Mapping of mangrove forest tree density using SENTINEL 2A satelit image in remained natural mangrove forest of Sumatra eastern coastal

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Abstract. The mangrove ecosystem in Forest Managemen Unit - VII (FMU) Sumatera Utara is a natural forest. FMU has not managed and utilizes mangrove forests optimally. It can open up opportunities for illegal loggers and trigger damage to these natural ecosystems. This condition requires prevention and mitigation so that severe damage to mangrove forests does not occur. This study aims to determine the relationship between vegetation index and mangrove density in the field and map the mangrove density distribution based on the image vegetation index value. The density distribution mapping was carried out by compiling a vegetation density estimator model NDVI, GNDVI, and TVI as independent variables. Correlation test and regression analysis between the vegetation index value (NDVI, GNDVI, and TVI) to the number of trees per unit area. The distribution model for the density of mangrove stands was chosen based on the coefficient of determination (R²). The study resulted from NDVI selected as the vegetation index used to map the distribution of mangrove density with a Pearson correlation coefficient (R) of 0.738. The selected model is Y = 2.48e^{2.8667x}, which is an exponential equation with a coefficient of determination (R²) of 61.3%. Based on this model, the distribution of mangrove density has the lowest density reaching 400, and the highest density is 2,200 trees per hectare
1. Introduction
Mangrove forest, as one of the coastal ecosystems, is the main ecosystem supporting life activities in coastal areas and plays an important role in maintaining the balance of the biological cycle [1,2]. As a country with the largest mangrove forest in the world, Indonesia has the highest mangrove forest area in Southeast Asia, which is around 3,244,018.64 hectares. This area is 19% of the total mangrove area in the world [3]. However, this ecosystem is threatened with sustainability and has become one of the centers of global environmental issues. This is caused by an increase in the rate of deforestation caused by population growth and an increase in world food needs, resulting in an increase in land use that causes degradation and a decrease in the area of the mangrove ecosystem. In addition, the lack of public attention in maintaining and utilizing the mangrove forest ecosystem is also one of the factors causing the increase in the rate of deforestation).

The mangrove forest ecosystem in FMU VII Aek Kanopan is an area of unspoiled mangrove forest. Until now, FMUs have not managed and optimally utilized mangrove forests. It can open up opportunities for illegal logging and trigger damage to the natural ecosystem. Based on this, it is necessary to carry out prevention and control activities such as mapping the distribution of mangroves and species inventory as the first step in managing and determining policies. In addition, to facilitate monitoring and evaluation of the area.

Monitoring using satellite imagery can cover a wider area. Monitoring indicators that can be used include vegetation density and biomass. Vegetation density can be estimated using the transformation of vegetation indices, including Normalized Difference Vegetation Index (NDVI) [4,5], Normalized Greens Difference Vegetation Index (GNDVI) [6], Transformed Vegetation Index (TVI), and other vegetation indices. In carrying out the inventory and monitoring In mangrove areas, data on vegetation index is very important because it can estimate biomass, leaf area index (leaf area index), and primary productivity [7]. NDVI (Normalized Difference Vegetation Index) is often used to calculate the density of vegetation. NDVI calculates how much solar radiation is absorbed by plants, especially in the leaves. This is due to the typical optical properties of chlorophyll; namely, chlorophyll absorbs the red spectrum and reflects the infrared spectrum.

Calculation of the value of the vegetation index is done by calculating several bands from satellite imagery. NDVI is calculated using the NIR (Near Infra-Red) and Red bands. In addition to NDVI, there is a vegetation index GNDVI, whose value is calculated using the Green band. [6] state that GNDVI compares the radiation absorbed by photosynthesis and then linearly correlated with leaf area index (LAI) and biomass. TVI is calculated to eliminate negative values and convert the NDVI histogram to a normal distribution. According to [8], this happens because eliminating the negative value in NDVI stabilizes the resulting variant. TVI values are calculated using the NIR and Red bands.

