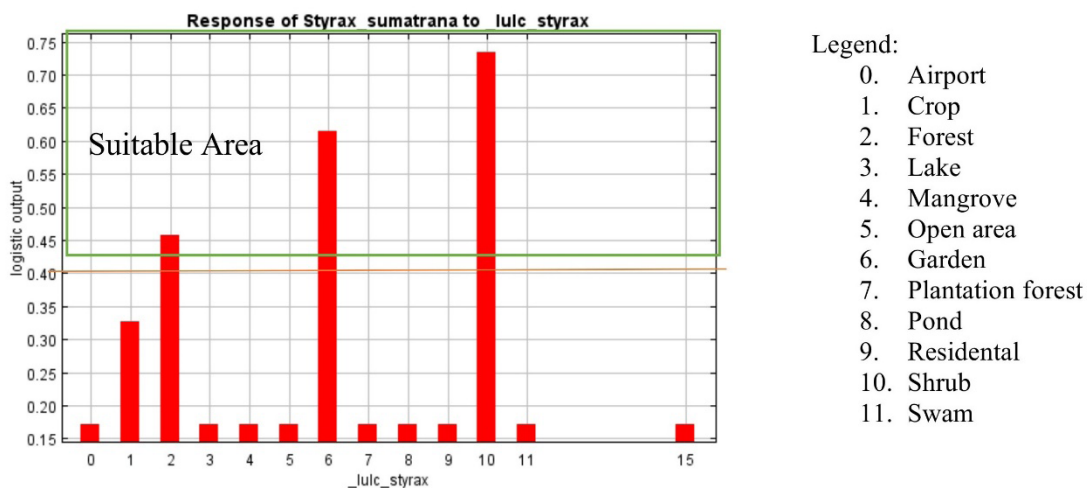7. Plantation forest
8. Pond
9. Residental
10. Shrub
11. Swam

Figure 4. Response of Styrax sumatrana to LULC. The horizontal orange line in y axis indicates the suitable threshold classification by 0.4 and higher probability value. The LULC classification in x axis explained in the legend. The red line presented the probability of species occurrence by the different LULC classification. While the shaded area shows the suitable condition for Styrax sumatrana to exist.

3.5. Potential Distribution of Styrax sumatrana

The result of Styrax sumatrana distribution is presented in Figure 5. The Suitable area for this species was 8.91% or around 663,221.94 ha from the total of North Sumatra. Meanwhile, data from agriculture agency of North Sumatra showed that the total area of Styrax Garden only 22,912.13 ha in 2017 (Dinas Perkebunan Sumatera Utara, 2018). It means that the potential area is high rather than the current area for *Styrax sumatrana* garden.
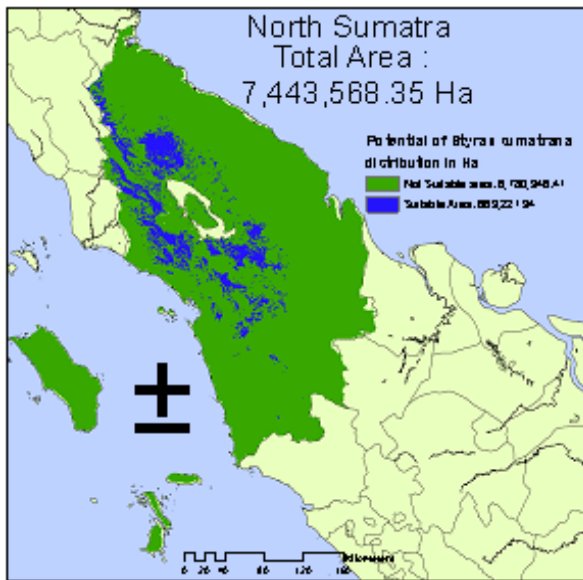

Figure 5. The map of suitable area for Styrax sumatrana in North Sumatra Province.

