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Vegetation Identification and Mangrove Distribution Mapping in North Sumatra Under Different Environmental Conditions

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Abstract

The diversity of mangrove vegetation in North Sumatra is quite high, and each mangrove species has unique ecological adaptations and a tendency to grow in specific habitats. The results of this study aim to identify the types of mangrove vegetation and their habitat characteristics in the coastal areas of North Sumatra. The approach used was descriptive qualitative research with data collection through a literature review of various journals and books whose research was located in North Sumatra Province. The data obtained was statistically processed and mapped using Artificial Intelligence, Excel, and a database from the Global Mangrove Watch website as supporting data to analyze the distribution and spread of mangroves in the region. Furthermore, the identification of mangrove habitats or zoning was carried out, which is influenced by environmental factors such as substrate, temperature, salinity, pH, and dissolved oxygen. The results of the study showed that there are 58 mangrove species in North Sumatra, and Langkat Regency has the highest number of mangrove species compared to other regencies in North Sumatra Province, namely 38 species with Very Good substrate suitability (fine muddy clay), as well as water quality suitable for mangrove plants, namely temperature (29.330C), salinity (25.50 ppt), and pH (7.13).

Keywords: Mangrove Habitatl Environment; Mapping of Mangrove Vegetation; North Sumatra.

1. Introduction

As the world's largest archipelago, Indonesia has a very rich coastal ecosystem, including mangrove forests that are widely distributed along its coastline. With a total mangrove area of more than 3 million hectares, Indonesia has the world's largest mangrove ecosystem. [1], [2].

North Sumatra Province has many mangroves found in coastal areas such as Langkat, Deli Serdang, Central Tapanuli, and Serdang Bedagai Regencies. Unfortunately, the existence of mangrove forests in this region has declined significantly due to land conversion into fish ponds, oil palm plantations, and other coastal developments. In 1990, the area of mangroves in North Sumatra was recorded at around 34,742.12 hectares, but this declined dramatically to 16,765.96 hectares in 2015 [3]. Currently, the remaining mangrove area is estimated at around 49,000 hectares, divided into dense, moderate, and sparse mangroves. [4].

The diversity of mangrove vegetation in North Sumatra is quite high. Several studies have recorded the existence of various species, such as in Tanjung Rejo Village, Percut Sei Tuan District, which has 14 types of mangroves [5], The Karang Gading and Northeast Langkat Wildlife Reserve, which has 32 species [6] as well as in the Central Tapanuli KKPD with 18 species [7]. However, to date there is no complete and comprehensive database on the types of mangroves and their habitat zoning throughout the coastal areas of North Sumatra.

Each mangrove species has unique ecological adaptations and a tendency to grow in specific habitats. For example, *Rhizophora sp*. is more dominant in muddy and sheltered substrates, while Sonneratia alba is often found in the front zone facing the sea

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directly [8]. Therefore, mapping mangrove types and their habitats is crucial as a basis for planning rehabilitation, conservation, and sustainable coastal ecosystem management. [9], [10].

This study aims to identify the types of mangrove vegetation and their habitat characteristics in the coastal areas of North Sumatra Province. The results of this study are expected to serve as baseline data for the development of conservation programs, coastal disaster mitigation, and environmentally-friendly spatial planning.

2. Materials and Methods

2.1. Tools and Materials

The tools used include laptops and smartphones as the main devices for data collection and processing. Supporting software includes the *MonMang* application for inventorying and monitoring mangrove species, ArcGIS for mapping the distribution of mangrove species, *Publish or Perish* for systematic literature retrieval and bibliometric analysis, *Artificial Intelligence* (AI) based tools to support data analysis and manuscript preparation, *Microsoft Excel* for data organization and quantitative processing, and *Mendeley* for reference management. Additional tools are used as needed to ensure accuracy and support the research process.

The materials used consisted of peer-reviewed scientific journals, books on mangroves, and mangrove distribution datasets obtained from the *Global Mangrove Watch* database (https://www.globalmangrovewatch.org/). Other supporting materials were included as needed to improve data completeness and strengthen the study's analytical framework.

2.2. Research Methods

This research method uses a descriptive qualitative approach, in which data collection is carried out through observation of several journals. The research was conducted in several districts in North Sumatra Province, namely Langkat, Deli Serdang, Serdang Bedagai, Asahan, and Tapanuli Tengah.

