Assessment of mangrove ecosystem conditions in Sepulu District, Bangkalan

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Abstract. The mangrove ecosystem is one of the many coastal and marine natural resources. This ecosystem has many benefits, both for society and the environment. The purpose of this study was to assess the state of the mangrove ecosystem in Sepulu District, Bangkalan. Sentinel-2A image data of 2021 downloaded from *https://scihub.copernicus.eu* and *in situ* data were used in this study. Three villages were used as data collection locations and in each village there are 6 - 15 transect plots. The structure of the mangrove ecosystem was studied using quadrat transects (10 x 10 m), hemispherical photography (4 - 9 photos for each plots) and the Normalized Difference Vegetation Index (NDVI) for calculating the density of mangrove. The mangrove canopy cover was analyzed using Image J software. The findings included *Sonneratia alba, Rhizopora mucronata, Rhizophora stylosa, Avicennia alba, Avicennia marina, Rhizophora apiculata, and Bruguera gymnorrhiza*. In general, the *Sonneratia alba* (147.07) had the greatest important value index (IVI), followed by the *Rhizophora mucronata* (96.71). Mangroves with a high IVI indicate the magnitude of the mangrove's influence in a location. Canopy cover and density were used to measure mangrove conditions. The results revealed that the overall canopy cover was 64.55 ± 9.31 (%) and the density was 2289 ± 1131 (ind/ha). Furthermore, the result indicated the average of NDVI (0.62) with dense conditions. Overall, the findings suggest that the Sepulu District mangrove ecosystem was in good/healthy condition and need potential action for improvement in mangrove conservation and management in Sepulu District.

Keywords: Hemispherical photography, Mangrove ecotourism, Normalized Difference Vegetation Index, Sentinel-2A.

1 Introduction

One of the coastal and marine natural resources found in almost all of Indonesia's coastal areas is the mangrove ecosystem [1]. Their growth is influenced by sea tides. Mangrove forests are a typical type of forest that located along the coast or river estuaries. Mangrove ecosystems are able to live in tidal areas, especially on protected beaches, lagoons and river estuaries that are flooded at high tide and free from puddles at low tide. Mangroves can also grow along sheltered, muddy beaches, free from strong winds and currents, for example at the mouths of large river estuaries [2].

Mangrove forests have physical functions, ecological functions, chemical functions and socio-economic functions [3, 4, 5]. The physical functions of mangroves include protecting land where humans live from the threat of tsunamis, tidal floods, high waves and salt water filtration. For instance [6] planted 1000 mangroves in Prapag Kidul and Prapag Lor Villages in Brebes Regency, Central Java to prevent abrasion and also develop the tourism potential of the Kalianyar area. The ecological functions of mangroves include as a spawning ground for marine biota, nursery ground, foraging for food and nutrient export. For instance [7] reported the mangrove forest ecosystem on Pramuka Island, Seribu Islands, is dominated by Terebralia sp. and Littorinidae sp (gastropods) and Brachyura (crustaceans). Apart from that, there are also other aquatic biota such as shrimp, cendro fish and juvenile fish. The chemical function of mangroves is that mangroves can absorb and store five times more carbon than terrestrial plants and produce twice as much oxygen. For instance [8] elucidated that with an average density of 192 mg C/ha, the current total mangrove carbon store of the entire island of Hainan was calculated to be 703,181 mg C, with an average of 44.7 mg C/ha for the above- and 147.3 mg C/ha for the below-ground carbon stocks. The island's north-eastern and western regions have the largest and lowest levels of mangrove carbon storage, respectively. The socio-economic functions of mangroves include fruit and leaves that can be processed and made into food products and forest areas can be used for ecotourism as an environmental service. For instance [9] exploring the

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mangrove fruit. They reported numerous processed food products are effectively made from mangrove fruit. In addition, [10] developing mangrove ecotourism in Nusa Penida Sacred Island, Bali, Indonesia.

A community-based ecotourism pattern is an ecotourism development pattern that supports and enables full involvement by local communities in the planning, implementation and management of ecotourism businesses and all the benefits they obtain. Community-based ecotourism is an ecotourism business that emphasizes the active role of the community. This is based on the fact that people have knowledge about nature and culture which has potential and selling points as a tourist attraction, so that community involvement is absolute. One of the a community-based ecotourism is mangrove ecotourism.