The central of *Styrax sumatrana* garden mostly distribute in three Sub-region which are Tapanuli Utara, Toba Samosir, Dairi, Humbang Hasundutan and Pakpak Barat (Dinas Perkebunan Sumatera Utara, 2018). Meanwhile, the maxent result shows that Karo regency has a high potential for *Styrax sumatrana*.

3.6. Validation

The model evaluation was presented in Maxent output as Receiver Operating Characteristic (ROC) curve. The ROC curve is a graph showing the performance of a classification model at all classification thresholds. The ROC curve consists of sensitivity and 1-sensitivity that showed in Figure 6.

The result showed that the Area Under Curve (AUC) number is 0.949. A high AUC indicates that sites with high predicted suitability values tend to be areas of known presence. An AUC score of 0.5 means that the model is as good as a random guess (Hijmans & Elith, 2013). The highest value in AUC describes the best model by considered all variable that used in the model and the lower than 0.5 show the model not even good rather than random prediction.
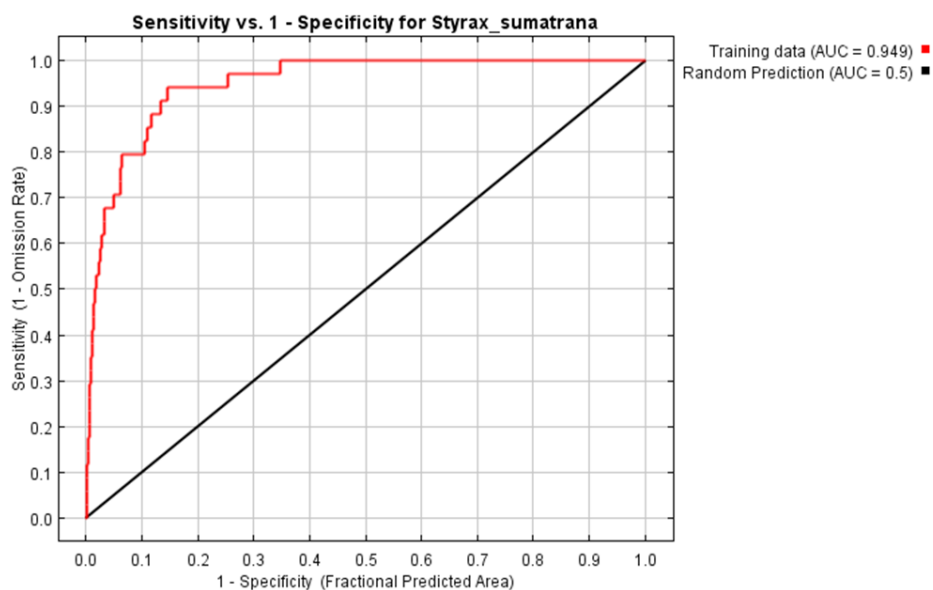

Figure 6. The Sensitivity and 1-sensitivity graph of Styrax sumatrana

3.7. Discussion

The models estimated the potential distribution of Styrax sumatraThe models estimated the potential distribution of Styrax sumatrana in North Sumatra with the highest validation based on ROC analysis. The model provides a statistical analysis that shows the percent contribution of every variable that include in the calculation. Three major variables that contributed to the model most decide the potential distribution of the species. The variables inform the suitable area which has a similar condition with the occurrence species in the area. Furthermore, in a geographical pattern, Styrax sumatrana has been distributed around LTCA as a garden for more than century. The temperature, altitude and LULC describe the sufficient condition for the distribution of the species.

Mean temperature in coldest quarter provides the seasonal distribution of Styrax sumatrana effected by low temperature. The research shows the impact of temperature to tree growth due to evaporation increment in tropical forest (Wright *et al.*, 2009). Small increment of temperature may reduce the probability distribution of this species (Herold, 2017). The result from Maxent analysis provide the high importance of mean temperature of the coldest quarter variable to the model. This means that the variable can explain the potential distribution of Styrax sumatrana without considering the other variable. The result is similar with the finding from the study of Dysoxylum binectariferum by Sohel et al (2017) in Bangladesh. Mean temperature in the coldest quarter provides the highest contribution to the model (Sohel *et al.*, 2017).