2.3. Data Analysis

The observational data will be statistically processed to identify trends in the number of species and habitats most suitable for mangroves based on ecological conditions. Subsequently, the number of mangrove species in each district with mangrove vegetation will be mapped. The following is the analysis and identification process.

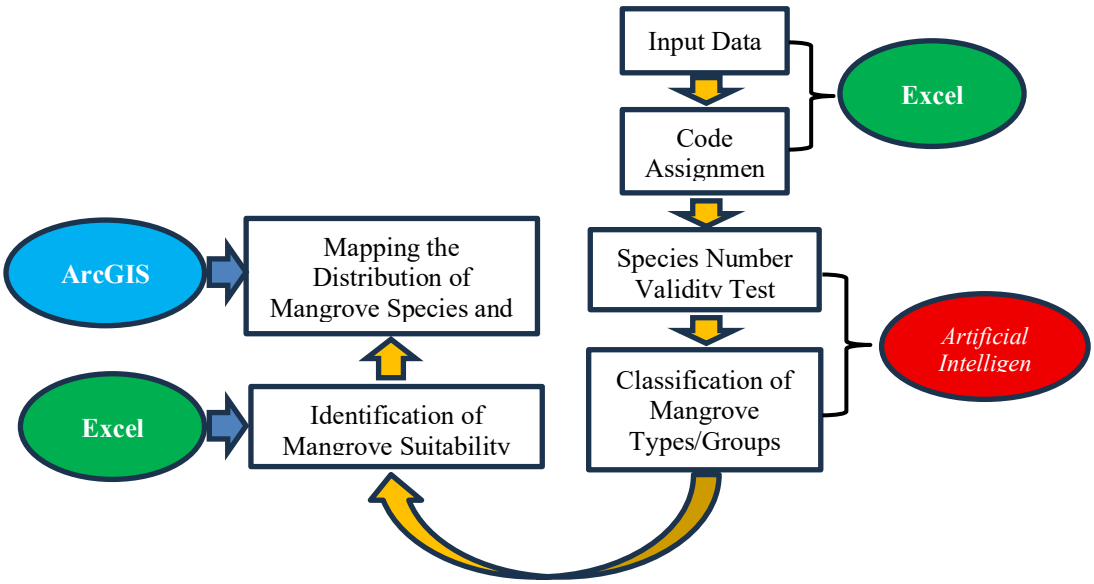


Figure 1. Mangrove Analysis and Identification Process

2.4. Implementation of Observation/Research Study

Publish or Perish application, websites, artificial intelligence (AI), and other software to help observe or examine research

data, thereby producing synthesized data that can be used as a database for mangrove conservation. The stages of conducting this research observation are as follows.

a) Search for journals that study mangrove vegetation identification using the Publish or Perish application and Artificial Intelligence (ChatGPT & Perplexity).
b) Collect data from several journals and then input it into the Ms. Excel application. Each journal will be mapped based on its district.
c) After all species found in several research journals are entered into Excel, the next step is to assign a code to each species. This allows us to determine the number of species in one district through data analysis of several journals that study mangrove vegetation in several districts in North Sumatra Province.
d) Next, we searched for data on the distribution of mangroves in North Sumatra Province through the website https://www.globalmangrovewatch.org/.
e) Then, we identified the habitat or zoning of mangroves. This zoning was done to find out in which zones mangrove vegetation was commonly found and which substrates were suitable or ideal for mangrove plants.

3. Results and Discussion

3.1. Distribution of Mangroves in North Sumatra Province

Environmental factors can influence mangrove diversity. Mangrove forest zoning is greatly influenced by substrate, salinity, and tides [11]. Mangrove plants that grow and live on the island of Sumatra, especially in North Sumatra Province, can be seen through the website https://www.globalmangrovewatch.org/. Based on the results of the website, it shows that the distribution of mangroves in North Sumatra Province is mostly found in the eastern coastal area. This illustrates that the habitat or substrate most suitable for the growth of mangrove species is the eastern coastal region of North Sumatra, and the results of this observation can be seen in Figure 2 below.