The tourism sector, which includes the mangrove tourism sector, has a lot of promise since it places a high priority on the preservation and sustainable use of natural resources. It is envisaged that the introduction of ecotourism to the mangrove ecosystem will lessen natural deterioration and damage to human-used mangrove regions [11]. In order for tourism destinations to grow sustainably, they must be developed in ecologically suitable locations that have positive effects on the environment, society, and economy [12].

Community-based ecotourism, including mangrove ecotourism, can create employment opportunities for local communities and reduce poverty, where ecotourism income comes from tourism services for tourists such as guide fees, transportation costs, homestays, selling crafts, etc. Ecotourism has a positive impact on preserving the environment and local indigenous culture.

According to [13] since the 1970s, conservation organizations have begun to see ecotourism as a conservation-based economic alternative because it does not damage nature or is not "extractive" with negative impacts on the environment such as logging and mining. Ecotourism is also considered a type of business that is economically and environmentally sustainable for people living in and around conservation areas. Ecotourism is valued and developed as a business program which can also be a conservation strategy and can open up economic alternatives for the community. With the ecotourism pattern, people can take advantage of natural beauty that still intact, local culture and history without destroying or selling the contents.

A mangrove habitat may be found in Bangkalan Regency's Sepulu District in East Java. Many of Sepulu District's mangrove ecosystems are now being utilized as mangrove tourist destinations. Nevertheless, there is not much information about the state of the mangrove ecosystem in this region at the moment. Determining the state of the mangroves and the potential for ecotourism in the area is the first step towards developing mangrove ecotourism. Therefore, efforts to improve mangrove ecotourism depend heavily on knowledge regarding the state of the mangrove ecosystem. The purpose of this study is to evaluate the state of the mangrove ecosystem condition in Sepulu District. The research contribution is to elucidate the mangrove ecosystem condition such as types of mangroves, canopy cover, density and important value index of mangrove in Sepulu District, Bangkalan.

2 Methodology

2.1 Study area

The study was conducted in East Java's Bangkalan Regency's Sepulu District (Figure 1). Three settlements, Maneron Village, Labuhan Village, and Lembung Paseser Village, served as the locations for the mangrove data collection (Table 1). This is one of the Madura region's well-protected mangrove conservation sites. Apart from that, in this area mangrove ecotourism has been formed like the one in Labuhan village. Information the condition of the mangroves is still very limited at this location.

Fig. 1. Study area.

2.2 Tools and data

The tools and materials used in this research include Sentinel 2A images obtained from www.scihub.copernicus.eu.com, personal protective equipment, global position system (GPS), raffia rope, transect/meter rope, sewing meter, pilox, camera or smart phone, maps, and office stationery. Sentinel 2A images were chosen because they have better resolution than other images such as Landsat. Sentinel 2A has a spatial resolution of 10 x 10 m while Landsat has a resolution of 30 x 30 m. Raffia rope was used to make a 10 x 10 m square transect, while pilox was used to mark mangroves from which data has been taken.

2.3 Quadratic transect and hemispherical photography

This activity of observing and monitoring the condition of the mangrove forest is an initial observation (t_0). Data was collected and analyzed in accordance with the COREMAP-LIPI mangrove monitoring criteria [14]. The quadratic transect and hemispherical photography methods were used for this task. After locating an appropriate observation and monitoring location using GPS, create a permanent plot. A square plot measuring

10m x 10m was created using a transect rope, and the plot shape was ensured to be square. The hemisperichal photography approach, which requires a camera at one place to take the photo [15, 16, 17], is used to compute the percentage of mangrove cover. This method is relatively new in Indonesian mangrove forests (Figure 2).

Table 1. Location of mangrove data collection.

