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Land characteristics and land suitability assessment for *Styrax* sp. in Humbang Hasundutan Regency, North Sumatra, Indonesia

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A R T I C L E I N F O

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GIS
Land unit
Limiting factors
Matching method
Sustainability

A B S T R A C T

Styrax sp. is a valuable latex-producing plant in North Sumatra Province, Indonesia, which requires sustainable land use practices to maintain its production and ecological value. This study aimed to assess the land characteristics and suitability of *Styrax* sp. in Humbang Hasundutan Regency, North Sumatra Province, to support the development of sustainable land use practices for the cultivation of this plant. The study employed a survey method to collect soil samples and evaluated the land suitability using a matching method and Geographic Information System (GIS) techniques. The results showed that *Styrax* sp. had moderately suitable land suitability in three villages in Humbang Hasundutan Regency. The limiting factors for land suitability were identified as rooting media, nutrient retention, water availability, and erosion hazard. These findings have important implications for the development of sustainable land use practices for *Styrax* sp. cultivation in the region, which can contribute to the conservation of this valuable plant species and the maintenance of ecological balance. Overall, this study provides valuable insights into the land characteristics and suitability of *Styrax* sp. in North Sumatra Province and highlights the importance of sustainable land use practices for the conservation of valuable plant species.

1. Introduction

The North Sumatra Province is a significant producer of *Styrax* sp. (kemenyan), also known as frankincense, a tree species that grows naturally in various districts of the province, particularly in the west coast region. *Styrax* sp. tends to grow in clusters and is often found in association with other trees [1,2]. The people in the region rely heavily on forest resources, and the kemenyan garden, locally known as "kebun kemenyan," is one of them. Owning a kemenyan garden is considered a symbol of higher social status. There are seven districts in the province that are known for *Styrax* sp. production, including Humbang Hasundutan, Tapanuli Utara, Toba

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Samosir (currently Toba Regency), Pakpak Bharat, Tapanuli Tengah, Dairi, and Tapanuli Selatan. The social capital of *Styrax* sp. farmers in Pandumaan Village, Pollung Sub-district, Humbang Hasundutan, plays a crucial role in preserving the *Styrax* sp. Forest [3]. From 2009 to 2013, the community, along with institutions such as the Forest Management Unit (FMU) and Non-Governmental Organizations (NGOs), struggled to maintain the sustainability of the *Styrax* sp. forest.

This study focuses on the land suitability assessment for *Styrax* sp. in Humbang Hasundutan Regency, North Sumatra, Indonesia, with the aim of promoting sustainable land use and conservation practices in the region. The study takes into account the social and economic importance of *Styrax* sp. to the local communities [4–6], as well as the ecological significance of the species in the forest ecosystem [7]. By conducting a thorough assessment of the land suitability for *Styrax* sp., the study provides valuable insights into the potential for sustainable cultivation of the species, which can help to reduce pressure on natural forests and promote the conservation of biodiversity in the region. Additionally, the study highlights the importance of community involvement in conservation efforts and the need for collaboration between local communities, government agencies, and NGOs to achieve sustainable land use practices.

To increase the production of *Styrax* sp., it is important to conduct land suitability evaluations to assess the potential of the land based on its characteristics [8]. This helps maximize land use and prevent damage to the land that can occur if it is used beyond its capabilities. Evaluating land characteristics is crucial as they affect the growth of crops and other land-based commodities [7,9,10]. The purpose of land evaluation is to determine the potential or value of the land based on its designated use, and it helps to establish a relationship between land conditions and their use [8]. Another approach to optimize land use is to adopt an agroforestry system for growing crops.

The demand for *Styrax* sp. resin are still very high. *Styrax* sp. communities/farmers in North Sumatra still cultivate *Styrax* sp. because it has high economic value and is a source of income [4–6]. The sap of *Styrax* sp. is sold by the public for export purposes. There were various studies on *Styrax* sp [4–7,9–14]. Base on previous studies, until now, *Styrax* sp. is still widely cultivated in several districts in North Sumatra Province. This research is focused in Humbang Hasundutan Regency on three styrax-producing villages. The management of styrax, especially those from Humbang Hasundutan Regency, has been very slow [5,12]. Therefore, research on the characteristics and evaluation of *styrax* sp. land needs to be carried out in this area. In Humbang Hasundutan Regency, out of 10 sub-districts, there are 6 sub-districts where *Styrax* sp. can be found. Dolok Sanggul is the sub-district that has the largest area of Styrax forest [15].

The unique growing conditions of *Styrax* sp. require a comprehensive understanding of the physical, chemical, biological, and climatic characteristics of its land. However, there is a notable lack of research on the land characteristics of *Styrax* sp., particularly in Humbang Hasundutan Regency. As a result, this study aimed to fill this gap by providing data and information on the suitability of land for *Styrax* sp. plantation and development. By conducting a thorough land evaluation, this study also identify the limiting factors for land management of *Styrax* sp. The study focus on assessing the characteristics of the *Styrax* sp. plant growing land, including soil physics, chemistry, biology, climate, and rainfall, and evaluate the actual and potential land suitability of *Styrax* sp. in Humbang Hasundutan Regency. Ultimately, the findings of this study will contribute to the sustainable land use and conservation efforts in the region.

2. Materials and methods

2.1. Location of the study area

This research was conducted in three villages in Humbang Hasundutan Regency. The three villages were selected for the study based on the presence of the plant species where *Styrax* sp. was found in the Humbang Hasundutan Regency. The selection of study sites based on the presence of a particular species is a common approach in ecological and environmental research studies, especially when focusing on understanding the distribution and habitat preferences of that species. By selecting study sites where *Styrax* sp. is present, the land characteristics and suitability for the growth and survival of that particular species can be assessed. A Description of the characteristic three villages where the research was carried out in Humbang Hasundutan Regency is presented in Table 1. The map of the study area can be seen in Fig. 1.

2.2. Data collection

Data collection in this study was carried out in several stages of research, including determining the research object, studying literature related to the research, and preparing research materials and tools in administrative maps and required data. Activities at

Table 1
The characteristic of the study area in Humbang Hasundutan Regency.

Village name	Sub-district name	Coordinate point	Altitude (m above sea level/mdpl)	Land cover	soil type	slope
Aek Nauli Village	Pollung	2°09°–2°25′ North Latitude - 98°35′-98°49′ East Longitude	1000–1500	Secondary dryland forest	Alluvial	Flat (0%–8%)
Hutagurgur Village	Dolok Sanggul	2°09′-2°25′ North Latitude - 98°35′-98°49′ East Longitude	1000–1500	Secondary dryland forest	Alluvial	Slightly steep (15%–25%).
Pusuk I Village	Parlilitan	2°12′-2°28′ North Latitude - 98°10′-38°39′ East Longitude	300 - 2000	Dryland agriculture	Alluvial	Slightly steep (15%–25%).