This vegetation index can be obtained from satellite images including Landsat, SENTINEL, and others. Sentinel-2A imagery, which is a European optical imaging satellite, launched in 2015. Sentinel 2-A has a spectral resolution of 13 channels that includes visible, near-infrared, and short-wave infrared sensors and a fairly high spatial resolution of 10 meters at red, blue, green, and near-infrared bands [9]. Sentinel 2A has four bands of 10 m resolution, six bands of 20 m resolution, and three 60 m spatial resolution bands with a swept area of 290 km. Sentinel 2-A images have the advantage of higher spatial resolution because they have a wider spectrum coverage [10]. Sentinel imagery is better in research on sensing in coastal ecosystems. It can be seen in the correlation coefficient, which will produce a strong relationship in several mangrove studies. Research on mangroves is influenced by the leaf's level of greenness [11,12].

The use of satellite imagery allows monitoring and data acquisition on a wide scale and in a fast time. Therefore, a study was conducted to use SENTINEL 2A satellite imagery to determine the condition of the mangrove forest stands in FMU VII. This study was conducted to determine the relationship between vegetation index and mangrove density in the field and to map the distribution of mangrove density based on the image vegetation index value.
2. Methods

2.1. Materials and tools
This research was conducted in the natural mangrove forest of the Forest Management Unit Region V Unit VII Aek Kanopan. This FMU is located in Panai Hilir District, Labuhanbatu Regency, North Sumatra Province (Figure 1). The tools used to retrieve data are GPS (Geographic Positioning System), digital camera, tally sheet, stationery, phi-band, hardware in the form of personal computer (Laptop), Microsoft Excel 2013 Microsoft Word. This study uses data processing tools: personal computer with ArcGIS 10.3 software, Microsoft Excel, Microsoft Word, and SPSS (Software Statistical For Social Science) Version 25. The research material used is administrative map data, forest area map of Sumatera Utara province in 2015, 2018, Sentinel 2A imagery, and mangrove forest stands.

2.2. Design sampling
The design of mangrove sampling was based on the alleged stand density class, namely the NDVI class. The NDVI value is divided into ten classes by ignoring the non-vegetative classes which are in the value of -1 to 0 [13]. After getting the density class, the plot is laid out in a systematic sampling with a random start, i.e., each NDVI class has a number of sample units according to its area.

2.3. Data collecting
The research took measurements in a plot measuring 10x10 meters. Each plot is divided into three subplots, namely the tree subplot (10 x 10 meters), saplings (5 x 5 meters), and seedlings (1 x 1 meter). The parameters measured were the number of individuals, diameter, and tree height of each type of vegetation in the plot [14].

2.4. Data analyze

2.4.1. Land cover classification. The initial stage in data analysis is to make a map of land cover classes, namely classifying mangrove and non-mangrove forest classes. Researchers do image pre-processing, which includes band merging, then image cutting. The combined bands are Red (4), Green (3), and SWIR (11). The land cover classification was carried out using the maximum likelihood classifier method. Furthermore, the classification results were tested for accuracy using a confusion matrix. The classification results are considered correct if the calculation of the confusion matrix is 80%.

2.4.2. Vegetation transformation index. The vegetation index formula used in this study (Table 1) is NDVI (Normalized Difference Vegetation Index), GNDVI (Green Normalized Difference Vegetation Index), and TVI (Transformed Vegetation Index). Pearson correlation test was applied to determine the relationship between mangrove stand density and the transformation of the vegetation index. Selection of the best model based on the value of $R^2$ (coefficient of determination)

| No | Vegetation index | Equation |
|----|------------------|----------|
| 1  | NDVI             | $NDVI = \frac{NIR-RED}{NIR+RED}$ |
| 2  | GNDVI            | $GNDVI = \frac{NIR-Green}{NIR+Green}$ |
| 3  | TVI              | $TVI = \sqrt{NDVI+0.5}$ |