Station	Point	Plot	Coordinate point	
			Longitude	Latitude
Station 1 (Maneron)	1	1	112° 56’ 24’’	-6° 53’ 20”
		2	112° 56’ 24’’	-6° 53’ 20”
		3	112° 56’ 25’’	-6° 53’ 20”
	2	1	112° 56’ 23’’	-6° 53’ 21”
		2	112° 56’ 24’’	-6° 53’ 21”
		3	113° 00’ 26’’	-6° 53’ 04”
Station 2 (Labuhan)	1	1	113° 00’ 24’’	-6° 53’ 04”
		2	113° 00’ 22’’	-6° 53’ 05”
		3	113° 00’ 26’’	-6° 53’ 06”
	2	1	113° 00’ 24’’	-6° 53’ 06”
		2	113° 00’ 22’’	-6° 53’ 06”
		3	112° 59’ 41’’	-6° 53’ 08”
	3	1	112° 59’ 70’’	-6° 53’ 50”
		2	112° 59’ 17’’	-6° 53’ 30”
		3	112° 59’ 55’’	-6° 53’ 19”
	4	1	112° 58’ 74’’	-6° 53’ 18”
		2	112° 58’ 92’’	-6° 53’ 89”
		3	112° 58’ 06’’	-6° 53’ 60”
	5	1	112° 59’ 08’’	-6° 53’ 16”
		2	112° 59’ 24’’	-6° 53’ 29”
		3	112° 59’ 39’’	-6° 53’ 34”
(Station 3) Lembung Paseser	1	1	112° 59’ 41’’	-6° 53’ 08”
		2	112° 59’ 43’’	-6° 53’ 08”
		3	112° 57’ 35’’	-6° 53’ 08”
	2	1	112° 59’ 41’’	-6° 53’ 10”
		2	112° 59’ 43’’	-6° 53’ 10”
		3	112° 59’ 45’’	-6° 53’ 10”

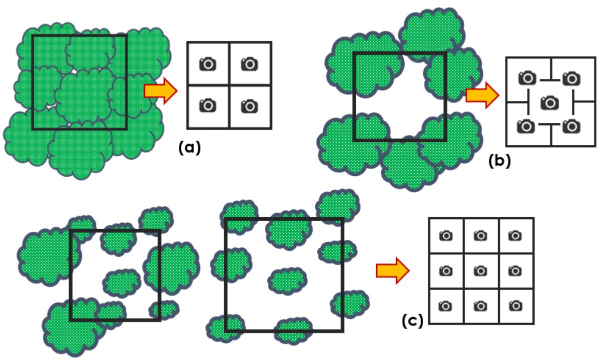

Fig. 2. Positions for photographing in diverse mangrove canopy conditions [14].

2.4 Data retrieval for mangrove community structure

In each plot measuring 10 m x 10 m, the trunk circumference of all mangrove trees (stem circumference ≥ 16 cm) was measured [18]. Measurements are made using a sewing meter in cm units. This measurement was carried out based on the opinion of [19] and Minister of Environment Decree No. 201 of 2004 concerning Standard Criteria and Guidelines for Determining Mangrove Damage (Figure 3). Based on the figure 3, it can be seen that the root and branch systems influence the measurement of stem circumference. For instance, if the branching occurs under a height of 1.3 m, then the trunk circumference of each branch will be measured. Identification of mangrove types refers to [20, 21, 22, 23].

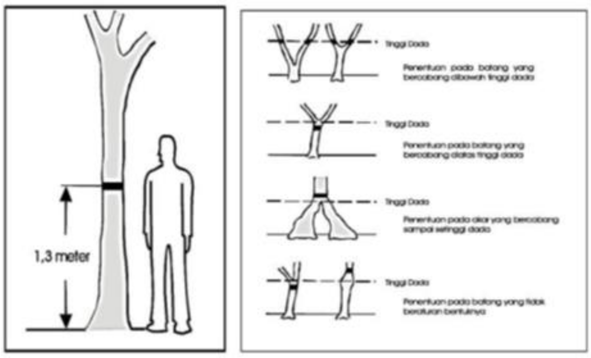

Fig. 3. Place for measuring mangrove tree trunks on several different types of trunks which are influenced by the root and branch systems (Minister of the Environment Decree No. 201 of 2004).