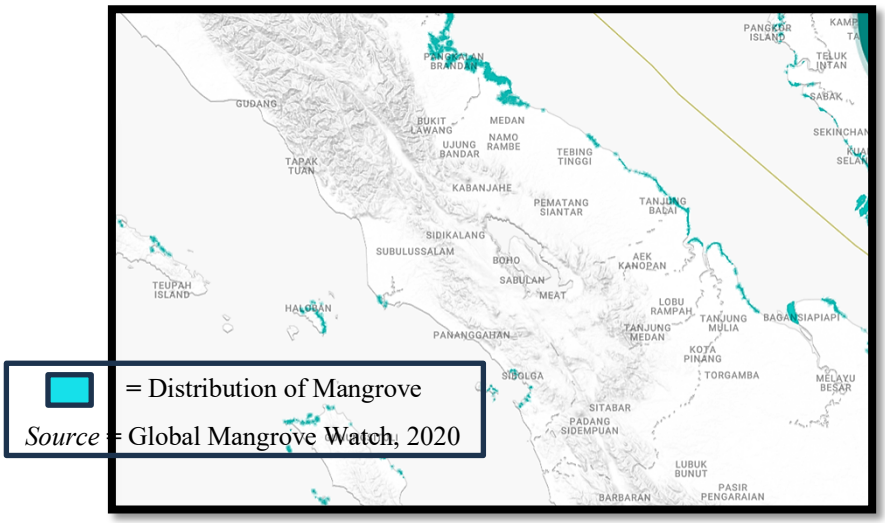


Figure 2. Distribution of Mangroves in North Sumatra Province in 2020 (https://bit.ly/3G5EFmqglobalmangrovewatch)

Figure 2 above shows that mangrove distribution in North Sumatra is more prevalent on the northern coast than on the western coast. This is due to the substrate or environment that affects mangrove growth. It is still possible that the eastern coast of Sumatra is more suitable for mangrove habitats with muddy substrates and calmer waters. [7][7]. The same applies according to [7], In the deeper bays (East Coast), mud and muddy sand generally dominate, while in the shallower bays in the west, sandy substrates dominate.

3.2. Substrate and Number of Mangrove Species

Based on the results of observations from several studies that were statistically processed, it was found that the substrate greatly affects the distribution and amount of mangrove vegetation growing in the coastal areas of North Sumatra, as can be seen in Table 1 below.

Table 1. Mangrove Vegetation Based on Substrate According to Several Studies in 5 Districts in North Sumatra Province

Substrat	Number of Species	List of Species
Muddy	22	*Rhizophora*, *Avicennia*, *Bruguiera*, *Sonneratia*, *Rhizophora apiculata*, *Sonneratia alba*, *Acrostichum aureum*, *Acanthus ilicifolius*, *Avicennia marina*, *Bruguiera sexangula*, *Cemara sumatrana*, *Ceriops tagal*, *Cynodon dactylon*, *Excoecaria agallocha*, *Lumnitzera racemosa*, *Morinda citrifolia*, *Nypa fruticans*, *Rhizophora stylosa*, *Sonneratia ovata*, *Thespesia populnea*, *Wedelia biflora*, *Xylocarpus granatum*, *Avicennia alba*
Sandy	8	*Avicennia sp.*, *Bruguiera sp.*, *Excoecaria agallocha*, *Lumnitzera racemosa*, *Rhizophora apiculata*, *Sonneratia alba*, *Sonneratia caseolaris*, *Avicennia alba*
Mainland	3	*Rhizophora sp.*, *Bruguiera sp.*, *Xylocarpus sp.*

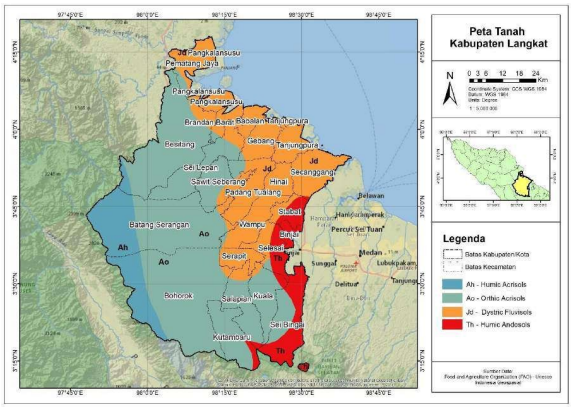
Source: Bengen, 2004; Parwansa, 2007; Fachrul, 2007; Ningsih et al., 2011; Sina et al., 2015; Siregar at al., 2022