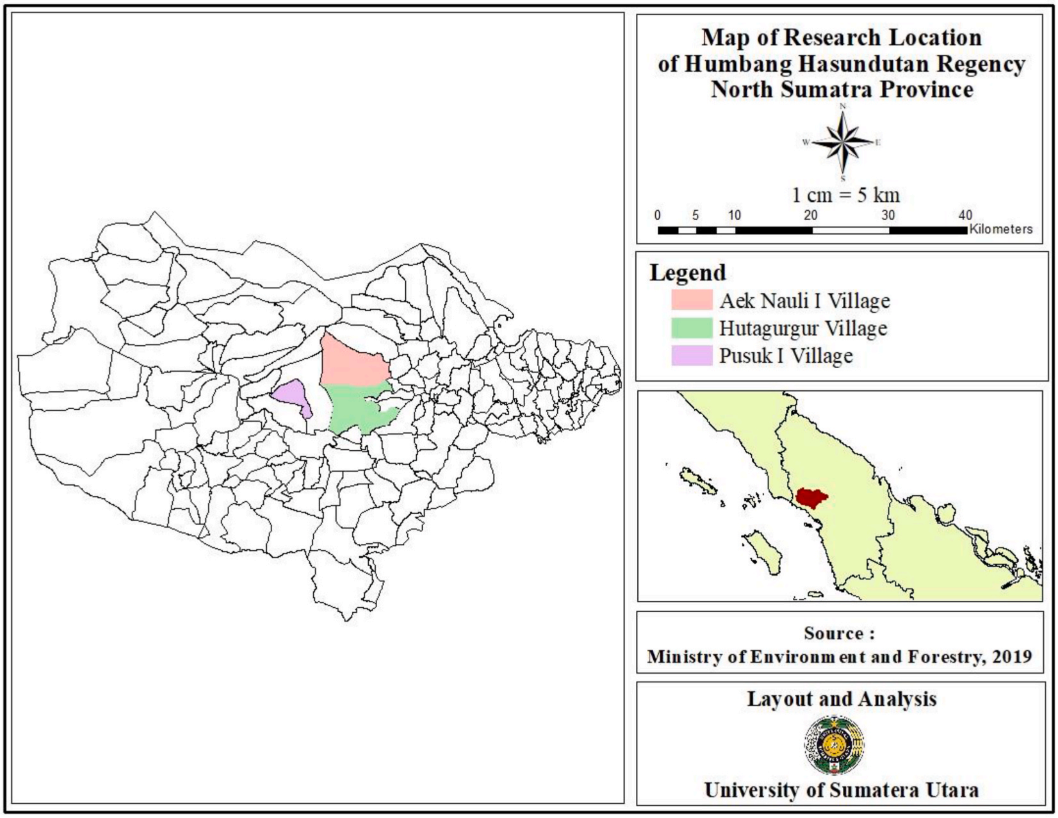

Fig. 1. Map of the study area in Humbang Hasundutan Regency, North Sumatra Province.

this stage include library research, secondary data collection in the form of temperature and rainfall data, and primary data in the form of general conditions of the research area, including data on terrestrial physical conditions obtained from the Central Statistics Agency. There are several maps used in this study, namaely: administrative map of Humbang Hasundutan Regency, elevation maps, Land cover maps, soil type maps, slope maps. All maps were obtained from the Forest Area Consolidation Agency, Ministry of Environment and Forestry. To generate land units, ArcGIS software was utilized to overlay all maps [7–10,16–18].

A land unit consists of land boundaries marked with symbols, colors, or special symbols on the map. Land units have the same system and are distinguished from each other in the field by natural boundaries that can be used as land units. The unit forming the character is often in the form of a body of land with a special identity that is distinguished by natural boundaries, where changes occur very rapidly in the lateral direction.

The overlay analysis yielded a total of 46 land units in Humbang Hasundutan Regency, as illustrated in Fig. 2. To determine the research village's location based on the land unit, the land unit map was overlayed on a map of the research location villages. The overlay results indicated that the three villages were situated within specific land units: Aek Nauli Village, Pollung Sub-district is located in Land Unit VI, Hutagurgur Village, Dolok Sanggul Sub-district is located in Land Unit XXI, and Pusuk I Village, Parlilitan Sub-district is located in Land Unit XXIX.

The *Styrax* sp. condition in research location as shown in Fig. 3. A land unit consists of land boundaries marked with symbols, colors, or special symbols on the map. Land units have the same system and are distinguished from each other in the field by natural boundaries that can be used as land units. The unit forming the character is often in the form of a body of land with a special identity that is distinguished by natural boundaries, where changes occur very rapidly in the lateral direction. Based on land units, the sampling points were taken in three villages. These three land units are used for collecting data, conducting field ground checks, observing land conditions and direct measurements, and taking soil samples for laboratory analysis [5,7]. The total number of samples taken is 30 samples. The soil samples were taken based on *Styrax* sp. production classes, namely very high, high, medium, and low production. A sampling of soil was carried out under the stand and as far as the stand canopy. After that, the soil sample was analyzed in the laboratory. Soil samples must be representative so that the analysis carried out on the soil samples can provide an overview of the soil properties in the field. Soil samples were taken using a purposive sampling technique. Sampling was done in a zig-zag way. Soil sampling was carried out by taking soil samples through four cardinal directions with two replicates, namely the top layer with a depth of 30 cm and the underground layer with a depth of 100 cm. Soil samples taken were then composited according to their respective soil layers. The overlaying administration map with the soil sampling point was carried out using a GIS as shown in Fig. 4.

Soil sampling is an essential component of any land suitability assessment, and in this study, soil samples were collected from three

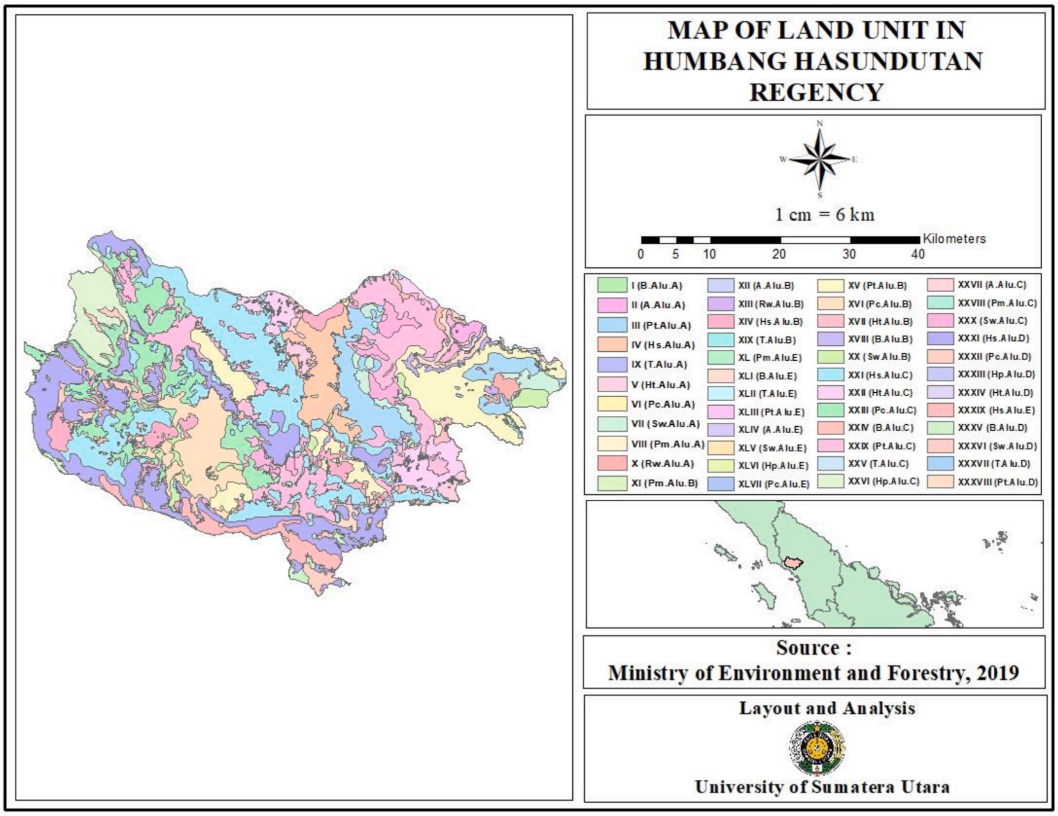

Fig. 2. Map of land unit in Humbang Hasundutan Regency.

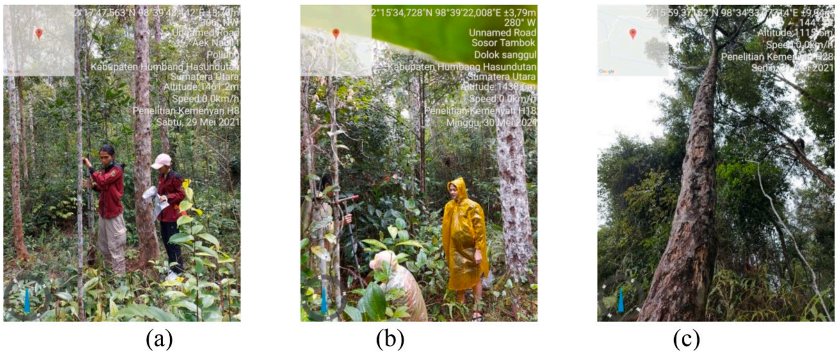

Fig. 3. The *Styrax* sp. condition in research location: a. Aek Nauli Village, Pollung Sub-district (Land Unit VI); b. Hutagurgur Village, Dolok Sanggul Sub-district (Land Unit XXI); c. Pusuk I Village, Parlilitan Sub-district (Land Unit XXIX).

land units located in three different villages in Humbang Hasundutan Regency, North Sumatra, Indonesia (Table 1). The first village, Aek Nauli, is characterized by well-maintained *Styrax* sp. fields. The area around the *Styrax* sp. is clean and free of brush, and the tree trunks are straight and tall. The flat topography of the area makes it easy to access the *Styrax* sp. fields. The production of *Styrax* sp. sap in this village is relatively high, reaching around 35 kg/ha/year.

