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The Analysis of Land Use Change of Mangrove Ecosystem in Langkat, North Sumatera, Indonesia

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ABSTRACT

Mangroves are subtropical and warm temperate intertidal ecosystems that sustain the well-being of humans and wildlife through a variety of services. However, the existence of mangroves is presently threatened by alterations in land use. From 2010 to 2022, mangrove areas in Pasar Rawa Village, Gebang District, Langkat Regency, North Sumatra province have decreased significantly. The destruction of mangrove forests is primarily caused by the neighboring community's activities. The purpose of this study was to assess the level of damage and density of mangroves in Pasar Rawa Village, as well as to examine the perceptions of locals regarding the management of mangrove ecosystems. The investigation was carried out from January to March 2023 by distributing the questionnaires to the 286 respondents. Based on the vegetation analysis and indexing vegetation analysis through Landsat 7 and Landsat 8 image processing, the amount of mangrove areas in Pasar Rawa Village decreased by 52.97 ha between 2010 and 2022, with the majority of mangrove areas being converted into oil palm plantations and fish farming ponds. It is dominated by the dense class of the Normalized Difference Vegetation Index (NDVI) in 2022, despite the condition of the mangroves in Pasar Rawa Village still being classified as damaged during this recovery process. In addition, the outcome of public perception demonstrates that the management of the mangrove ecosystem is suitable and supports the capacity to create a sustainable mangrove ecosystem.

Keywords: landsat image, public perceptions, sustainable mangrove ecosystem, vegetation analysis

1. Introduction

The word mangrove comes from the word 'mangal,' a community of plants. Mangroves were first used to define plants and communities in a dense ecosystem in the intertidal area of tropical coastal waters [1]. As a plant community, a forest mangrove is a collection of tropical and sub-tropical coastal vegetation that grows and develops in tidal, muddy coastal areas, providing various essential functions for nature and supporting human well-being [2]. In the last 30 years of the 20th century, the world lost about 35% of its mangrove ecosystem. On a national scale, Indonesia has 4,120,263 ha of mangrove ecosystem [3].

The processes that drive deforestation and mangrove degradation are geographically significant, one of which is in Langkat Regency, North Sumatra Province. The area of the mangrove ecosystem in North Sumatra itself is 57,490 ha, with the largest mangrove ecosystem in Langkat Regency covering an area of 11,709.16 Ha in 2010, and there was a change in the area of the mangrove ecosystem in 1980-2010 covering an area of 25,816.01 Ha. One of the causes of changes in the mangrove ecosystems in Langkat Regency is the conversion of the mangrove ecosystem into aquaculture and oil palm plantations. Used land is a primary determining factor in environmental management [1].

Anthropogenic activities like land conversion from the mangrove ecosystem into other land uses (ponds, agricultural lands, human settlement), extractive activities (mining and logging), and industry activities in mangrove areas can directly influence mangrove composition and other structural properties. Regeneration, tree growth, and the productivity of stocks and structures are disrupted, which will impact climate change and damage to mangrove ecosystem ecosystems [5]. In the case study in 2020, the encroachment of a mangrove ecosystem area for an oil palm plantation was carried out by the local community with an area of mangrove ecosystem of 58 ha [6]. This condition requires awareness from all parties to rehabilitate the damage to the mangrove ecosystem. Success or failure in mangrove ecosystem rehabilitation is inseparable from the participation of the community around the mangrove ecosystem, which has a vital role in the preservation of the mangrove ecosystem, so it is necessary to know the perceptions of the community regarding mangrove rehabilitation [7]. This study aimed to analyze the density and damage to mangrove ecosystem vegetation and community perceptions of mangrove ecosystem rehabilitation in Pasar Rawa Village, Gebang District, Langkat Regency, North Sumatra.