Four regression models were examinded as below:
1. Linear: \[ Y = b_0 + b_1X \]
2. Logarithmic: \[ Y = b_0 + b_1\ln(X) \]
3. Power: \[ Y = b_0 + X^{b_1} \]
4. Exponential: \[ Y = b_0\exp(b_1X) \]

whereby:
- \( Y \) = un-independent variable (number tree per ha)
- \( X \) = independent variable (transformation of vegetation index NDVI, GNDVI, and TVI)
- \( b \) = constant

3. Result and discussion

3.1. Land cover
The land cover class map of the research location was presented in Figure 1. The classification of SENTINEL satellite imagery resulted in 2,559.61 hectares of mangrove and 3879.39 hectares of non-mangrove. In supervised classification, accuracy calculation is an absolute prerequisite that must be done. The confusion matrix shows the accuracy or accuracy of the image that has been classified with the reference data it has. In this study, the reference data is used as ground truth in the field. The accuracy test) shows the overall accuracy (OA) value of 93.97% and kappa accuracy of 86.90% (Table 2. It is following [15] the accuracy value must be more than 85%. So, the image interpretation results in this study are reliable and can be used for further analysis.

![Land Cover Map](image)

**Figure 1.** Landcover class map
Table 2. Accuration test of image classification

| Classified               | Field verified | Total | UA (%) |
|--------------------------|----------------|-------|--------|
|                         | Mangrove       | Non-mangrove |        |
| Mangrove coverage        | 51             | 0     | 51     | 100.00 |
| Non mangrove coverage    | 5              | 27    | 32     | 84.37  |
| Total                    | 56             | 27    | 83     |        |
| PA (%)                   | 91.07          | 100   |        |
| Average UA (%)           |                | 92.18 |
| Average PA (%)           |                | 95.53 |
| OA (%)                   |                | 93.97 |
| Kappa Accuracy (%)       |                | 86.90 |

3.2. Mangrove forest vegetation

At the seedling level, eight species of mangrove were found (Table 3). The species with the highest density was *Avicennia marina* with a percentage of 31.02, then the species with the lowest relative density was *Xylocarpus granatum* with a percentage of 0.23%. *Rhizophora apiculata* has the highest relative frequency with a percentage of 24.74% and *Xylocarpus granatum* has the lowest relative frequency of 0.85%. From Table 7, the most dominant species at the seedling level at the study site were *Avicennia marina*, *Avicennia alba*, *Rhizophora apiculata*, *Rhizophora mucronata*, *Bruguiera parviflora*, *Sonneratia alba*, and *Xylocarpus granatum*.

Table 3. Seedling density of mangrove forest based on field measured

| No | Local name | Scientific name | Density       |
|----|------------|-----------------|---------------|
| 1  | Bakau Hijau| *Rhizophora mucronata* | 8,500,00     |
| 2  | Bakau Merah| *Rhizophora apiculata* | 10,666,67    |
| 3  | Perepat    | *Sonneratia alba*   | 500,00       |
| 4  | Niri       | *Xylocarpus granatum* | 166,67      |
| 5  | Lenggadai  | *Bruguiera parviflora* | 13,166,67   |
| 6  | Api-api    | *Avicennia marina*   | 22,333,33    |
| 7  | Api-api Putih | *Avicennia alba* | 16,666,67    |
|    | Total      |                 | 72,000,00    |

At the sapling level, there are eight types of mangroves (Table 4). Both types of *Avicennia marina* and *Avicennia marina* have the highest density. It is because the research location is a tidal-prone location with a sandy mud soil type of substrate. Sequentially, the stand density was *Avicennia marina*, *Rhizophora apiculata*, *Bruguiera hainessi*, *Rhizophora mucronata*, *Bruguiera parviflora*, *Avicennia alba*, *Sonneratia alba*, and *Xylocarpus granatum*.
Table 4. Sapling density of mangrove forest based on field measured