In contrast, the *Styrax* sp. fields in Sigurgur Village are not well managed, and the area around the *Styrax* sp. is overgrown with shrubs. The owner only visits the land during the harvest season, as access to the location is quite difficult. As a result, the production of *Styrax* sp. sap in this village is relatively low, ranging from 20 to 30 kg/ha/year.

Lastly, Pusuk 1 Village has *Styrax* sp. fields located in a hilly area, which makes it more challenging to access. However, the owner takes good care of the land, resulting in a satisfactory production of *Styrax* sp. sap, which reaches around 40–45 kg/ha/year. Overall, the soil sampling was conducted in areas with varying degrees of *Styrax* sp. field management and accessibility, providing a comprehensive understanding of the land characteristics and suitability for *Styrax* sp. cultivation in Humbang Hasundutan Regency.

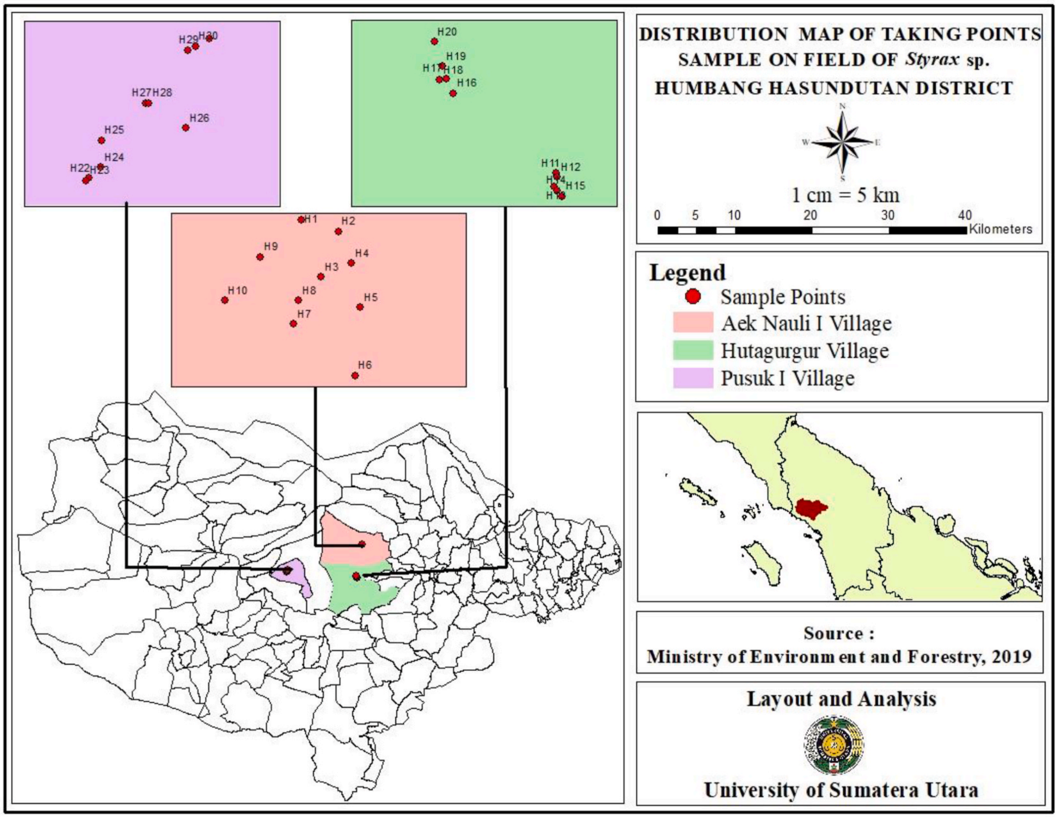

Fig. 4. Map of sampling point distribution.

For measured of temperature and humidity, a sampling of temperature and humidity was carried out at three different locations, with 10 points taken at each location. At each point, sampling will be carried out in the morning (07.00 a.m.), afternoon (1.00 p.m.), and afternoon (5.00 p.m.). After sampling each day, it will be averaged to determine the daily average temperature and relative humidity at the study site.

Determine land quality and classify land characteristics for each land unit by comparing land quality and characteristics. Activities at this stage begin with primary data collection, which includes physical parameters measured in the field, namely soil depth, erosion damage, and drainage. The soil samples taken then be analyzed in the laboratory for soil texture, acidity, C-organic, soil CEC, and bulk density.

Soil sampling in the field was divided into two: disturbed soil sampling using a soil drill and intact soil sampling using ring samples. Soil samples are collected in a representative manner so that the analysis carried out on the soil samples can provide insight into the actual soil properties in the field. The physical properties of the soil assessed were soil texture, soil depth, erosion damage, bulk density, and drainage capacity. Soil texture was defined as the ratio of the parts of the soil (sand, silt, and clay). Fractions based on the texture of the soil layer, while the chemical properties measured in this study were soil CEC, soil organic matter and soil pH, which were analyzed in the laboratory.

The land evaluation uses the matching method by comparing land quality with plant growth requirements (land requirements). Matching methods involves matching the requirements of a particular land use with the characteristics of the land, and then assigning a suitability rating based on the degree of match. The land characteristics may be assessed based on factors such as soil type, topography, and climate. The degree of match between the requirements and characteristics is then determined using a set of criteria [19]. The criteria for growing *Styrax* sp. plants refer to the results of previous studies [2,7,19], which are summarized in a table (the land suitability characteristics of *Styrax* sp. During the matching process, Leibig's law of minimums is used to identify the limiting factors that will affect the land suitability class and classification. The soil suitability results for each plant product are displayed as a table of actual and potential soil suitability using GIS software [16,17]. In addition, actual suitability and potential land suitability were mapped [18].

The land evaluation resulted in four land suitability classes based on FAO (Food and Agriculture Organization) framework, namely: highly suitable (S1), moderately suitable (S2), Marginally suitable (S3), and not suitable (N) [19]. The method used in this study for land suitability assessment because of a widely recognized and internationally accepted method for land suitability assessment and is used in many countries worldwide. The framework provides a systematic approach to land evaluation that takes into account the physical, chemical, and biological properties of the soil, as well as the environmental and socio-economic factors that influence land use.

The FAO method is designed to be flexible and adaptable to different contexts and can be customized to suit local conditions and requirements. Therefore, the survey method used in this study is based on the FAO framework but has been adapted to the specific context of the study area. Class S1 is a land that does not have significant obstacles to carry out the required management or only has insignificant boundaries and has no significant effect on land productivity. Class S2 means that the land has rather severe limitations to maintain the management level that must be applied. S3 class indicates that the land has strict boundaries to maintain the level of management that must be used. Finally, class N means this land has permanent and irreversible limiting factors [19]. Activities at this stage are in the form of land suitability analysis and classification by comparing or matching data obtained from primary, secondary and laboratory data with land use needs.

Land suitability classification involves comparing (matching) land suitability to the desired land use needs. The final ranking result is determined. Based on the worst class, it removes all existing barriers. Changing the ranking to a better level is possible if all existing obstacles can be fixed. There are eight types of inhibitors known, namely average temperature (tc), water availability (wa), oxygen availability (oa), root media (oa), nutrient retention (nr), erosion hazard (eh), flood hazard (fh) and land preparation (lp). There are no known limiting constraints in the land suitability classification, so all limiting factors in the land unit were included. It is possible to change the land class to a better level if all the obstacles in the land unit can be fixed. For this reason, land units with inhibiting factors tc, wa, and rc are difficult to repair, and limiting factors tc, wa, rc are weight-limiting factors. Mild inhibiting factors such as nutrient retention (nr), erosion hazard (eh), flood hazard (fh), and land preparation (lp). As for the elements that block the light, they can be increased so that the suitability of the soil increases by one or two levels. Land suitability classification is done by classifying land characteristic data according to land suitability criteria for each plant. The final output of the matching method is a map or a rating that identifies the suitability of the land for a particular use. This method is used in combination with overlay analysis, to provide a more comprehensive assessment of land suitability land suitability maps for *Styrax* sp. plants in the three villages.

2.3. *Data analysis*

2.3.1. *Land characteristics for* Styrax **sp.**

Climate-related data include temperature, relative humidity, rainfall, and duration of wet months and dry months. Soil biological and chemical data analyzed included the degree of soil acidity (Soil pH), soil C-Organic (%), N-Total (%), C/N ratio, Available P, Cation Exchange Capacity (CEC), base saturation, and total soil microorganisms. The data on the physical properties of the soil measured are soil texture, bulk density, soil permeability, and effective depth, which is carried out in the field by drilling to determine how deep the plant roots can still be found. Soil depth can also be measured by drilling as deep as 100 cm or until a layer of rock that plant roots cannot penetrate is found using a soil drill at the study site.