2.5 Data analysis

2.5.1 Percentage of mangrove canopy cover

Measurement of the percentage of canopy cover was carried out using the hemispherical photography method. This method is used by using a fish-eye camera or using a cellphone in squere mode with the camera positioned parallel to the chest and facing upwards. The concept of this method is to separate sky and vegetation pixels so that the percentage of pixels covered by mangrove vegetation can be calculated in binary image analysis [24]. The photos taken are then analyzed using ImageJ software which can be downloaded for free http://imagej.nih.gov/ij/download.html.

2.5.2 Satellite image processing

Image processing was carried out using SNAP software which includes image cropping, vegetation index analysis and ArcGIS software for layout. Normalized Difference Vegetation Index (NDVI) was used to analyze the mangrove density. The density can be seen from the value between -1 and +1. A higher index value typically denotes better health than a lower score [25]. The formula for calculating NDVI was as follows [26]:

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{1}$$

Where:
NIR = near infrared radiation channel (Band 8)
Red = red light radiation channel (Band 4)

2.5.3 Mangrove Community Structure Data Analysis

[14] stated that the Minister of Environment Decree no. 201 of 2004 can be used as an initial reference in determining the status of mangrove forests in Indonesia. Table 2 shows three categories of mangrove conditions based on the value of density or mangrove canopy cover. The higher the % cover or density value indicates the healthy condition of the mangrove ecosystem. A healthy ecosystem can indicate that many mangroves were growing healthy.

Table 2. Mangrove degradation status category in Minister of Environment Decree no. 201 of 2004.

Category	% cover	Density (ind/ha)
Bad/Damage	< 50%	< 1000
Moderate	50 – 75%	1000 – 1500
Good/Healthy	≥ 75%	≥ 1500

The structure of the mangrove community analyzed was species density, relative density, species frequency, relative frequency, species cover and relative cover. The formulas used were as follows [19].

$$Di = \frac{Ni}{A} \tag{2}$$

Where:
Di = Species density to - i (ind/m^2)
Ni = Total number of individuals of type to - i (ind)
A = The total area of sampling (m^2)

$$RDi = \frac{Ni}{\sum n} \times 100\% \tag{3}$$

Where:
RDi = Relative Density (%)
Ni = Number of individuals of the type to - i (ind)
Σn = Total number of individuals (ind)

$$Fi = \frac{pi}{\sum p} \tag{4}$$

Where:
Fi = Frequency of type to-i
pi = Number of sample plots created
∑p = The total number of sample plots created

$$RFi = \frac{Fi}{\sum F} \times 100\% \tag{5}$$

Where:
RFi = Relative Frequency (%)
Fi = Frequency of type to-i (ind)
ΣF = The total frequency of all types (ind)

$$Ci = \frac{\sum BA}{A} \tag{6}$$

Where:
Ci = Species cover to-i
BA = Tree diameter from type to-i
A = Total area of sampling area (plot)

$$RCi = \frac{Ci}{\sum C} \times 100\% \tag{7}$$

Where:
RCi = Relative cover (%)
Ci = The area of cover type to-i
ΣC = The total area of cover for all types

The Importance Value Index (IVI) provides an overview of the influence or role of a type of mangrove in the mangrove community. The value was the sum of the relative density of species (RDi), relative frequency of species (RFi), and relative cover of species (RCi). The IVI ranges from 0% - 300% and can be calculated using the following formula:

$$IVI = RDi + RFi + RCi \tag{8}$$

3 Results and discussion

3.1 Types of mangrove

Field data collection was carried out to determine the type, condition and structure of the mangrove community at the research location. There are 7 types of mangroves found at the research location, including *Sonneratia alba* (SA), *Rhizopora mucronata* (RM), *Rhizophora stylosa* (RS), *Avicennia alba* (AA), *Avicennia marina* (AM), *Rhizophora apiculata* (RA) and *Bruguera gymnorrhiza* (BG) (Table 3).

Table 3. Types of mangroves and number of stands.