The mean temperature in coldest quarter index calculated based on the summed average temperatures of each month in the quarter. Thus, the quarter with the lowest value is selected (O'Donnell & Ignizio, 2012). The coldest temperature in Indonesia is fall between last September until November (BMKG, 2015). In this quarter Styrax sumatrana flowering phase was passed and the fruit was occur (Kholibrina *et al.*, 2018). The abundance genetic

material is available in this quarter which is increase the probability for distribution of Styrax sumatrana.

The high altitude mean the temperature become colder which is important variable for the Styrax sumatrana distribution (Sunandar, 2012). Based on the first environment variable, the temperature increases the distribution probability of Styrax sumatrana. The comparison with other species in same Styrax Genus shows the same condition. From the other species of Styrax the distribution of species is occur in high elevation (1,100-1,500 meters above sea level) such as Styrax wuyuanensis in North America and Styrax nicaraguensis in Costa Rica and Nicaragua. Eventhough the distribution of the species has a wide range from low to high altitude, the better performance of yield and phenology are presented in elevation above 600 to 1,500 meters (Anas & Kholibrina, 2018; Sunandar, 2012; Susilowati *et al.*, 2018).

Styrax sumatrana has been cultivated more than 200 years. Since that time, the Styrax has been established as plants in the garden and used by the farmer in North Sumatra. Although it has been cultivated, the distribution in forests and shrub areas still exist (García-Fernández *et al.*, 2003). The Styrax sumatrana found in the small population in forest area than in cultivated (García-Fernández *et al.*, 2003; Puspitaningtyas, 2005). The probability distribution in the garden has a higher value than the forest due to the intensive cultivation. However, intensive management reduces the diversity of large tree. The shrub area is the ex-intensive cultivation garden which is abandoned by the farmer. In this area, the number of seedlings and natural regeneration increase the probability of distribution rather than in garden which is the area limited and less natural regeneration was occur (García-Fernández *et al.*, 2003).

Based on the result, Styrax sumatrana has the future potential as the garden in a wider area. Regarding the result, most of the abandoned area that became shrub can be cultivated as the garden and this also help

farmer to generate more income. The Styrax sumatrana plantation as a garden will protect the LTCA from erosion by strap the soil. Finally, the plantation program in suitable area will enhance the area to be more productive and beneficial for the farmer and environment.

4. Conclusion and Recommendation
4.1. Conclusion

This paper has conducted model that can predict the potential area of Styrax sumatrana in North Sumatra using Maximum Entropy modeling approach. Based on AUC result of 0.949, the model can be classified as very well prediction. Three most influence environmental variable for Styrax sumatrana distribution were mean temperature in coldest quarter (28.5%), elevation (26.3%) and LULC (15.4%). It explains that Styrax sumatrana distributed across the area from high altitude, lower temperature with high precipitation. The suitable area for Styrax sumatrana is wider than the current Styrax garden existing area. Only 22,912.13 ha area was developed as the styrax garden, while there are 553,221.94 ha area is suitable for this species cultivation. Most of the suitable area is still abandon such as the open area and shrub. Furthermore, the prediction of climate change can be used to predict the distribution of Styrax sumatrana in future scenario.

4.2. Recommendation

Maxent presents the result of high potential area in Karo regency and around LTCA. The potential area for Styrax sumatrana was recorded in around LTCA and the northern part of North Sumatra Province. With a large amount of potential area compare to the current plantation, there is high opportunity for the authority to enrichment the area to be more productive by reforestation using Styrax sumatrana. Due to the advantages of this species as the non-timber product and the ecological benefit, the authority needs to consider this species as the prospective species to develop in North Sumatra. This species will also be able to support farmer's additional income sources.

Acknowledgements

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