Through observation, the results of the above research show that mangrove substrates are divided into three parts, namely sandy, muddy, and land. The highest number of mangrove species is found on muddy substrates. This is because mangroves are plants that are very well suited to wet soil conditions, in the sense that they are alluvial soils affected by tidal fluctuations, forming their own ecosystem where mangroves growing on muddy substrates are home to many crabs, shrimp, lobsters, shellfish, and fish. According to research [5], The type of substrate suitable for mangrove growth is soft mud, which contains silt, clay, and soft organic materials.

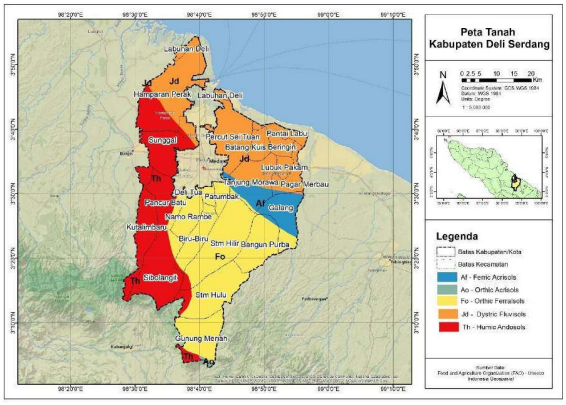
North Sumatra Province consists of several regencies and has different types of soil. Based on the results of the soil type map unit created in the 2021 North Sumatra Province Agricultural Development Road Map book and written by the UISU Faculty of Agriculture in collaboration with the North Sumatra Province Food Security, Food Crops and Horticulture Agency, it can be seen in Figure 3 below.

Based on the results of soil mapping in North Sumatra Province in several districts such as Langkat, Deli Serdang, Serdang Bedagai, Asahan, and Central Tapanuli. Based on these results, it is known that the soil type on the coast of these regencies is Jd (Dystric Fluvisols). According to the World Reference Base for Soil Resources (WRB), Fluvisol is one of the soil unit names in the Reference Soil Groups (RSG) category. Fluvisol is genetically classified as young soil found in alluvial deposits. Based on these results, mangrove plants are very suitable for growing and developing in this area, where they will grow and develop in the appropriate zone and substrate. Figure 4 shows that the mangrove habitat with the most species is the Central Zone with muddy substrate. According to [12] Mangroves are plants that live in communities and in areas affected by tidal fluctuations, mainly growing in alluvial mud on coastal environments and river estuaries. This is also in line with [8] Defining mangrove forests as forests that primarily grow on alluvial mudflats in coastal areas and river estuaries affected by tidal fluctuations, and consisting of tree species such as *Avicennia, Sonneratia, Rhizophora, Bruguiera, Ceriops, Lumnitzera*, According to [13] Fluvisol soil is undeveloped soil (horizon A only) formed from sedimentary (fluvial) material in an udic (humid) moisture regime. Its profile is characterized by several layers with clear, flat boundaries. This soil has a coarse (Sandy) to medium (Loamy) texture and is undeveloped (A horizon only). The organic carbon content varies irregularly with depth; the topography is flat. This soil is usually very fertile and is used for rice fields and settlements. In rice fields, a 10–15 cm impermeable layer is formed.

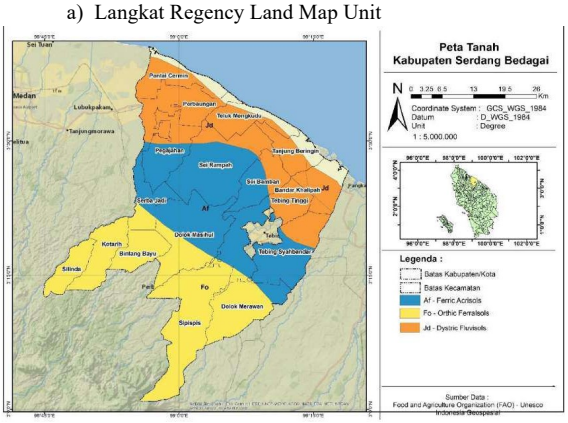
Based on the results of soil type mapping in Langkat, Deli Serdang, Serdang Bedagai, Asahan, and Central Tapanuli Regencies, these areas have the same soil type in their coastal regions. However, it has been observed that these regencies have different substrates, which affect the number and vegetation of species living and growing in these areas. The substrate results can be seen in (Table 1 and Table 2) above, which provide data on the relationship between the substrate and the number of species growing in the area. Then, the map unit of the number of mangrove species in North Sumatra Province in several regencies can be seen in Figure 4 below.