Temperature measurements are carried out three times a day to determine the average daily temperature. Relative humidity measurements were carried out three times a day. This measurement is carried out to find the daily average relative humidity. The angle of incidence of sunlight will affect moisture sampling in the morning, afternoon, and evening. Rainfall data is totaled and averaged over the last ten years at rain gauge stations. The indicators in determining the climate are wet months, humid months, and dry months. Based on the results of Oldman's research, the criteria and category indicators can be classified as follows: dry months (have rainfall less than 100 mm each month), humid months (have a rainfall of 100–200 mm each month), wet month (has rainfall of more than 200 mm each month). Soil sampling was carried out in Dolok Sanggul Village, Pollung Sub-district, Hutagurgur Village, Dolok Sanggul Sub-district, and Pusuk I Village, Parlilitan Sub-district, Humbang Hasundutan Regency, North Sumatra, Indonesia. Analysis of soil chemical properties was carried out at the Sucofindo Laboratory, Medan, North Sumatra, Indonesia. While analysis of soil physical properties was carried out at the Central Agricultural Laboratory, and soil biological analysis was carried out at the Soil Biology Laboratory of the Universitas Sumatera Utara. After that, data processing was carried out at the Forest Inventory Laboratory, Forestry Study Program, Faculty of Forestry, Universitas Sumatera Utara.

2.3.2. *Land suitability for* Styrax sp.

The matching method determined the suitability class [20]. The results of observations in the field and laboratory analysis were matched with the criteria/conditions for growing *Styrax* sp. The physical and chemical properties of the soil used in the land suitability analysis were analyzed in the laboratory. Physical and chemical properties were analyzed according to the land characteristics needed to evaluate the suitability of *Styrax* sp. Some of these criteria that can represent land quality include temperature (tc), water availability (wa), oxygen availability (oa), nutrient retention (nr), erosion hazard (eh), and flood hazard. (fh). Determination of the value of land characteristics related to nutrient retention (nr), such as texture, Cation Exchange Capacity (CEC), acidity (pH), organic C, and base saturation adjusted to the depth of the root zone of the plant to be planted and categorized into land suitability classes based on the interval values obtained [19].

3. Results and discussion

3.1. *Land characteristics of* Styrax *sp.*

3.1.1. *Microclimate characteristics of* Styrax *sp.*

The characteristics of the microclimate in kemenyan fields can be divided into four parameters, namely: temperature, humidity, rainfall and wet months and dry months. Microclimate is one of the factors that affect the environment [21]. In the air layer near the earth's surface with a height of more or less 2 m, air movement tends to be smaller because the earth's surface is rougher and the temperature difference is greater. Microclimate measured in this study include temperature, humidity and rainfall intensity. Daily temperature measurements and humadity at the study site based on land suitability class can be seen in Table 2.

Based on Table 2, the daily temperature at the study site consisted of two classes, namely: low temperature and moderate temperature. The difference in temperature at the study site is caused by the altitude and environmental conditions such as rain, and light intensity. This is in accordance with the previous research [23], which states that the air temperature on the earth's surface is affected by the intensity of light, so there are several plants that can grow that can adapt to this environment. *Styrax* sp. grow well in the highlands with low temperatures and moderate temperatures. Based on Table 2, the difference in average humidity in the three villages is caused by the altitude, and the intensity of light received by the area. High humidity is caused by low temperatures, while high temperatures will result in low humidity with insufficient water conditions for the growth of *Styrax* sp. Conversely, if the air temperature in a place is low, the humidity in that place will be even higher at a higher location, which is 330–2075 m above sea level [24].

In Tables 2 and it can be seen that the three villages in the study location have high humidity. *Styrax* sp. grows well in areas that have high humidity. This category of high humidity is very good for the growth of *Styrax* sp. because *Styrax* sp. grows well at an altitude of more than 600 m above sea level. The altitude of 600 m above sea level has a low temperature so the humidity is high. This is in accordance with the research that have conducted before which states that *Styrax* sp. grows well in areas with an altitude of more than 600 m above sea level where the temperature at this altitude tends to be low so the humidity is high [10].

High temperatures and low temperatures are influenced by several factors, such as altitude, the light intensity which is affected by canopy shade and so on. Irregular spacing also affects the temperature at the sampling point. Close spacing tends to have low temperatures because the amount of light intensity that enters the soil surface decreases because it is held back by the plant canopy. In addition, close spacing of *Styrax* sp. will also cause the *Styrax* sp. production to be not optimal because the nutrients needed by the plant must be shared a lot by other plants. The density of spacing will cause the temperature below the canopy to be lower, so that plants that tend to require light cause smaller leaf growth [13]. Whereas for plants excess light intensity will cause disruption to plant growth and even experience death. The condition of the dense canopy at the research location causes the intensity of incoming light to be less so that the temperature under the canopy will be lower. The spacing at the research location tends to be dense so the temperature at the research location is low [24].

A dense canopy and one with gaps will affect the microclimate at that location due to a reduction in the intensity of light entering the plant canopy. Humbang Hasundutan Regency has moderate temperatures which are supported by its altitude which is 330-2075 m above sea level. The altitude of a place will affect the air temperature in that place. The altitude of a place is inversely proportional to the air temperature. The higher a place, the temperature at that location will be lower and the lower a place, the air temperature in that place will be higher. The altitude of the research location which is at an altitude of 330-2075 m above sea level causes this location to have low to moderate temperatures. This is in accordance with the previous research [2,24], which states that the altitude of a place affects the climate and temperature in the area, where the higher the place, the lower the temperature in that area and vice versa. The altitude of a place affects its growth. The altitude where the growth of *Styrax* sp. is good is at more than 600 m above sea level (masl). The altitude of the research site which is at 330–2075 masl is in accordance with the criteria for good *Styrax* sp. growth. The altitude where the research tends to have a low temperature so that the humidity is high [2]. The factors that influence the growth of *Styrax* sp. are altitude, slope, soil type, and rainfall [2,7]. *Styrax* sp. can grow at an altitude range of more than 900 m above sea level. Altitude (elevation) is the most influential factor. Besides temperature and humidity as mention above, rainfall also very important for *Styrax* sp. growth. The rainfall data at the research location can be seen in Table 3.

Based on Table 3 it can be seen that the rainfall in the last 10 years in Aek Nauli Village, Pollung Sub-district and Hutagurgur Village, Dolok Sanggul Sub-district, Humbang Hasundutan Regency was dominated by moderate rainfall. In Pusuk I Village, Parlilitan Sub-district, Humbang Hasundutan Regency, rainfall is dominated by high category. This high and moderate rainfall makes *Styrax* sp. very suitable for planting in this area because high and moderate rainfall will cause lower temperatures and higher humidity. The altitude affects the growth of *Styrax* sp [2]. The altitude of the research site is at 330–2075 masl and tends to have low temperatures so that the humidity tends to be higher so it is very suitable for planting *Styrax* sp. It grows well in areas with high rainfall and high humidity because they will support the growth of *Styrax* sp. plants which require more water. The high rainfall tends to be better for the growth of *Styrax* sp. because it fulfils the need for water for its growth. The research location which is located in the highlands causes rainfall and humidity in that area to be higher. The higher the place, the lower the temperature and the higher the humidity. For every 100 m above sea level increase in altitude, the temperature will drop by 0.6 °C which is known as the normal temperature decrease rate because it is the average value at all latitudes and times [2]. Wet and dry month data at the research location can be seen in Figs. 5–7.

Table 2
Temperature measurements and humadity at research location.

Land unit	Research location	Temperature		Humidity	
		(°C)	Criteria	(%)	Criteria
VI	Aek Nauli Village (Pollung Sub-district)	22.16	moderate	81.85	high
XXI	Hutagurgur Village (Dolok Sanggul Sub-district)	22.25	moderate	85.00	high
XXIX	Pusuk I Village (Parlilitan Sub-district)	20.24	low	94.66	high

Source: primary data and criteria refer to reference number [22].

Table 3
Rainfall data at the research locations for 2011–2020.