| No. | Local name | Scientific name | Density trees/hectares |
|-----|------------|------------------|------------------------|
| 1   | Bakau Hijau | Rhizophora mucronata | 393.33 |
| 2   | Bakau Merah | Rhizophora apiculata | 720.00 |
| 3   | Perepat     | Sonneratia alba   | 180.00 |
| 4   | Niri        | Xylocarpus granatum | 53.33 |
| 5   | Mata Buaya  | Bruguiera hainessi | 393.33 |
| 6   | Lenggadai   | Bruguiera parviflora | 473.33 |
| 7   | Api-api     | Avicennia marina   | 946.67 |
| 8   | Api-api Putih | Avicennia alba  | 380.00 |
|     | Total       |                  | 3,540.00 |

At the tree level, nine mangrove species were found (Table 5). *Rhizophora apiculata* and *Avicennia marina* were the species with the highest number found at the study site. *Scyphiphora hydrophyllacea* is the species with the smallest number. *Rhizophora mucronata* is a species found in several plots with different soil substrates but is more commonly found in sandy soil types. Of the 60 plots, this species was found in 45 sample plots in the field.

Table 5. Tree density of mangrove forest based on field measured

| No. | Local name | Scientific name | Density trees/hectares |
|-----|------------|------------------|------------------------|
| 1   | Bakau Hijau | Rhizophora mucronata | 271.67 |
| 2   | Bakau Merah | Rhizophora apiculata | 285.00 |
| 3   | Perepat     | Sonneratia alba   | 50.00 |
| 4   | Niri        | Xylocarpus granatum | 41.67 |
| 5   | Mata Buaya  | Bruguiera hainessi | 98.33 |
| 6   | Lenggadai   | Bruguiera parviflora | 198.33 |
| 7   | Api-api     | Avicennia marina   | 275.00 |
| 8   | Api-api Putih | Avicennia alba  | 130.00 |
| 9   | Singgam     | Scyphiphora hydrophyllacea | 1.67 |
|     | Total       |                  | 1351.67 |

At the tree level, *Rhizophora mucronata* dominates the all mangrove species in the study area. The most dominant species sequentially based on Table 5 are *Rhizophora mucronata*, *R. apiculata*, *Avicennia marina*, *Bruguiera parviflora*, *B. hainessi*, *A. alba*, *Sonneratia alba*, *Xylocarpus granatum*, and *Scyphiphora hydrophyllacea*.

Figure 2. Vegetation index transformation result (a) NDVI, (b) GNDVI, and (c) TVI
The results of the correlation coefficient test (Table 6) show that the vegetation index has a relationship with mangrove density if the Pearson correlation value is not equal to zero (R ≠ 0). The correlation between NDVI and tree density is 0.738, GNDVI is 0.641, and TVI is 0.624. The results of the significance test between variables (Sig. (2-tailed) < 0.05) indicate that NDVI has an r-value of 0.738, where the r value is in the range of 0.71 – 0.90. According to [16], this value is included in the category of strong correlation. So that in determining the density model, the NDVI value is used as the independent variable.

Table 6. Pearsons correlation test

| Pearson number | NDVI | GNDVI | TVI |
|---------------|------|-------|-----|
| Pearson correlation | 0.738 | 0.641 | 0.624 |
| Sig (2-tailed) | 0.000 | 0.000 | 0.000 |

3.3. Model for estimating the density of mangrove forest vegetation
Regression analysis between mangrove tree density (bound variable) and NDVI value (independent variable) was used to obtain the best mathematical model between the two variables. The results of the regression analysis (Table 7) show the formed equation. The value of R² as the coefficient of determination is used as a determinant of the best model.