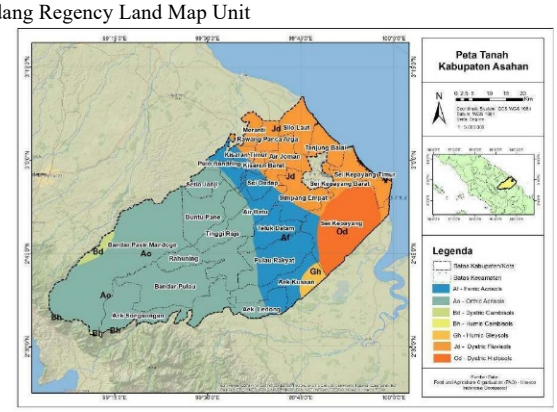
a) Langkat Regency Land Map Unit



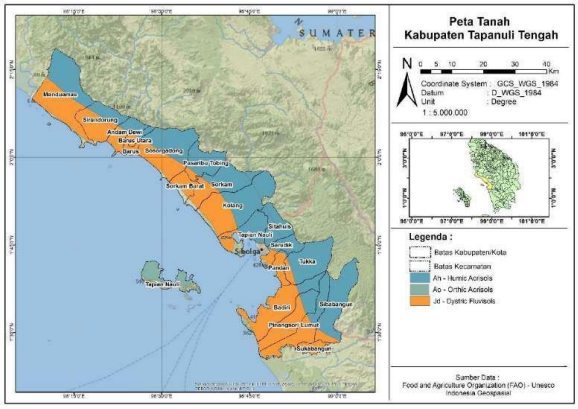
b) Deli Serdang Regency Land Map Unit



c) Serdang Bedagai Regency Land Map Unit



d) Asahan Regency Land Map Unit



e) Central Tapanuli Regency Land Map Unit

Figure 3. Soil Map Units in North Sumatra Province in 5 Districts

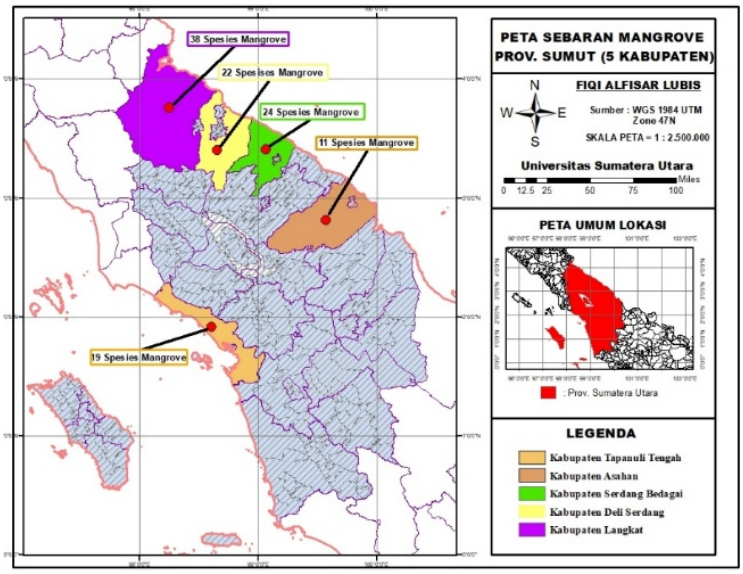


Figure 4. Map of Mangrove Species Numbers in Several Districts in North Sumatra Province

3.3. Mangrove Habitat/Zoning

Based on the results of observations in the research results [12], [14] It is known that there are types or species of mangroves that live and grow in several zones, namely the Open Zone, Middle Zone, and Land Zone, and there are also those that grow and live in all three zones. This can be seen in Figure 5 below.