Year	Aek Nauli Village (Pollung Sub-district)		Hutagurgur Village (Dolok Sanggul Sub-district)		Pusuk I Village (Parlilitan Sub-district)	
	Rainfall (mm)	Criteria	Rainfall (mm)	Criteria	Rainfall (mm)	Criteria
2011	2686	moderate	1827	low	3140	High
2012	2459	moderate	1927	low	3745	High
2013	2328	moderate	2358	moderate	3770	High
2014	2424	moderate	2764	moderate	2221	Moderate
2015	2602	moderate	2992	moderate	3582	High
2016	1944	low	1811	low	3139	High
2017	2075	moderate	2192	moderate	4705	High
2018	2388	moderate	2189	moderate	4606	High
2019	2706	moderate	2393	moderate	3514	High
2020	2347	moderate	2164	moderate	4395	High

Source: primary data and criteria refer to reference number [25].

In Land Unit XXI, Dolok Sanggul Sub-district is in the C climate category and has rather wet criteria with jungle and autumn during the dry season. In Land Unit VI, Pollung Sub-district is categorized in a moderate climate which is in climate D. in Land Unit XXIX, Parlilitan Sub-district has a B climate with a wet climate category. The difference between wet months and dry months at the research location is caused by the different altitudes.

The duration of the wet and dry months in Humbang Hasundutan Regency is influenced by the altitude. The altitude of the research location causes monthly rainfall to tend to be high, namely, the research location is in the B climate category with rainfall >200 mm. The height of a place affects the length of the wet and dry months in that place. The higher the place, the higher the rainfall so the wet month will increase [26].

3.1.2. Characteristics of soil properties

The result of soil properties characteristics of *Styrax* sp. in research location, namaely: soil texture, bulk density, porosity, permeability, soil pH (Potential of Hydrogen), C-Organic, Cation Exchange Capacity (CEC) and base saturation. can be seen in Table 4.

In Table 4 it can be seen that. the soil content in all land units at the study site is sandy loam which has the following characteristics: somewhat rough in shape, forming a hard ball, easily crushed and attached. Soils that have sandy loam properties usually contain more sand. In sandy loam soils, the soil structure will allow water to pass through easily so that water will be easily absorbed by plant roots and meet the water needs of plants. Well-textured soil will support plant growth [28]. With the easy flow of water, air and heat on the ground, it will fulfill the good growth of *Styrax* sp. which require a lot of water availability for their growth [28]. With lots of water available, it will support low temperatures and high humidity so that it is good for the growth of *Styrax* sp.

For the results of bulk density, porosity, and permeability measurements based on land suitability class can be seen in Table 5.

Based on Table 5 it can be seen that the amount of bulk density that is in this range has a high organic matter [29,30]. An ideal organic soil has a bulk density in the range of 0.1–0.9 gr/cm^3. Ideal organic soil will generally contain enough organic matter for plant growth. The lower the density of the soil, the mass of the soil will be lower and the ability to drain water will be higher (faster). Bulk density indicates the density of a soil. The higher the density of a soil, the higher the weight of the soil and the longer it will drain water. Conversely, the lower the density of a soil, the higher (faster) the flow of water and the lower its mass.

Bulk Density that is not good will cause plant growth to be disrupted. Dense soil causes the growth of plant roots to be disrupted and it is difficult to penetrate the soil so that water absorption for plant needs will be reduced and productivity will be disrupted (decreased). Soil that is dense or does not have space in the soil volume will make it difficult for plants to get nutrients from the soil because plant roots do not develop. Therefore, it is necessary to improve the physical properties of the soil such as adding organic matter to the soil so that the soil has good physical properties so that plant roots can have good function. The growth of *Styrax* sp. also

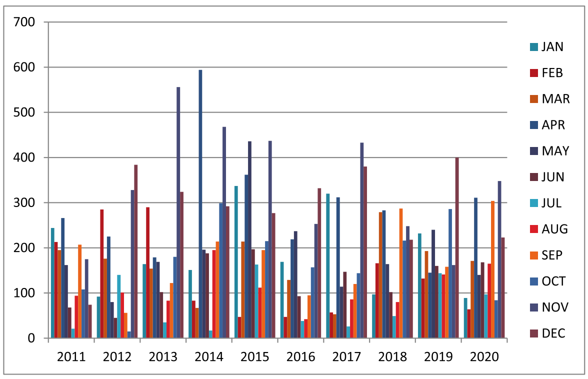

Fig. 5. Wet month and dry month data in Aek Nauli Village, Pollung Sub-district, 2011–2020.

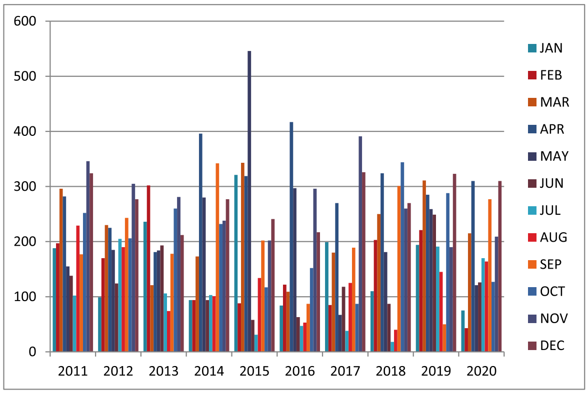

Fig. 6. Wet month and dry month data in Hutagurgur Village, Dolok Sanggul Sub-district 2010–2020.

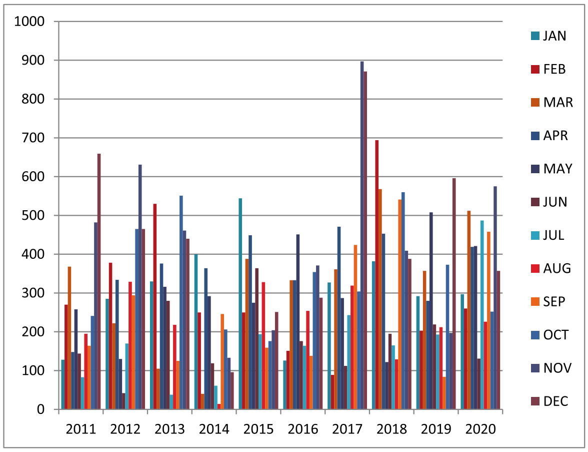

Fig. 7. Dry month and wet data in Pusuk I Village, Parlilitan Sub-district in 2011–2020.

Table 4
Measuring results of average soil texture at the research location in Humbang Hasundutan Regency.

Land unit	Research location	Fraction (%)			Fraction
		Clay	Dust	Sand	
VI	Aek Nauli Village (Pollung Sub-district)	15.16	17.91	63.67	sandy loam
XXI	Hutagurgur Village (Dolok Sanggul Sub-district)	16.95	25.90	56.20	sandy loam
XXIX	Pusuk I Village (Parlilitan Sub-district)	17.11	34.14	55.32	sandy loam

Source: primary data and criteria refer to reference number [27].

Table 5
Average bulk density measurements at the research location.

Land unit	Location	Bulk density (gr/cm^3)	Porosity (%)	Permeability (cm/hour)
VI	Aek Nauli Village (Pollung Sub-district)	0.64	75.06	4.52
XXI	Hutagurgur Village (Dolok Sanggul Sub-district)	0.40	85.63	2.08
XXIX	Pusuk I Village (Parlilitan Sub-district)	0.42	83.97	3.55

Source: primary data and criteria refer to reference number [27].

requires soil conditions that have good bulk density and have pore space to drain nutrients, especially water for growth, so that the production of *Styrax* sp. plants can increase. The increased production of *Styrax* sp. will boost the economy of local communities who cultivate *Styrax* sp.

Based on Tables 5 and it can be seen that the average value of the porosity measurements is in the high and very high criteria. In

Land Unit VI it is known that the Porosity value is 75.06%, in Land Unit XXI it is known that the porosity value is 85.63% and in Land Unit XXIX it is known that the porosity value is 83,97%. Porosity values at the three locations are above 50% which indicates optimal conditions, namely in good conditions. Porosity that is good for the soil is soil that has large pores so that the flow of water and nutrients flows more easily. Axial soil has a high nutrient content so it is good for plant growth. The greater the porosity value of a soil, the better plant growth. The larger the available soil pores, the more water availability for plants and the better the growth of plant roots [31], so that it will increase plant growth and productivity by absorbing nutrients and water from in the soil for the growth of *Styrax* sp. The factor that influences plant growth is the size of the soil porosity [32]. Where the larger the soil porosity, the better the growth of plant roots and the smaller the porosity, the growth of plant roots will be disrupted and cause plant growth to run abnormally.