2. Methods

2.1 Place and Time Research

The research was conducted at the Pasar Rawa Village Forest Management Institution (LPHD) in Pasar Rawa Village, Gebang District, Langkat Regency, North Sumatra Province (Figure 1). The time used for this research is from January to March 2023

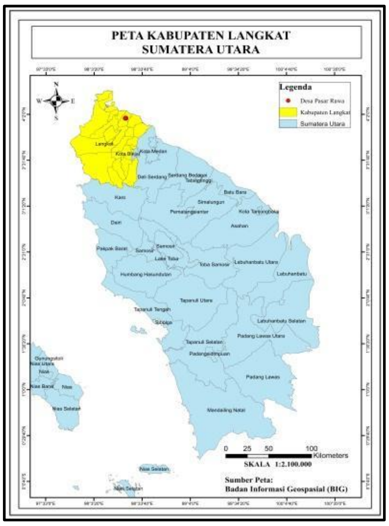

Figure 1. Map of Langkat Regency, North Sumatra
Source: Geospatial Information Agency, 2023

Figure 1. Map of Langkat Regency, North Sumatra
Source: Geospatial Information Agency, 2023

2.2 Tools and Materials of Research

Field data collection tools are wooden stakes, raffia ropes, tree diameter, phi bands, tape measure/roll meter, tally sheets, stationery, Global Positioning System, questionnaires, and digital cameras; these tools are used for vegetation analysis. The data analysis tools used were computers/laptops, Erdas Imagine 9.1 software to identify the land cover of Pasar Rawa Village, ArcGIS 10.8 software to analyze Normalized Difference Vegetation Index value, and SPSS 23 software to analyze community perception of mangrove rehabilitation, with a total of 74 respondents who are members of the village ecosystem management community group.

The materials or objects used in this study were the mangrove area of Pasar Rawa Village, Landsat 7 imageries for 2010 and Landsat 8 imageries for 2013, 2016, 2019, and 2022, which were sourced from the United States Geological Survey (USGS), a guidebook for identifying mangrove species.

2.3 Quantitative Method

2.3.1 Image Processing Method

The stages of image processing are radiometric correction, image composite, image clipping for research locations, supervised classification by grouping image pixels based on the *training area*, accuracy test to determine the accuracy of supervised classification results, and NDVI transformation. The accuracy test can use the error matrix measurement method (confusion matrix), which includes Producer Accuracy (PA), User

Accuracy (UA), Overall Accuracy (OA), and Kappa Accuracy (K). Data validation of the classification results is said to be correct and feasible if the results are OA is more than 85%.

One index that can be used to determine the density of mangrove vegetation is the NDVI (Normalized Difference Vegetation Index), which uses the NIR band (near-infrared band) and the red band. NDVI calculation can be described as follows:

$$\text{NDVI} = \frac{NIR - RED}{NIR + RED}$$

2.3.2 Vegetation Analysis

A vegetation survey was made using a circle plot method and circle sub-plots. Sampling used the different circular quadrant methods to measure the observation plots with a radius of 10 m for the tree level, 3 m for the sapling level, and 2 m for the seedling level (Figure 2). The circular plot design is relatively easy to make and efficient to measure in knowing the composition of mangrove vegetation [8]. The following formula was used for the vegetation analyses.

a. Density
- Density Type (K) (ind/Ha)
  $K = \frac{Number\ of\ individuals\ of\ a\ species}{sample\ plot\ area}$
- Relative Density
  $K = \frac{Density\ of\ species}{density\ of\ all\ species}\ x\ 100\ \%$

b. Frequency
- Type Frequency (Fi)
  $F = species$
- Relative Frequency (FR) (%)
  $F = \frac{Frequency\ of\ species}{frequency\ of\ all\ species}\ x\ 100\ \%$

c. Base Area
   $LBDS = \frac{\pi\ d^2}{4}$
   π = Constant (3,14)
   d = tree diameter

d. Dominance
- Dominance Something Type (D) (m2 / Ha)
  $D = \frac{Basic\ area\ of\ species}{sample\ plot\ area}$
- Relative Dominance
  $D = \frac{Dominance\ of\ species}{dominance\ of\ all\ species}\ x\ 100\ \%$

e. Important Value Index (IVI)
   IVI = KR + FR + Dr (for level vegetation tree)
   IVI = KR + FR (for seedling and sapling vegetation levels)

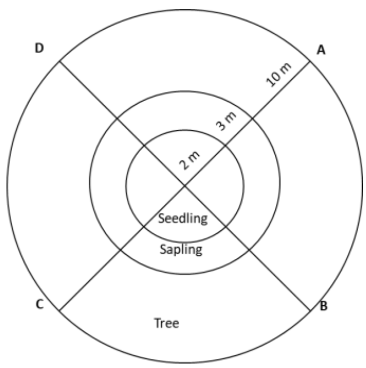

Figure 3. Circle plot method
Source: Kauffman dan Donato, 2012

Level of Mangrove Damage

a. Closure Species

This is the ratio between the area of species I closure (Ci) and the total area of closure for all species (ΣC):

$$RC_i = (C_i / \Sigma C) \times 100$$
$$C_i = \Sigma BA/A$$

Where :