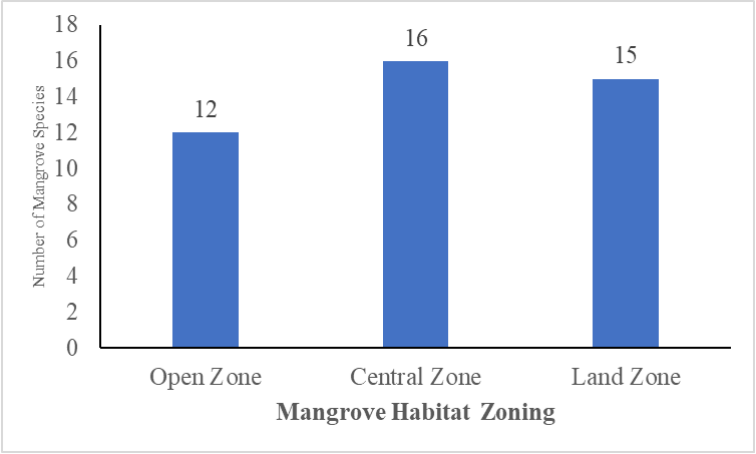


Figure 5. Number of Mangrove Species Growing in Several Zones

Table 2. Mangrove Species Growth Zoning

No.	Spesies Mangrove	Mangrove Habitat		
		Open zone	Central zone	Land zone
1	*Avicinnea alba*	√		
2	*Avicinnea marina*	√		
3	*Avicinnea lanata*	√		
4	*Sonneratia alba*	√	√	
5	*Sonneratia ovata*	√		
6	*Scyphiphora hydrophyllacea*	√		
7	*Ceriops tagal*	√	√	
8	*Rhizophora apiculata*	√	√	
9	*Rhizophora mucronata*		√	
10	*Rhizophora stylosa*		√	
11	*Bruguiera parviflora*		√	
12	*Bruguiera gymnorrhiza*		√	
13	*Bruguiera sexangula*		√	
14	*Ipomea pes-caprae*		√	√
15	*Scaevola taccada*		√	√
16	*Sesuvium portuculacastrum*		√	√
17	*Excoecaria agallocha*	√	√	
18	*Acanthus ilicifolius*		√	√
19	*Hibiscus tillaceus*	√	√	
20	*Lumnitzera racemosa*		√	√
21	*Terminalia catappa*			√
22	*Nypa fruticans*			√
23	*Casuarina equisetipolia*			√
24	*Calophyllum inophylum*			√
TOTAL		**10**	**15**	**9**

Sumber: [14]

Table 3. Mangrove Species Growth Zone

No	Spesies mangrove	Mangrove Habitat		
		Open zone	Central zone	Land zone
1	*Avecennia marina*	√	√	√
2	*Rhizophora apiculata*	√	√	√
3	*Rhizphora mucronata*	√	√	√
4	*Rhizophora stylosa*	√	√	√
5	*Soneratia alba*			√
6	*Ceriops tagal*			√
TOTAL		**4**	**4**	**6**

Source: [12]

Based on the results shown in Figure 4 and Tables 2 and 3 above, it is known that there are 12 mangrove species that can grow in the open zone, 16 species that grow in the middle zone, and 15 species in the mainland zone. Meanwhile, Table 20 shows that there are 4 species that can grow and live in 3 zones, namely *Avecennia marina, Rhizophora apiculate, Rhizphora mucronate*, and *Rhizophora stylosa*. These results are also reinforced by a book written by [8] explains that the open zone is dominated by S*onneratia, Avicennia*, and often *Rhizophora*. The middle zone is dominated by *Rhizophora*, but *Bruguiera* also often grows there. Meanwhile, the mainland and brackish zones are dominated by *Nypa* or *Sonneratia*. According to [15] In mangrove ecosystems, only a few species can grow well because mangroves have many limitations that support plant growth, such as substrate conditions, flooding, and wind speed, so only a few species are able to survive and grow in the Open Zone. Therefore, only ± 4-10 species are known to live and grow in the Open Zone. The mangrove species *R. apiculata* and *R. mucronata* are always found at every observation point or zone, while L. Racemosa is only found at points 4 and 20. The *Rhizophoraceae* family consists of mangroves, which can be found wherever you go. According to zoning, the species *R. apiculata* and *R. mucronata* are in the foremost zone (sea). *N. Frutican, B. Tcylindrica*, and *Lumnitzera*, as well as *E. agallocha* are in the rearmost zone. Ferns (*A. Aureum*) are a type of mangrove that grows inland in the middle with sea water rarely entering [7].

