Abstract. The existence of mangrove ecosystems is increasingly threatened due to the rapid development of tourist destinations and the increasing number of residents in Harapan, Kelapa and Pamegaran island, so that monitoring of mangrove ecosystems is necessary. The purpose of the research is to map the distribution of mangroves using remote sensing technology in Harapan, Kelapa and Pamegaran island. The field survey was conducted on April 1-10, 2021, taking 189 sample points using a hemispherical photography method. The maximum likelihood classification method is used to classify mangrove and non-mangrove vegetation. Normalized Difference Vegetation Index (NDVI) is an algorithm used to calculate vegetation indexes from satellite imagery. The Sentinel-2A image was classified into 3 classes of mangrove density, namely dense, moderate, and rare density classes, with the dominant class being the dense class. The total mangrove area on Pamegaran Island in 2015 amounted to 1.81 ha and the total mangrove area in 2021 amounted to 2.97 ha. The area of mangrove distribution in Harapan and Kelapa Island in 2015 amounted to 4.1 ha and in 2021 amounted to 6.56 ha. Mangrove density classification accuracy test using confusion matrix showed an accuracy of 82.95%.

Keywords: density, mangrove, NDVI, remote sensing, Sentinel-2A

1. Introduction

A mangrove ecosystem is a coastal ecosystem affected by the sea's tides so that the area is always flooded [1]. Mangrove ecosystems are one of the main components of the coastal ecosystem environment because mangrove forests have a fairly high ecological and economic value. The ecological function of mangrove forests includes spawning grounds, nursery ground, a feeding ground for marine life, and land protection from abrasion [2]. The existence of mangroves is spread throughout Indonesia, one of which is in Seribu Islands, Jakarta.

Seribu Islands consists of a cluster of tiny islands and shallow ocean waters that surround it [3]. The geographical location of Seribu Islands is close to Jakarta City makes Seribu Islands a frequently visited tourist destination. The increasing number of tourists visiting Seribu Islands impacts the environmental damage of coastal ecosystems in the Seribu Islands, especially mangrove ecosystems. The rapid development of tourist destinations and the increasing number of residents demand land-use changes that caused the decrease of mangrove ecosystems. To prevent damage to marine and coastal ecosystems in Seribu Islands, especially around Kelapa Island, Harapan Island and Pamegaran, it is necessary to monitor periodically the coastal ecosystems, especially mangrove ecosystems.
Monitoring the condition of mangrove ecosystems can be done by utilizing remote sensing technology based on a mathematical model using the Normalized Difference Vegetation Index (NDVI). NDVI is an algorithm for guessing vegetation indexes from satellite imagery [4]. Mapping the distribution of mangrove vegetation needs to be carried out by further research in the Thousand Islands National Park. Especially in Harapan Island, Kelapa and Pamegaran to monitor the existence of mangrove areas and to prevent the damage caused by tourism destinations and nature.

2. Methodology

2.1. Time and research location
This research began with ground-truth survey on April 1 - 10, 2021 in Harapan, Kelapa, and Pamegaran Seribu Island National Park. The data processing was conducted in April - May 2021 at the Spatial Mapping and Modeling Laboratory, Department of Marine Science and Technology, Faculty of Fisheries and Marine Sciences, IPB University. The research site is presented in Figure 1.

![Figure 1. Research site in Harapan, Kelapa and Pamegaran Island.](image)

2.2. Data and tools
Tools used include ASUS ROG Core i7 Laptop hardware equipped with ArcGIS 10.3 software, Microsoft Excel 2019, ENVI 5.3, ImageJ and Microsoft Word 2019. Tools used during field surveys include Garmin 64s Global Positioning System (GPS), stationery, and camera. Materials used include Sentinel-2A imagery acquisition on March 25, 2021 and November 22, 2015, Digital Elevation Model National (DEMNAS) data, Indonesia Topographic Map (RBI) 1:25,000, and mangrove density data. Data and sources can be seen in Table 1.
Table 1. Sources of information and data acquisition.

| No | Data                          | Data Sources                          | Resolution |
|----|-------------------------------|---------------------------------------|------------|
| 1  | Sentinel-2A imagery           | Scihub Copernicus (https://scihub.copernicus.eu) | 10x10 m    |
| 2  | Indonesia Topographic Map (RBI) | Indonesia Geospatial Information Agency (http://tanahair.indonesia.go.id) | 1:25.000   |
| 3  | Mangrove’s density data       | Field survey                          | -          |

2.3. Data processing and analysis

Stages in data processing included firstly preliminary image data processing, consisting of atmospheric correction, image composite, image cropping, and image masking, followed by image classification, calculating the percentage of mangrove canopy cover, mangrove distribution analysis using the Normalized Difference Vegetation Index (NDVI), and accuracy tests using confusion matrix methods to see the level of accuracy between image classification results and data obtained based on groundtruth surveys using hemispherical photography. Specifications of Sentinel-2A Satellite can be seen in Table 2.