BA = ΣDBH ^{2}/4 (in cm ^{2}), Σ (3.1416) is a constant, and DBH is the diameter of the tree trunk of the species. A = total area of intake area sample (total area of sample plots). DBH=CBH/Σ (in cm). CBH is a circle tree as high as a chest.

b. Density

Is the ratio between the number of stands of the i-th species (ni) and the total number of stands of all species with the following formula:

$$(\sum n): Rdi= (ni/\sum n) \times 100$$

Where :

Rdi = tree species density/Ha

Ni = Number of species that stands

2.4. Qualitative method

Assessment of respondents' answers using the Likert Scale method.

Table 1. Scale category

Scale	Category
1 - 1.80	Very low
1, 81 - 2.60	Low
2, 61 - 3,40	Currently
3, 41 - 4,20	Tall
4, 21 - 5.00	Very high

Source: Sugiyono, 2015

To analyze the factors of age, length of residence, and level of education related to the level of participation in the development of mangrove ecosystems at the research location, which is measured based on income using the Spearman correlation test, with the following formulation:

$$Pp \frac{1 - 6\sum D2}{n\,(n2 - 1)}$$

Description:

Ƥ (Rho) = Spearman correlation coefficient

D = Difference in scores between the two variables

N = Amount Group

In this study, the sample used was from a population of 286 people with the Slovin formula used as follows:

$$n = \frac{N}{1 + (N \,.\, e^2)}$$

$$n = \frac{286}{1 + (286 \; x \; 0{,}10^2)}$$
$$n = \frac{286}{3{,}86}$$
$$n = 74{,}09$$
$$n \approx 74 \text{ people}$$

Description:

n = Total of sample

N = Total of population

e = Percentage of inaccuracy due to sampling error that is tolerable or desirable (e.g., 1%, 5%, 10%)

2.5. Cobb-Douglas Model Regression Analysis

To measure community participation, the method the author uses is the Cobb-Douglas model. The data analysis technique used in this study was carried out through the Cobb-Douglas production function. Mathematically, the Cobb-Douglas function can be written as follows.

$$Y_{at} = \alpha X_1^{\beta 1} X_2^{\beta 2} X_3^{\beta 3} X_4^{\beta 1} \varepsilon \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (1)$$

Description:

$Y_{at} = f(X_{1t}, X_{2t}, X_{3t}, X_{4t})$ where

Yes _ is the level of public awareness of mangrove damage

X_{1t} is Participation based on age

X_{2t} is Participation based on length of stay

X_{3t} Participation is based on income level

X_{4t} Participation is based on the education level

3. Result & Discussion

3.1 Identification and Distribution of Mangrove Vegetation Density Classes Based on NDVI

The results of the analysis of image interpretation show that there has been a change in the mangrove area in Pasar Rawa Village from 2010 to 2022 (Figure 4 – Figure 8). Reducing the area of the mangrove ecosystem can result in a decrease in their function. A dense mangrove ecosystem will cause additional land along the coast (accretion), and conversely, areas of rare or missing mangrove ecosystems will trigger coastal abrasion. Both conditions can cause shoreline changes in the long term in coastal areas [13]. Reduced mangrove areas will have an impact on coastal quality. Other impacts arising from the destruction of mangrove ecosystems can affect the condition of seagrass meadow ecosystems and coral reef ecosystems in coastal areas [2].