The value of soil porosity is influenced by soil texture. Soil texture that has properties that easily drain water has a good influence on plant growth, where the water needs needed by plants will be fulfilled. Porosity is the pore space in the soil that can affect soil fertility. Porosity is an indicator of soil fertility. Poor soil porosity is caused by low organic matter content, poor soil structure and texture [33].

The results of the porosity measurements in this research on *Styrax* sp. fields are classified as very porous. The condition of the soil which has very porous criteria has a high organic matter content. The higher the porous value of the soil, the better the soil condition or it can be said to have a high organic matter content that can meet the needs of plant growth. Furthermore, the addition of organic matter in fertilization will increase the total pore size of the soil and reduce the unit weight of the soil [33]. The lower the volume weight of the soil, the higher the total pore value of the soil and the higher the organic matter content so that the flow of water for plant needs will be fulfilled.

The results of soil permeability measurements show that soil permeability has moderate criteria in all land units. In general, soil permeability is affected by the pore value of the soil. A large soil pore value will allow water to pass through and not store water so that the permeability value of the soil will be higher. The pore relationship to permeability is very clear where permeability may have a zero value if the pore value of the soil is getting smaller [34]. Permeability is influenced by the magnitude of the pore value of the soil where the greater the pore value of the soil, the higher the permeability of the soil. The lower the pore value of soil, the lower the permeability value. Soil permeability is influenced by several soil physical factors such as soil texture, soil pore space, and soil unit weight. The greater the volume weight of the soil, the smaller the soil pore space and the smaller the permeability. In addition, soil permeability is also affected by soil density. The denser the soil content, the lower the pore value, the lower the unit weight, and the lower the permeability (water flow rate). Furthermore, the factors that affect the size and the value of soil permeability are soil texture, soil structure, aggregate stability, soil pore size, porosity and soil organic matter content [34]. For results of soil pH, C-Organik, CEC, and base saturation analysis results at the study sites are presented in Table 6.

Based on the results of Tables 6 and it can be seen that the soil pH at the study site is included in the acid criteria in all land units. Soil acidity occurs due to the very fast weathering of minerals and rocks and leaching [35]. The intensive weathering process can release nutrients which can eventually be washed away leaving only the end product of weathering and which generally doesn't contribute enough nutrients to plants. But if you look at the *Styrax* sp. fields in Humbang Hasundutan Regency, the community does not cultivate the *Styrax* sp. fields intensively, they just let the *Styrax* sp. fields grow with grass and only clear the roads to collect the sap. The sampling location is a hill area with quite high rainfall. This also causes acidity in the soil in the area. Meanwhile, according to the book Atlas of Seeds of Indonesian Forest Plants, it is said that *Styrax* sp. grows well at pH 4–7. This shows that the pH of the soil in Humbang Hasundutan Regency is in accordance with the pH of *Styrax* sp. growth.

Based on the results of Table 5, the highest C-Organic value is 10.7 in land unit XXI and the lowest C-Organic is 7.71 in Land Unit VI. The cause of high C-Organic in kemenyan fields is caused by plant or animal residues contained in the soil. So without the provision of nutrients, C-Organic in *Styrax* sp. fields is very high. The highest Cation Exchange Capacity (CEC) value is 37.57 in Land Unit VI and the lowest CEC is 28.49 in Land Unit XXI (Table 5). Cation exchange capacity has an important role in terms of the adsorption of cations which can then be exchanged in the soil solution.

In Table 6 show that the highest Base Saturation value is 1.80 in Land Unit XXI and the lowest Base Saturation is 1.05 in Land Unit VI. If base saturation is low, base cations will decrease and be replaced by $H+$ ions which can cause soil pH to decrease [36], where the base saturation value has a close relationship with pH so it affects the level of soil fertility. The acidity will decrease and fertility will increase with increasing base saturation.

Base on Tables 4–6, The soil texture is sandy loam in Aek Nauli Village (Pollung Sub-district), Hutagurgur Village (Dolok Sanggul Sub-district), and Pusuk I Village (Parlilitan Sub-district). The lowest bulk density is found in Hutagurgur Village (Dolok Sanggul Sub-district) and the highest is in Aek Nauli Village (Pollung Sub-district). In Aek Nauli Village (Pollung Sub-district) it is known that the Porosity value is high, in Hutagurgur Village (Dolok Sanggul Sub-district) it is known that the porosity value is very high and in Pusuk I Village (Parlilitan Sub-district) it is known that the porosity value is very high. Soil permeability has moderate criteria in research

Table 6
Results of soil pH, C-Organik, CEC, and base saturation analysis at the study site.

Land unit	Location	Soil pH	C-Organik	CEC	Base saturation
VI	Aek Nauli Village (Pollung Sub-district)	4.54	7.71	37.57	1.05
XXI	Hutagurgur Village (Dolok Sanggul Sub-district)	4.53	10.07	28.49	1.80
XXIX	Pusuk I Village (Parlilitan Sub-district)	4.67	9.35	31.67	1.47

Source: primary data and criteria refer to reference number [27].

location. The soil pH at the study site is included in the acid criteria in all research location. The C-Organic is high in research location. The CEC is high in research location. Base saturation is very low in research location.

3.2. *Assessment of actual and potential land suitability for* Styrax *sp.*

Based on the results of measuring the land characteristics of *Styrax* sp. at the research location, an evaluation of the actual and potential land at the research location was carried out, to find out the limiting factors that become obstacles if want to cultivate *Styrax* sp. at this location. Actual land suitability refers to the current suitability of the land for a particular use or cover, based on its current conditions and management practices. This assessment considers the current land use, soil properties, and other factors that affect the land's ability to support a specific use or cover. Potential land suitability, on the other hand, refers to the future suitability of the land for a specific use or cover, based on its inherent physical and biological properties. This assessment considers the natural potential of the land to support a particular use or cover, as well as the potential impacts of land management practices on the land's suitability. Both actual and potential land suitability assessments are critical for effective land use planning and management. Actual land suitability assessment provides information on the current state of the land, while potential land suitability assessment provides insight into the land's future potential for specific uses or covers. By considering both actual and potential land suitability, land managers can make informed decisions about land use and management practices that will promote sustainable land use and conservation efforts. The parameters used for land suitability assessment for *Styrax* sp. and the results of land evaluation using the matching method at the three study locations are presented Tables 7–9.

The results of the actual land evaluation for *Styrax* sp. in Aek Nauli Village (Table 6) show that the average temperature (°C), rainfall (mm), availability of oxygen (oa), drainage, soil texture, soil depth (cm), CEC soil (cmol), base saturation (%), C-organic (%), slope (%) and erosion hazard are highly suitable (S1). only the soil pH and soil texture (rc) factors showed moderately suitable (S2). Soil pH is a limiting factor that can be overcome while soil texture is an inhibiting factor that is difficult to overcome. This is in accordance with some of the results of research conducted in North Sumatra Province where rc is an inhibiting factor [7–10], so the potential land suitability for *Styrax* sp. in Aek Nauli Village is moderately suitable with the limiting factor rooting media (rc).

The results of the actual land evaluation for *Styrax* sp. in Hutagurgur Village (Table 7) show that average temperature (°C), rainfall (mm), availability of oxygen (oa), drainage, soil texture, soil depth (cm), CEC soil (cmol), base saturation (%), C-organic (%), and erosion hazard are highly suitable (S1). Soil texture, soil pH and slope are moderately suitable (S2). Soil pH and slope (%) are limiting factors that can be overcome while soil texture is an inhibiting factor that is difficult to overcome. The results of this study were supported by several previous studies that have been conducted in North Sumatra Province [7–10], so that the potential land suitability for *Styrax* sp. in Hutagurgur Village is moderately suitable with the limiting factor being rooting media (rc).

The actual land evaluation results for *Styrax* sp. in Pusuk I Village (Table 9) shows that Average temperature (°C), Rainfall (mm), Availability of oxygen (oa), Drainage, Soil depth (cm), CEC soil (cmol), Base saturation (%), C -organic (%), and Erosion hazard are very suitable (s1). Availability of water (wa), soil ph, soil texture (rc) and slope (%) which shows moderately suitable (S2). Soil pH and Slope (%) are limiting factors that can be overcome while Availability of water (wa), and soil texture are inhibiting factors that are difficult to overcome, this is in accordance with several research results conducted in North Sumatra Province [9,10] where wa and rc are inhibiting factors. so that the potential land suitability for kemenyan in Pusuk I Village is moderately suitable with the wa and rc limiting factors. The actual and potential land suitability of *Styrax* sp. in research location is presented in Table 10.