Table 2. Specifications of Sentinel-2A Satellite.

| Band | Spectrum                  | Wavelength (μm) | Spatial Resolution (m) |
|------|---------------------------|-----------------|------------------------|
| 1    | Coastal aerosol           | 0.433 – 0.453   | 60                     |
| 2    | Blue                      | 0.458 – 0.523   | 10                     |
| 3    | Green                     | 0.543 – 0.578   | 10                     |
| 4    | Red                       | 0.650 – 0.680   | 10                     |
| 5    | Vegetation Red Edge 1     | 0.698 – 0.713   | 20                     |
| 6    | Vegetation Red Edge 2     | 0.733 – 0.748   | 20                     |
| 7    | Vegetation Red Edge 3     | 0.765- 0.785    | 20                     |
| 8    | NIR                       | 0.785- 0.900    | 10                     |
| 8A   | Vegetation Red Edge 4     | 0.855- 0.875    | 20                     |
| 9    | Water Vapour              | 0.855 – 0.875   | 60                     |
| 10   | SWIR-Cirus                | 1.365 – 1.385   | 60                     |
| 11   | SWIR 1                    | 1.565 – 1.655   | 20                     |
| 12   | SWIR 2                    | 2.100 – 2.280   | 20                     |

2.3.1. Normalized Difference Vegetation Index (NDVI). NDVI is an algorithm used to calculate vegetation index from satellite imagery [4]. This vegetation index value is calculated as the ratio between the measured reflection of the red band and the infrared band (approached by the NIR band) [5] as written in the following equation:

\[ NDVI = \frac{NIR - R}{NIR + R} \] (1)

Notes:

\( NDVI \) = Normalized Difference Vegetation Index

\( NIR \) = Spectral value of near-infrared band
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\[ R = \text{Spectral value of red band} \]

2.3.2. **Hemispherical photography method.** Hemispherical photography is a well-known method used to calculate the percentage of canopy cover of vegetation by utilizing a camera to take pictures of tree canopy cover. Mangrove canopy cover data obtained will be processed using Image J software. Analysis is done to separate the pixel value of canopy cover and the pixel value of the cloud. The equation that used during the analysis based on [6];

\[
\%C = \frac{P_{255}}{\Sigma P} \times 100\% \tag{2}
\]

Notes:
- \(\%C\) = Percent of mangrove canopy
- \(P_{255}\) = Pixel value 255
- \(\Sigma P\) = total number of Pixel image

The number of pixels from the analysis of the density and percent of mangrove cover is used to explain the status or condition of mangrove forests. The percentage category of mangrove canopy cover refers to [7] and the mangrove density category based on NDVI [8]. Mangrove density level criteria can be seen in Table 3.

**Table 3.** Mangrove density category based on percent canopy and NDVI.

| Mangrove Category | Percent canopy [7] | NDVI [8] |
|-------------------|-------------------|----------|
| Sparse            | 0 - 50%           | 0 to \(\leq 0.33\) |
| Moderate          | 50% - 69%         | 0.34 to \(\leq 0.42\) |
| Dense             | 70% - 100%        | 0.43 to \(\leq 1\) |

3. **Results and discussion**

3.1. **General condition of research site**
The territory of Harapan, Kelapa, and Pamegaran Island belong to the Seribu Islands National Park. Mangroves species are dominated by *Rhizophora stylosa* and *Rhizophora mucronata*. Some mangroves have grown naturally such as *Rhizophora apiculata*, *Bruguiera gymnorrhiza*, *Sonneratia alba*, *Xylocarpus rumphii*, *Xylocarpus granatum*. The substrate where the mangroves grow is a sand substrate. According to [9], the sand substrate is a very suitable location for mangrove growing for *Rhizophoraceae*, *Avicenniaceae*, and *Sonneratiaceae* families. Mangroves species in Harapan, Kelapa and Pamegaran Island can be seen in Figure 2.