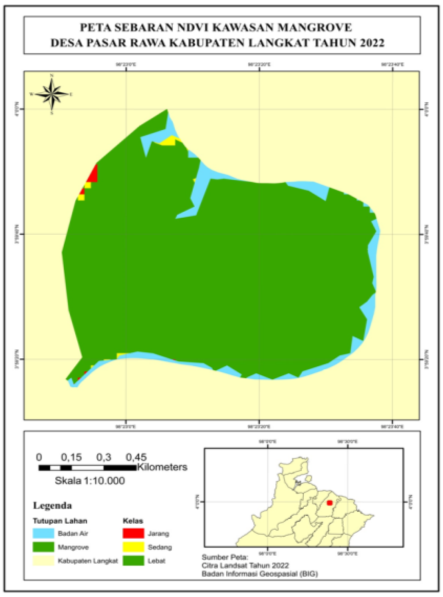

Figure 4. Map of Mangrove Forest Vegetation Distribution and Land Cover of Pasar Rawa Village in 2010
Source: Data processing, 2023

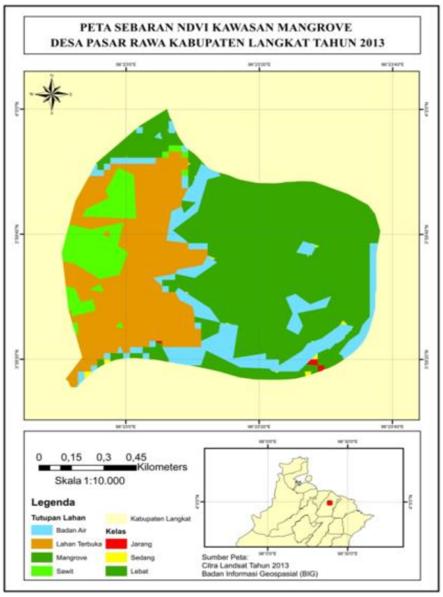

Figure 5. Map of Mangrove Forest Vegetation Distribution and Land Cover of Pasar Rawa Village in 2013
Source: Data processing, 2023

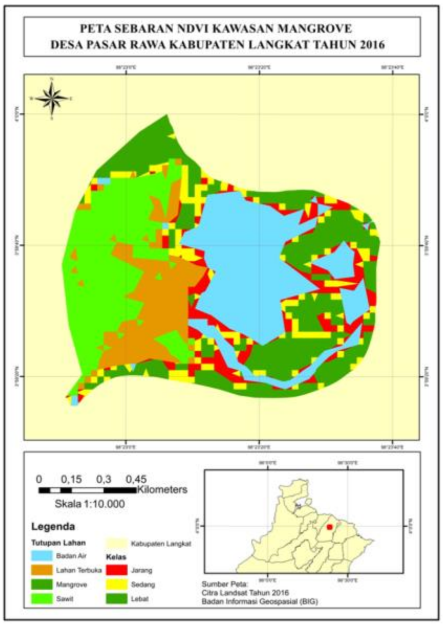

Figure 6. Map of Mangrove Forest Vegetation Distribution and Land Cover of Pasar Rawa Village in 2016
Source: Data processing, 2023

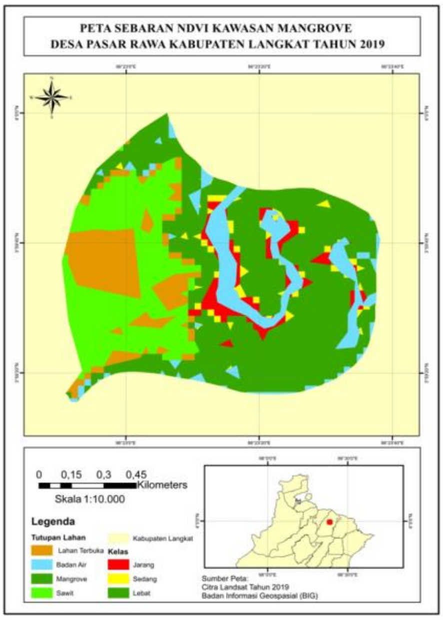

Figure 7. Map of Mangrove Forest Vegetation Distribution and Land Cover of Pasar Rawa Village in 2019
Source: Data processing, 2023

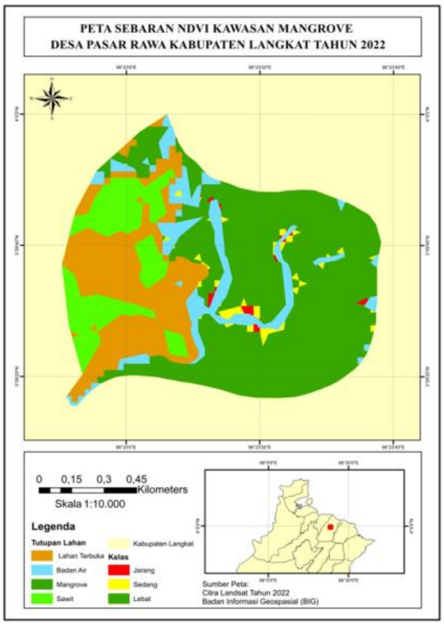

Figure 8. Map of Mangrove Forest Vegetation Distribution and Land Cover of Pasar Rawa Village in 2022
Source: Data processing, 2023