In fact, *Styrax* sp. on Land Unit VI is moderately suitable (S2) with limiting factors being rooting media (rc) and nutrient retention (nr). On Land Unit XXI is moderately suitable (S2) with limiting factors are rooting media (rc), retention nutrient (nr) and erosion hazard (eh). On Land Unit XXIX is moderately suitable (S2) with a limiting factor limiting factors are water availability (wa), rooting

Table 7
Criteria for land evaluation in Aek Nauli Village (Pollung Sub-district).

Terms of use/land characteristics	Observation data	Actual land suitability class	Limiting factor	Potential land suitability class
Temperature (tc)				
Average temperature (°C)	22.16	S1	tc	S1
Availability of water (wa)				
Rainfall (mm)	2395.9	S1	wa	S1
Availability of oxygen (oa)				
Drainage	Well	S1	oa	S1
Rooting media (rc)				
Soil texture	Sandy loam	S2	rc	S2
Soil depth (cm)	>100	S1	rc	S1
Nutrient retention (nr)				
CEC soil (cmol)	37.57	S1	nr	S1
Base saturation (%)	1.05	S1	nr	S1
soil ph	4.54	S2	nr	S1
C-organic (%)	7.71	S1	nr	S1
Erosion hazard (eh)				
Slope (%)	0–8%	S1	eh	S1
Erosion hazard	Low	S1	eh	S1
Land suitability		**S2.rc,nr**		**S2.rc**

Source: primary data and criteria refer to reference number [3,5,19].

Table 8
Criteria for land evaluation in Hutagurgur Village (Dolok Sanggul Sub-district).

Terms of use/land characteristics	Observation data	Actual land suitability class	Limiting factor	Potential land suitability class
Temperature (tc)				
Average temperature (°C)	22.25	S1	tc	S1
Availability of water (wa)				
Rainfall (mm)	2261.7	S1	wa	S1
Availability of oxygen (oa)				
Drainage	Well	S1	oa	S1
Rooting media (rc)				
Soil texture	Sandy loam	S2	rc	S2
Soil depth (cm)	>100	S1	rc	S1
Nutrient retention (nr)				
CEC soil (cmol)	28.49	S1	nr	S1
Base saturation (%)	1.80	S1	nr	S1
soil ph	4.53	S2	nr	S2
C-organic (%)	10.07	S1	nr	S1
Erosion hazard (eh)				
Slope (%)	15–25%	S2	eh	S1
Erosion hazard	Low	S1	eh	S1
Land suitability		**S2.rc,nr,eh**		**S2.rc**

Source: primary data and criteria refer to reference number [2,7,19].

Table 9
Criteria for land evaluation in Pusuk I Village (Parlilitan Sub-district).

Terms of use/land characteristics	Observation data	Actual land suitability class	Limiting factor	Potential land suitability class
Temperature (tc)				
Average temperature (°C)	20.24	S1	tc	S1
Availability of water (wa)				
Rainfall (mm)	3681.7	S2	wa	S2
Availability of oxygen (oa)				
Drainage	Well	S1	oa	S1
Rooting media (rc)				
Soil texture	Sandy loam	S2	rc	S2
Soil depth (cm)	>100	S1	rc	S1
Nutrient retention (nr)				
CEC soil (cmol)	31.67	S1	nr	S1
Base saturation (%)	1.47	S1	nr	S1
soil ph	4.67	S2	nr	S1
C-organic (%)	9.35	S1	nr	S1
Erosion hazard (eh)				
Slope (%)	15–25%	S2	eh	S1
Erosion hazard	Low	S1	eh	S1
Land suitability		**S2.wa, rc,nr,eh**		**S2.wa,rc**

Source: primary data and criteria refer to reference number [2,7,19].

media (rc), nutrient retention (nr) and erosion hazard (eh). The limiting factor is classified as heavy due to the availability of water (wa), and root media (rc) cannot be repaired due to natural factors themselves. Meanwhile, nutrient retention (nr) can be improved by limiting the soil, applying organic and inorganic fertilizers and adding ash from combustion to increase soil pH and fertility, and erosion hazard (eh) can be improved by planting parallel to the contours and making terraces. Hence, after the improvement efforts were made, the potential land suitability class on Land Unit VI and Land Unit XXI is moderately suitable (S2) with limiting factors are rooting media (rc) and On Land Unit XXIX is moderately suitable (S2) with a limiting factor are water availability (wa) and rooting media (rc). The mapping of land suitability classes for *Styrax* sp. is shown in Figs. 8 and 9.

Based on the results of the evaluation of *Styrax* sp. land suitability classes in three villages in Humbang Hasundutan Regency, this *Styrax* sp. is worth maintaining for development, especially in this area. If it is to be developed in other areas, then the characteristics of the land found at this research location must be considered, because it will affect the success of growth and productivity of *Styrax* sp. Planting of *Styrax* sp. activities by farmers are carried out by cultivating in monoculture and are usually passed down from generation to generation [37]. The planting of *Styrax* sp. by the community is limited to embroidering which is done to replace unproductive plants or cover vacant land. Only the saplings scattered on the forest floor are used as seeds in embroidery activities by farmers. The planting distance used by the community is between 3 m × 3 m and 5 m × 5 m so the planting density is around 400–700 trees/ha. In terms of maintenance of *Styrax* sp. gardens by farmers it is done traditionally where the farmers only weed the plants around the plants. The condition of *Styrax* sp. in the research location can be seen in Fig. 10.

For the development and marketing of *Styrax* sp. in Pollung Village, several things need to be considered, such as the need to form business groups and cooperatives at the village level to avoid price speculation by collecting agents [37], Styrax forests/gardens

Table 10
Actual and potential land suitability of *Styrax* sp. in Humbang Hasundutan Regency.

Land unit	Location	Actual land suitability	Potential land suitability
VI	Aek Nauli Village (Pollung Sub-district)	**S2.rc,nr**	**S2.rc**
XXI	Hutagurgur Village (Dolok Sanggul Sub-district)	**S2.rc,nr,eh**	**S2.rc**
XXIX	Pusuk I Village (Parlilitan Sub-district)	**S2.wa, rc,nr,eh**	**S2.wa,rc**

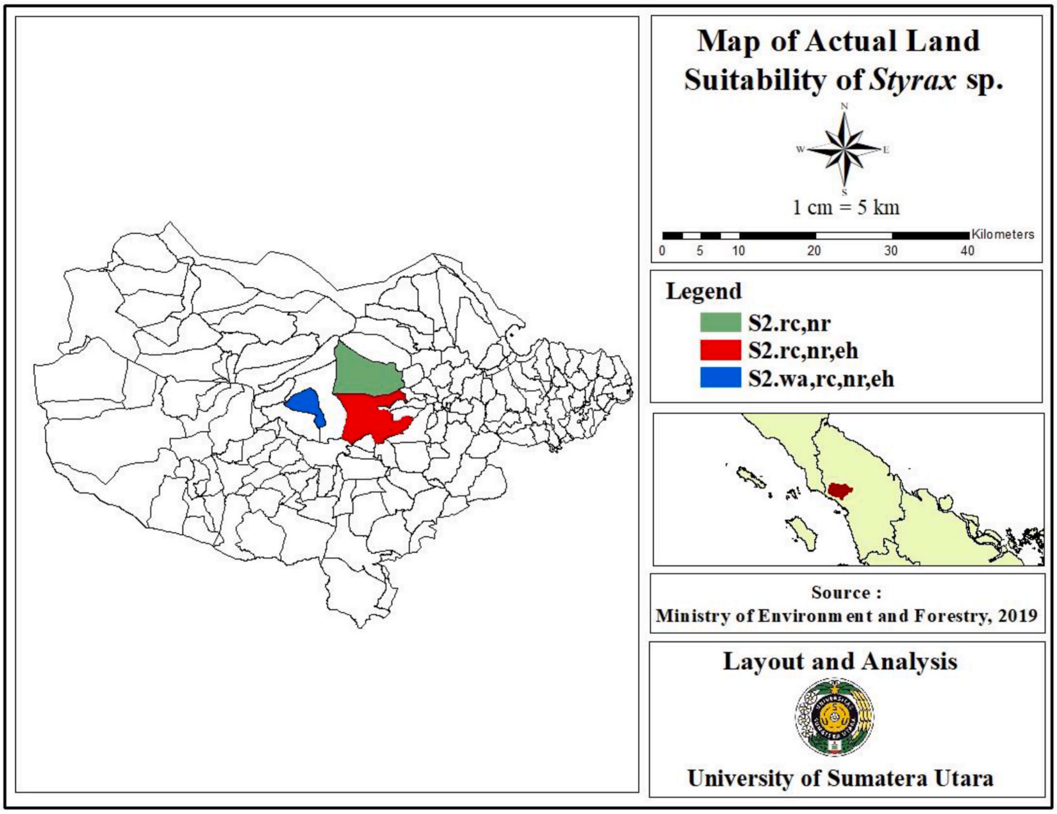

Fig. 8. Map of actual land suitability of *Styrax* sp. in Humbang Hasundutan Regency.

managed through an agroforestry system [7] to increase *Styrax* sp. production and combining with shade tolerant plants such as coffee, research and technical guidance is needed for Styrax farmers, use of superior *Styrax* sp. seeds to increase sap productivity and also accelerate harvest (production), expansion of *Styrax* sp. forests/gardens as part of recovery efforts land, and improvement of environmental quality and carrying capacity. The role of the government, private sector, academics and NGOs is expected to help promote *Styrax* sp. products.