3.4. Suitability of Mangroves in Different Substrate and Environmental Conditions

The results of this study are also supported by data synthesized from several journals using the ChatGPT application, which shows that Langkat Regency is an ideal location for mangrove plants. It has been identified that Langkat Regency has the largest number of mangrove species, and dissolved oxygen in the water does not have much of an effect because mangrove plants have

breathing roots. The following is the supporting data for the results of this study (Table 4).

Table 4. Comparison of Coastal Substrates in Several Districts in North Sumatra Province

Regency	Substrate Type	Organic Content	Suitability for Mangroves
Langkat	Fine mud, clay	Height	Sangat Baik
Deli Serdang	Fine mud	Height	Baik
Serdang Bedagai	Fine mud	Moderate-High	Baik
Asahan	Sandy mud	Low	Kurang
Tapanuli Tengah	Variable (mud-sand)	Varied	Bervariasi

Note: This data synthesis is the result of using the Perplexity.ai application.

Based on the results of this study, the following are the findings for identifying the number of species found in several districts in North Sumatra Province. I obtained the following results from several journals that studied mangrove vegetation in North Sumatra.

One factor that influences the formation of mangrove zoning is substrate conditions. The vertical distribution of mangrove species along the coastline is called mangrove zoning. Mangrove zoning is influenced by the ability of each mangrove species to adapt to its environment.

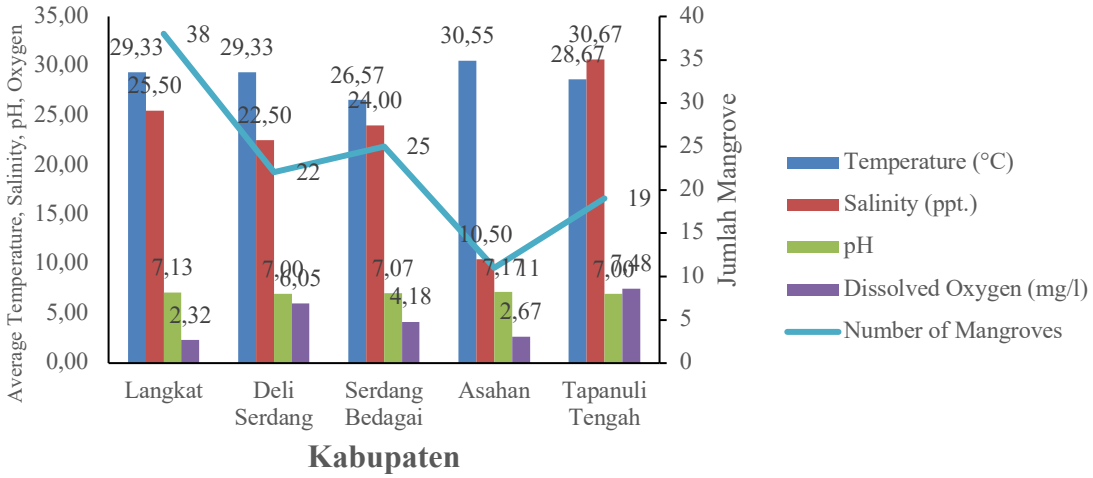


Figure 6. Relationship between the number of mangrove species and the physical and chemical properties of the waters in several districts in North Sumatra Province