3.2. Identification of Land Cover in Pasar Rawa Village from 2010-2022

Land cover type analysis is needed to determine the direction of development of an area and thus benefit the community and the sustainability of land resources. Land cover, in contrast, is defined as the type of appearance on the Earth's surface [10]. The results of the identification of land cover in Pasar Rawa Village, with an area of 138,638 ha for the study site, were produced using the supervised classification method so that four types of land cover were obtained, namely mangrove, oil palm, water bodies, and open land (Figure 9). The results of the classification of land cover classes that have been tested for accuracy obtained an overall accuracy value of 92.86%, which means that it is good and almost correct with the conditions in the field. The classification results show a change in mangrove areas from 2010 to 2022.

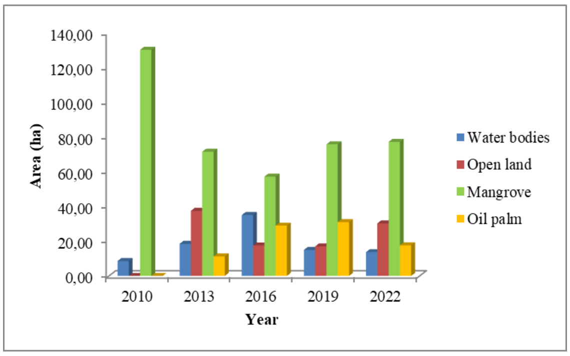

Figure 9. Graph of the land cover area of Pasar Rawa Village in 2010 - 2022
Source: Data processing, 2023

The analysis results show that the research location in Pasar Rawa Village was dominated by mangroves in 2010, with an area of 130.08 ha (93.83%) and a body of water covering an area of 8.55 ha (6.17%). Meanwhile, starting in 2013, the mangrove area was degraded to 71,46 ha (51,55%) due to land use for other purposes, so four types of land cover were obtained: water bodies, open land, mangroves, and oil palm. Land use changes were considered loss (reduction) and gain (increase) of areas. The loss of area was measured as a loss of area from dense area to open area and dense and open area to other types of land use [11].

The decline in mangrove area continued in 2016, with a mangrove area of 57.13 ha (41.21%). The increase in the area of water bodies can be affected by encroachment on mangrove areas by the community. Likewise, oil palm is increasing because it is planted in open lands. The rehabilitation efforts carried out by the Pasar Rawa Village Forest Management Institute (LPHD) in 2019 through planting mangrove saplings succeeded in increasing the area of mangroves to 75.71 ha (54.61%). Even though the oil palm class still experienced an increase of 30.98 ha (22.34%). Even though the existence of oil palm in mangrove areas harms ecological functions and economic functions in coastal areas, the expansion of oil palm plantations could make coastal areas vulnerable to flood because oil palm is unable to withstand seawater intrusion, and coastal communities will also find it increasingly difficult to find fish and shrimp in their fishing areas [12]. The increase in the area of mangroves will continue until 2022, with the area of mangroves becoming 77.11 ha (55.63%).
Meanwhile, the oil palm area decreased drastically to 17.60 ha (12.70%). The decrease in the area of oil palm caused an increase in the area of open land to 30.21 ha (21.79%) and water body class to 13.70 ha (9.88%). This can be seen from the observation conditions in the field, where a lot of palm vegetation was cut down, and some even experienced drought so that a lot of it became open land and seawater entered the land that was initially oil palm. Each land cover class in Pasar Rawa Village can be seen in Figure 10.