Table 7. Regression model analyze

| No | Vegetation | Regression | Equation | R  | R²  |
|----|------------|------------|----------|----|-----|
| 1  | NDVI       | Linier     | y = 39.099x – 9.0508 | 0.738 | 0.545 |
| 1  | NDVI       | Logarithmics | y = 19.991ln(x) + 24.585 | 0.705 | 0.497 |
| 1  | NDVI       | Power      | y = 30.071x^{0.857} | 0.758 | 0.574 |
| 1  | NDVI       | Exponential | y = 2.48e^{2.866x} | 0.783 | 0.613 |
| 2  | GNDVI      | Linier     | y = 26.752x + 3.5742 | 0.641 | 0.411 |
| 2  | GNDVI      | Logarithmics | y = 9.4812ln(x) + 23.319 | 0.610 | 0.372 |
| 2  | GNDVI      | Power      | y = 26.266x^{0.6804} | 0.633 | 0.401 |
| 2  | GNDVI      | Exponential | y = 6.453s^{1.3081x} | 0.655 | 0.429 |
| 3  | TVI        | Linier     | y = 40.201x – 26.289 | 0.624 | 0.389 |
| 3  | TVI        | Logarithmics | y = 39.452ln(x) + 14.013 | 0.616 | 0.380 |
| 3  | TVI        | Power      | y = 13.468x^{2.893} | 0.642 | 0.412 |
| 3  | TVI        | Eksponensial | y = 0.7504e^{2.8005x} | 0.647 | 0.419 |

From the four equation models, the results show that the exponential equation model is the best model based on the coefficient of determination (R²), which is 0.613. The coefficient of determination is a measure to determine the suitability or accuracy between the estimated value or the regression line with the sample data. So from these results, NDVI can be used to explain the mangrove density of 61.3% using this equation.

3.4. Mapping tree mangrove density
The application of the selected model on the NDVI map produces a stand density map. The mangrove forests' density is divided into four density classes (Table 8). Mangroves with low-density class are 177,526 ha, mangroves with medium-density class are 575,930 ha, mangroves with high-density class are 962,065 ha, and mangroves with very high density are 835,069 ha.

Table 8. Mangrove tree density within NDVI class from tree measured

| No. | NDVI class | Density class | Tree per hectares | Area (hectare) |
|-----|------------|---------------|------------------|----------------|
| 1   | 0.1802 - 0.4755 | Low density   | 400 - 1100       | 177,526        |
| 2   | 0.4755 - 0.5845 | Moderate density | 1100 - 1500     | 575,930        |
| 3   | 0.5845 - 0.6527 | High density  | 1500 - 1700      | 962,065        |
The mangrove forest density values (Figure 3) are in the range 0.1802 – 0.7594; then, this value is divided into four categories of mangrove density using the rank ArcGIS 10.3 natural breaks method. Mangroves that fall into the low-density category are in the NDVI range of 0.1802 – 0.4755, with many trees per hectare of 400 – 1,100 trees. Mangroves with medium density are in the NDVI range between 0.4755 – 0.5845 with 1100 – 1500 trees per hectare. In mangroves with high density, the NDVI value is between 0.5845 – 0.6527, with 1,500 – 1,700 trees per hectare. Then, the mangrove with the highest density value was in the NDVI range between 0.6527 – 0.7594 with the number of trees 17,00 – 2,200 per hectare.

Based on the distribution of the density data, the mangrove forest at the study site is included in the category of very dense mangrove density. It can be seen from the mangrove area with high and very high-density classes dominating at 71.21%; and has several trees ranging from 1,500 – 2,200 trees per hectare.

Figure 3. Tree density map of mangrove forest in FMU VII Sumatera Utara

4. Conclusions
The normalized difference vegetation index (NDVI) in SENTINEL 2 imagery has the highest close relationship to tree density with a Pearson correlation coefficient value of 73.8% (R = 0.738). The model chosen for mapping the distribution of mangrove density in this study is \( y = 2.48e^{2.8667x} \). This model was chosen to have the highest determination test results, namely \( R^2 = 0.613 \). Chosen model map a tree mangrove density shows the natural mangrove forest is in the high-density category. About 71.21% of natural mangrove forests are classified as dense and very high density, with the number of trees ranging within 1500 – 2200 trees per hectare.

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