3.2. **Mangrove distribution**
The mangrove forests derived from satellite data based on NDVI value consists six classes, namely (1) shallow waters, (2) land (3) non-mangrove (4) sparse mangroves (5) moderate mangroves, (6) dense mangrove, then these classes was reclass to three classes. The results showed that mangrove density in 2015 was dominated by sparse category (2.22 ha), moderate category (0.54 ha), and dense category (1.34 ha). The area of mangrove density in 2015 is presented in Table 4.
Figure 2. Mangrove species on Harapan, Kelapa, and Pamegaran Island.
Table 4. Mangrove area on Harapan and Kelapa Island in 2015.

| No | Mangrove density class | Area (ha) |
|----|------------------------|-----------|
| 1  | Sparse                 | 2.22      |
| 2  | Moderate               | 0.54      |
| 3  | Dense                  | 1.34      |

Mangrove density and distribution on Harapan and Kelapa Islands in 2015 were presented in Figure 3.

![Mangrove density and distribution map on Harapan and Kelapa Island in 2015.](image)

**Figure 3.** Mangrove density and distribution map on Harapan and Kelapa Island in 2015.

The results of the density class obtained through the analysis of vegetation index (NDVI) in Harapan and Kelapa Island in 2021 showed a change in the area compared to the result of 2015. The mangrove density in 2021 is dominated by a dense class (4.07 ha), moderate (0.56) ha, and sparse (1.92) ha. The changes in mangrove density can be seen in Table 5.

Based on Figure 4, there was a change in density class, mangrove density class in Harapan and Kelapa Island in 2021 was dominated by the dense class. The increase of dense mangroves caused by mangrove vegetation in the region is dominated by mangroves planting, mangrove planting distance has been designed close together so that artificial mangroves have a dense density. Mangrove density and distribution on Harapan and Kelapa Island in 2021 are presented in Figure 4.
Table 5. Mangrove area in Harapan and Kelapa Island 2021.

| No | Mangrove density class | Area (ha) |
|----|------------------------|-----------|
| 1  | Sparse                 | 1.92      |
| 2  | Moderate               | 0.56      |
| 3  | Dense                  | 4.07      |

Figure 4. Mangrove distribution and density map on Harapan and Kelapa Island in 2021.

The results of the reclass of NDVI values found that the mangrove distribution on Pamegaran Island in 2015 was dominated by a dense density class of 0.86 ha, then a sparse density class of 0.67 ha, and an intermediate density class with an area of 0.28 ha. Mangrove area on Pamegaran Island in 2015 is presented in Table 6.

Table 6. Mangrove area on Pamegaran Island in 2015.

| No | Mangrove density class | Area (ha) |
|----|------------------------|-----------|
| 1  | Sparse                 | 0.67      |
| 2  | Moderate               | 0.28      |
| 3  | Dense                  | 0.86      |
Mangrove density on Pamegaran Island is also categorized into 3 density categories, namely sparse mangrove, moderate mangrove, and dense mangrove. The dominant category in the area is dense category with 1.7 ha. Mangrove density on Pamegaran Island in 2015 is presented in Figure 5.

The density class obtained through the analysis of vegetation index (NDVI) on Pamegaran Island in 2021 showed a change in area at each density. Changes in mangrove density can be seen in Table 7.

| No | Mangrove density class | Area (ha) |
|----|------------------------|-----------|
| 1  | Sparse                 | 0.97      |
| 2  | Moderate               | 0.3       |
| 3  | Dense                  | 1.7       |

Based on image in 2021 showed an increase in the area of mangrove density class in Pamegaran Island in 2021. The density class is dense at 1.7 ha, the sparse density class is 0.97 ha, and the moderate density class is 0.3 ha. Mangrove density and distribution on Pamegaran are mapped and presented in Figure 6.
Based on the analysis of image in 2015 and 2021, the total density of mangroves in Harapan Island, Kelapa and Pamegaran in 2015 is as follow: dense category of 2.2 ha, then the moderate of 0.82 ha, and the sparse class of 2.89 ha, while for 2021 there was a significant increase for mangrove dense by 5.06 ha, moderate by 1 ha, and sparse class of 1.59 ha. The distribution of mangroves in Harapan Island, Kelapa and Pamegaran is dominated by mangroves with a dense category. This is because the substrate is suitable for mangrove development in Harapan, Kelapa and Pamegaran Island.