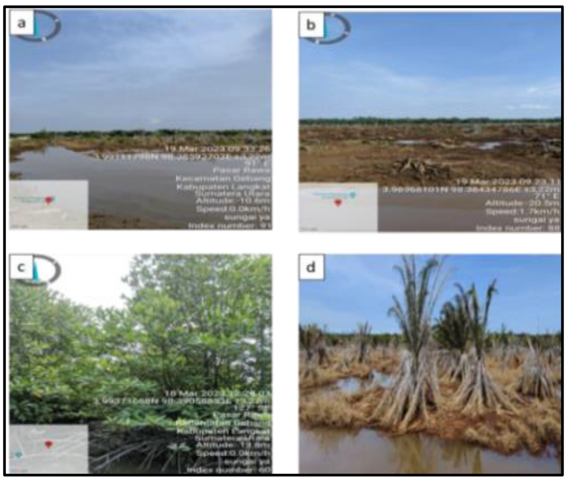

Figure 10. Land cover conditions in Pasar Rawa Village: a) water bodies; b) open land; c) mangroves; d) oil palm
Source: Data processing, 2023

3.3. Composition of Vegetation and Level of Mangrove Damage in Pasar Rawa Village

Assessment of mangrove vegetation structure can serve as an early warning sign and help identify opportunities to reduce the risks associated with mangrove degradation to communities [5]. Only one species of mangrove vegetation was found at the seedling growth rate, namely Bakau (*Rhizophora apiculata*), totaling 23 individuals with a 66.59 ind /ha density. Species density is a parameter to determine the number of individuals of a species in an area so that abundance and growth can be determined [14]. The greater the density of a species, the more individuals of that species per unit area. The small amount of mangrove vegetation found at this seedling growth rate could be affected by the condition of the mangrove land, which is less than optimal for the growth of other types of seedlings.

The composition of the vegetation at the sapling growth rate in Pasar Rawa Village obtained two types of mangrove vegetation, namely the type of Bakau (*Rhizophora apiculata*) totaling 88 individuals and the type of Brembang (*Sonneratia caseolaris*) totaling 2 individuals (Table 3). Ecologically, the types of *Rhizophora apiculata* and *Sonneratia caseolaris* are more adaptable to muddy substrates and are still affected by tides; however, types of *Sonneratia caseolaris* are intolerant of water conditions with high salinity and shade.

Table 2. Composition of mangrove vegetation growth rate of seedlings in Pasar Rawa Village

Scientific Name	Total	KR (%)	FR (%)	IVI (%)
Rhizophora apiculata	23	100	100	200
Total	23	100	100	200

Source: Data processing, 2023

Table 3. Composition of mangrove vegetation growth rate of saplings in Pasar Rawa Village

Scientific Name	Total	KR (%)	FR (%)	IVI (%)
Rhizophora apiculata	88	97,78	85,14	182,91
Sonneratia caseolaris	2	2,22	14.86	17,09
Total	23	100	100	200

Source: Data processing, 2023

Table 4. Composition of mangrove vegetation growth rate of trees in Pasar Rawa Village

Scientific Name	Total	KR (%)	FR (%)	DR (%)
Avicennia alba	1	1,79	10,00	33,90
Rhizophora apiculata	36	64,29	40,00	12,57
Sonneratia caseolaris	15	26,79	30,00	42,14
Excoecaria agallocha	4	7,14	20,00	11,39
Total	56	100	100	100

Source: Data processing, 2023

The highest IVI value at the tree growth rate was found in the type of Bakau (*Rhizophora apiculata*) at 116.85%, and the lowest was in the type of Buta-buta (*Excoecaria agallocha*) at 38.53% (Table 4). IVI can interpret the composition of a plant community through the types of vegetation that dominate and influence the community. The higher the IVI value of a species, the greater its role in the community.

The criteria for mangrove damage are based on the Decree of the Minister of Environment in 2004. The results of the analysis of the level of damage to mangroves in Pasar Rawa Village show the criteria for damage (rare) for each type so that the analysis results follow the research hypothesis. This can be seen from the species density (K), which is <1000 ind/ ha, and the relative coverage (RCi), which is <50%.

The level of damage to mangroves in Pasar Rawa Village is included in the damaged category (rare). When compared with the results of the NDVI analysis, tree canopy density does not guarantee good quality of the mangrove area because the level of damage to mangroves is seen from the growth density of the species and the large diameter of the number of individuals of each species obtained. Damage to mangrove areas can be caused by human activities in the form of expansion of land used as oil palm areas, while rehabilitation efforts through replanting have been ongoing for 3 years, so the trees still need time to achieve optimal growth.