Styrax sp. sap produced from trees of the Styracaceae family is classified as non-timber forest products (NTFPs) [12]. The demand for *Styrax* sp. resin are still very high. *Styrax* sp. communities/farmers in North Sumatra still cultivate *Styrax* sp. because it has high economic value and is a source of income. The sap of *Styrax* sp. is sold by the public for export purposes. *Styrax* garden in North Sumatra Province were plants that lived naturally in the forest. Then, after knowing the economic benefits, planting started to increase the number of kemenyan trees in the forest. Kemenyan forests have economic and ecological functions. Aside from being a source of community income, the kemenyan forest also functions as a water system regulator and maintains soil fertility. Kemenyan sap has economic value as a non-timber forest product and is used in cosmetics, preservatives, religious events, perfumery, and the tobacco industry. Kemenyan forests are a simple livelihood passed down from generation to generation [38].

Future distribution and management of the *styrax* sp. were mainly based on LULC changes and future climate conditions. Climate change has a great impact on *Styrax* sp. distribution with increasing temperature. Tree species cannot survive in areas with high temperatures outside of the shrub, forests, and gardens [39]. *Styrax* sp. requires the mean temperature of the coldest quarter between 13 and 19 °C to survive. Additionally, biophysical factors such as altitude, slope, aspect, and soil type are important data sets for predicting the suitability site for *styrax* sp.

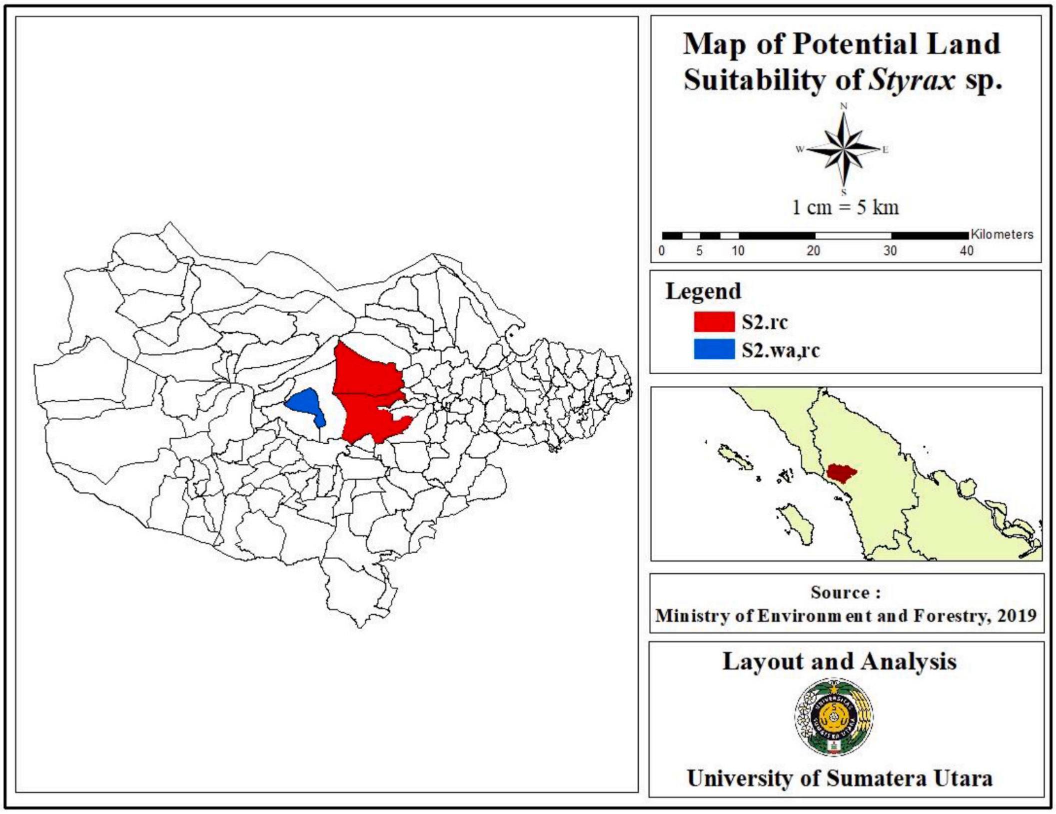

Fig. 9. Map of potential land suitability of *Styrax* sp. in Humbang Hasundutan Regency.

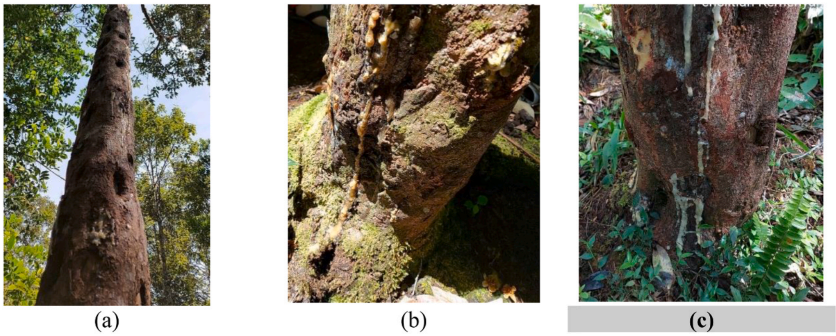

Fig. 10. The tree trunk of *Styrax* sp. in research location: a. Hutagurgur Village (Dolok Sanggul Sub-district); b. Pusuk I Village (Parlilitan Sub-district); c. Aek Nauli Village (Pollung Sub-district).

4. Conclusion

Based on the findings of this study, it can be concluded that the land characteristics of the research location, which consists of Aek Nauli Village, Hutagurgur Village, and Pusuk I Village, have moderate to low temperatures, high humidity, and varying levels of rainfall. The soil texture is sandy loam, with high levels of organic matter and cation exchange capacity. However, the base saturation is very low in all land units in the research location. aIn terms of land suitability for *Styrax* sp., the study found that Land Unit VI, Land Unit XXI, and Land Unit XXIX are moderately suitable (S2). The limiting factors for Land Unit VI are rooting media and nutrient retention, for Land Unit XXI are rooting media, nutrient retention, and erosion hazard, and for Land Unit XXIX are water availability, rooting media, nutrient retention, and erosion hazard. However, after implementing the improvement efforts, the potential land suitability class for Land Unit VI and Land Unit XXI remains moderately suitable (S2) with the limiting factors being rooting media, and for Land Unit XXIX, it is moderately suitable (S2) with the limiting factor being water availability and rooting media. Overall, this study provides valuable information on the land characteristics and suitability for *Styrax* sp. in the Humbang Hasundutan Regency, North Sumatra, Indonesia. The findings can be used to guide sustainable land use and conservation efforts in the region, with a focus on addressing the identified limiting factors to improve the potential land suitability for *Styrax* sp.

Author contributions

Rahmawaty; designing the study, methodology, data analysis, writing original draft, supervision, funding acquisition, project administration: Mohd Hasmadi Ismail; correction of data analysis, supervision: Abdul Rauf; supervision, conceptualization, methodology, data analysis: Ridwanti Batubara; designing the study, methodology, data analysis, supervision, funding acquisition, project administration: El Winni Elena Sitorus, Zetro Simamora, and Ema Franisa Ginting; data collection, data analysis, project administration.

Data availability statement

Data will be made available on request.

Declaration of competing 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

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