Several coastal districts in North Sumatra, namely Langkat, Deli Serdang, Serdang Bedagai, Asahan, and Central Tapanuli, show variations in water parameters, including temperature, salinity, pH, and dissolved oxygen levels. Mangrove habitat and community structure are influenced by these important parameters. Figure 6 illustrates the spatial variation of physical-chemical water parameters such as temperature, salinity, pH, and dissolved oxygen along with the variation in mangrove species and abundance along various coasts in North Sumatra, Indonesia. These results show that Langkat Regency has the most species compared to other regencies due to its suitable environment, namely temperature (29.33 ^{0}C), salinity (25.50 ppt), pH 7.13, dissolved oxygen (2.32 mg/l), while Asahan Regency has the fewest mangrove species due to its less suitable environment, such as temperature (30.55°C), salinity (10.50 ppt), pH (7.17), and dissolved oxygen (2.67). According to the results of the data synthesis, I used (Table 1 & Table 4), this data study shows that the ideal water temperature for mangroves is 25-30°C, salinity 10-30 ppt with a substrate of fine silt, clay soil with low aeration. The results of this study are also reinforced by the synthesis of data from several journals through the ChatGPT application, which shows that Langkat Regency is an ideal location for mangrove plants, thus identifying Langkat Regency as having the highest number of mangrove species.

Overall, environmental conditions are generally suitable for mangrove growth. However, salinity emerges as the most influential ecological factor shaping mangrove distribution, with higher densities or numbers of mangrove species seen in areas with ideal salinity levels for mangroves. This occurs because if salinity (Na^{+}) is too high, Ca^{2+} and Mg^{2+} elements will disperse in soil colloids and prevent these elements from being absorbed by mangrove plants. In mangrove plants, Ca^{2+} has the main function of being a component of cell walls (calcium pectate) that strengthens root, stem, and leaf tissue, thereby increasing resistance to mechanical stress and extreme coastal conditions. Ca^{2+} also plays a role in regulating cell membrane permeability and ion balance, which is very important for mangroves in coping with high salinity. By helping to control excessive sodium ion (Na^{+}) absorption, Ca^{2+} contributes to reducing salt stress and maintaining ionic homeostasis [16]. In addition, Ca supports root tip growth, cell division, and the formation of a healthy root system, which is important for plant stability in muddy and flooded substrates.

Magnesium (Mg) plays a direct role in photosynthesis and energy production because it is an essential element at the center of chlorophyll molecules. The rate of carbon assimilation, light capture efficiency, and mangrove biomass productivity all increase with adequate Mg^{2+} availability. Mg^{2+} also activates various metabolic enzymes. This includes enzymes responsible for respiration, protein synthesis, and carbohydrate metabolism. Mg supports crown and root growth and increases the efficiency of translocating photosynthetic products from leaves to growing tissues in dynamic coastal environments. Mg^{2+} also increases plant tolerance to abiotic stresses such as salinity and nutrient fluctuations, which are common in mangrove ecosystems [17]. In addition, magnesium and potassium synergistically help regulate ion balance, activate antioxidant enzymes, and increase tolerance to oxidative stress and salinity. This helps mangroves ecologically adapt to extreme and variable coastal conditions [18].

Water temperature acts as a secondary regulatory factor that supports physiological performance, but does not independently explain spatial differences in mangrove density, while pH remains within a neutral range, indicating stable chemical conditions that are unlikely to limit mangrove formation. Relatively low dissolved oxygen concentrations were observed across all locations, consistent with the hypoxic conditions typical of mangrove sediments, highlighting the adaptive capacity of mangrove species to oxygen-limited environments rather than dependence on high oxygen levels. Overall, these findings indicate that mangrove abundance is primarily influenced by hydro-salinity dynamics, with temperature, pH, and dissolved oxygen playing complementary or indirect roles, highlighting the importance of maintaining hydrological connectivity and optimal salinity conditions in mangrove conservation and restoration strategies. Dissolved oxygen is not particularly influential, as mangrove plants have lenticels or breathing roots.

4. Conclusion

There are 58 species of mangroves in North Sumatra Province, represented by Langkat, Deli Serdang, Serdang Bedagai, Asahan, and Central Tapanuli Regencies. Each regency has a different number of species, such as Langkat Regency (38 species); Deli Serdang Regency (22 species); Serdang Bedagai Regency (24 species); Asahan Regency (11 species) and Central Tapanuli Regency (19 species).

The eastern coastline has more mangrove vegetation than the western coastline of North Sumatra Province due to the influence of waves and tidal movements. The zone with the most mangrove vegetation is the Central Zone. The substrate suitable for mangrove plants is muddy, clayey alluvial soil (Fluvisols) with high organic content. Temperature and salinity in the water greatly affect the growth and development of mangrove vegetation, but dissolved oxygen in the water does not because mangrove plants have breathing roots.

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