Table 5. Density and relative cover of mangrove vegetation in Pasar Rawa Village

Scientific Name	Total	K (ind/ha)	Rci (%)	Criteria
Avicennia alba	1	2,90	34,35	Damage
Rhizophora apiculata	36	104,23	12,66	Damage
Sonneratia caseolaris	15	43,43	41,48	Damage
Excoecaria agalloch	4	11,58	11,51	Damage
	56	162,131	100	

Source: Data processing, 2023

3.4. Measurement of Community Perception Level of Mangrove Ecosystem Management

The active role of coastal communities can help rehabilitate damaged mangroves. Community perception analysis aims to determine the suitability of mangrove ecosystem management; the analysis is based on age, length of residence, income, and education with a Likert Scale approach (Table 6 to Table 9).

Table 6. Characteristics of respondents by age

Age	< 35 year	35-45 year	45-55 year	Total
Frequency	5	32	37	74

Source: Data processing, 2023

Table 7. Characteristics of respondents by length of stay

Time	< 15 year	15-20 year	20-25 year	Total
Frequency	2	53	19	74

Source: Data processing, 2023

Table 8. Characteristics of respondents by income

Income	< 2 million	2-3 million	3-4 million	Total
Frequency	31	34	9	74

Source: Data processing, 2023

Table 9. Characteristics of respondents by education

Education	Elementary school	Junior High School	Senior High School	Total
Frequency	10	49	15	74

Source: Data processing, 2023

3.5. Cobb-Douglas Model Regression Analysis

The Cobb-Douglas function is a function or equation that involves two or more variables. One variable is called the dependent variable, which is explained (y), and the other is called the independent variable, which is explained (x). In this study, the Cobb-Douglas production function. From the research results, the Cobb-Douglas production function is obtained; it is Y = 0.202 + 0.569 X1 + 0.316 X2 + (-207) X3+ 0.302 X4+e. The constant value (β0) is 0.202; this indicates a constant level, where if the variables are age (X1), length of residence (X2), education (X3), and income (X4) are 0, then the value of the community participation variable (Y) will remain at 2.02% assuming other variables remain constant. The age variable (X1) is 0.569 positive, indicating that the older the community, the greater the desire to participate in rehabilitating mangroves. The length of residence variable (X2) is 0.316, indicating that the longer the community lives, the higher the level of community participation in mangrove rehabilitation. The education variable (X3) is -0.207 with a negative value; this indicates that the lower the community's education, the less they want them to participate in mangrove rehabilitation activities. The income variable (X4) is 0.302, indicating that if the community increases its income, it will increase its awareness of participation in mangrove rehabilitation.

4. Conclusion

1. Mangrove density in Pasar Rawa Village, Gebang District, Langkat Regency, from 2010 - 2022 has decreased in the area from 130,08 ha to 77,11 ha, with the highest decrease of 57.13 ha in 2016 due to other land uses, especially for oil palm plantations. However, the planting efforts carried out in 2019 have succeeded in increasing the area of mangroves until 2022, reaching a total area of 77.11 ha, dominated by dense class areas.
2. The condition of damaged mangroves in Pasar Rawa Village, Gebang District, Langkat Regency, is still included in the damaged criteria caused by land degradation due to land conversion, like oil palms, which reached 30,98 ha. While efforts to rehabilitate land through planting mangrove vegetation have been ongoing for 3 years since 2019, the types of mangrove vegetation planted still need time to achieve optimal growth of tree height, diameter, and number of leaves.
3. Community participation in improving the mangrove ecosystem in Pasar Rawa Village, Gebang District, Langkat Regency, is following the expectations of the community and the government because the results of the questionnaires distributed show that the community perceptions are good. From the results, we can see that the variables age, income, and length of stay in the village show positive values, which means that the greater the variable's value, the higher the level of community participation in mangrove rehabilitation. Meanwhile, the income variable shows a negative value, that a small income indicates a low level of community participation in mangrove rehabilitation, which can cause mangrove damage due to the use of mangroves as an additional source of income. The community is still aware of the importance of mangrove rehabilitation by participating in mangrove planting. The results of revitalizing mangroves through planting mangrove vegetation have shown promising results because the area of mangrove land and the density of mangroves have increased since 2019.

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