3.3. Mangrove distribution area changes

Figure 7 shows the widespread changes in mangrove distribution on Harapan and Kelapa Islands over the past 6 years. The area of mangrove distribution in 2015 amounted to 4.1 ha and in 2021, there was an increase in mangrove area to 6.56 ha. Mangroves in Harapan and Kelapa Island increased by 2.25 ha and decreased by 0.26 ha, while the area of mangroves with no change is 4.05 ha. In general, the addition of mangrove areas in the Area of Harapan and Kelapa Island is caused by a routine mangrove planting program. Mangrove density and distribution changes on Harapan and Kelapa Islands are mapped and presented in Figure 7.
Figure 7. Map of mangrove density and distribution changes on Harapan and Kelapa Islands.

Figure 8 showed a change in mangrove distribution on Pamegaran Island in 2015 - 2021. The area in 2015 amounted to 1.81 ha and in 2021, there was an increase in mangrove area to 2.97 ha. Mangroves in the Pamegaran Island area increased by 0.58 ha and decreased by 0.07 ha, while mangroves did not change by 2.39 ha. Mangrove density and distribution changes on Pamegaran Island are mapped and presented in Figure 8.

Changes in mangrove vegetation areas can also be caused by the dynamics of the waters of the research site at the time of satellite detection. Detection at low tide causes land areas not flooded by water to be more than at the time of detection at high tide [10]. Pixels from the mangrove classes can mix with sea classes. According to [11], if the satellite is recording at the highest tide, then it is likely that mangroves of *Rhizophora* sp. or other types of mangroves that have a lower height than sea tides will be covered by high tides so that this causes mixing with other categories or classes.

3.4. The correlation between percent canopy cover and NDVI value

Correlation analysis is a statistical method of calculating linear relationships between two or more variables. Correlation analysis in this study was used to determine the intensity between variable (x) which is mangrove canopy cover data based on the survey and variable (y) which is NDVI index vegetation value [12]. The correlation test that used in this study is simple linear regression. The result of regression test can be seen in Figure 8.
Figure 8. Map of mangrove density and distribution changes in Pamegaran Island.

Figure 9. The correlation between percent canopy cover and NDVI value.

The percent relationship of canopy cover with NDVI is illustrated by a simple regression model presented in Figure 9. The regression model resulted in an equation of $y = 0.821x + 0.0308$ with a correlation coefficient ($r$) of 0.93, which means that NDVI and mangrove canopy cover has a close
relationship [13]. The coefficient of determination is 0.87 which means that 87% of NDVI values are affected by mangrove canopy cover and 13% are influenced by other factors.

3.5. Validation
Classification results are tested for accuracy using the confusion matrix test. Accuracy tests in Harapan, Kelapa and Pamegaran Island resulted in overall accuracy (OA) of 82.95%. Overall accuracy greater than 70% means the accuracy of an acceptable classification [14]. The result of confusion matrix is presented in Table 8.

| Classification Results | Field Survey |
|------------------------|--------------|
|                        | M  | S  | NM | D  | Total | UA (%) |
| M                      | 24 | 2  | 0  | 4  | 30    | 80.00  |
| S                      | 0  | 19 | 0  | 2  | 21    | 90.91  |
| NM                     | 0  | 4  | 0  | 0  | 4     | 0      |
| D                      | 1  | 2  | 0  | 30 | 33    | 90.48  |
| Total                  | 25 | 27 | 0  | 36 | 88    |         |

| PA (%)                  | 96.00       |
|                        | 70.37       |
|                        | 83.33       |
| OA (%)                 | 82.95       |

The variation in value of the accuracy of the classification is influenced by various factors. These factors are differences in image time acquired with ground-truth time, atmospheric conditions when retrieving data, object identification errors, and reference data errors [15].

4. Conclusion
The distribution of density and mangrove area in Harapan, Kelapa and Pamegaran Island has increased every year. Sentinel-2A image classification produces 3 classes of mangrove density, namely the density class dense, moderate, and sparse, with the dominant class being the dense class. The total mangrove area on Pamegaran Island in 2015 amounted to 1.81 ha and the total mangrove area in 2021 amounted to 2.97 ha. Mangrove area in Harapan and Kelapa Island in 2015 amounted to 4.1 ha and in 2021 amounted to 6.56 ha. Mangrove density accuracy test results using confusion matrix in density classification with field survey resulting 82.95%.

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