No	Types of Mangrove	Number of Stands.
1	*Sonneratia alba*	285
2	*Rhizopora mucronata*	222
3	*Rhizophora stylosa*	32
4	*Avicennia alba*	32
5	*Avicennia marina*	23
6	*Rhizophora apiculata*	20
7	*Bruguera gymnorrhiza*	10

Sonneratia alba and *Rhizopora mucronata* are the two types of mangroves most commonly found. [27, 28] explained that *Sonneratia alba* has a height of up to 15 m. The bark is dark white to brown. The roots are shaped like cables underground and emerge to the surface as respiratory roots which are shaped like blunt cones and reach a height of 25 cm. Leaves are leathery, have undeveloped glands at the base of the leaf stalk.

Bisexual flowers; blunt flower stalk 1 cm long. The fruit is like a ball, has a stem at the end and the base is covered in flower petals. The fruit contains many seeds (150-200 seeds). Fruit diameter 3.5-4.5 cm. This species is a pioneer, not tolerant of fresh water for long periods. Likes soil mixed with mud and sand, sometimes rocks and coral. This species is found in coastal locations that are protected from pounding waves, as well as in estuaries and around offshore islands. In addition [29, 30] reported that *Sonneratia alba* is a type of mangrove that is often found in tidal areas and has high ability and tolerance to environmental conditions. This species can adapt to various types of substrates. [31] stated that *Sonneratia alba* produces more seeds and has a longer lifespan, so it dominates a wider area. According to [32] this species can grow on much coarser soil but still has a fine texture. Furthermore, **[**33] reported that *Sonneratia alba* can be found throughout the study area, from sand to sandy clay substrates.

[27, 28] explained that *Rhizopora mucronata* has a height of up to 27 m, rarely exceeding 30 m. The stem has a diameter of up to 70 cm with dark to black bark. Supporting roots and aerial roots grow from the lower branches of the skinned leaves. The leaves are leathery with green stems, 2.5-5.5 cm long. The flower heads are like forks, bisexual, each attached to an individual stalk 2.5-5 cm long. Fruit oval/long to egg-shaped measuring 5-7 cm, brownish green, often rough at the base, has a single seed. In addition [29] reported Rhizophora sp is a type of mangrove that is often found in zones near the sea. Rizhopora sp has supporting roots that are used to support the body and are able to adapt to unstable environments [34]. *Rhizophora mucronata* is very well adapted or more tolerant to harder substrates and sand [35]. [36] stated that this type is more tolerant of denser and sandy substrates, grows in groups and is one type of mangrove that is widely distributed.

[27, 28] elucidated that *Rhizophora stylosa* is a mangrove that has one or many stems, up to 10 m high. The bark is smooth, fissured, gray to black. It has supporting roots up to 3 m long, and aerial roots that grow from the lower branches. Leaves are leathery, regularly spotted on the lower layer. The leaf stems are green, the stems are 1-3.5 cm long, with the leaf pins 4-6 cm long. The shape of the leaves is wide elliptical and the tip is tapered. The flower heads are fork-like, bisexual, each attached to an individual stalk 2.5-5 cm long. The fruit is 2.5-4 cm long, pear-shaped, brown, contains 1 fertile seed. This species can grow in a variety of habitats in tidal areas: mud, sand and rocks. This species likes tidal river embankments, but is also a pioneer species in coastal environments or inland parts of mangroves.

[27, 28] explained that *Rhizophora apiculata* is a mangrove with a height of up to 30 m with a trunk diameter of up to 50 cm. It has distinctive roots reaching a height of 5 meters, and sometimes has aerial roots coming out of the branches. The bark is dark gray and variable. Bisexual flowers, yellowish flower heads located on pedicels measuring <14 mm. The rough fruit is round and elongated to pear-like, brown in color, 2-3.5 cm long, contains one fertile seed. Prefers tidal waters that have a strong permanent influence of freshwater input. Grows in muddy, smooth, deep soil and is flooded at normal tide. Does not like harder substrates mixed with sand.

[27, 28] explained that *Avicennia alba* grow spread to a height of up to 25 m. Groups of trees form a complex system of horizontal roots and respiratory roots. The respiratory roots are usually thin, finger-shaped (or asparagus-like) covered by lenticels. The outer bark is grayish or dark brownish, some are covered with small bumps, while others sometimes have a smooth surface. On the old stems, sometimes a thin powder is found. The surface of the leaves is smooth, the top is shiny green, the bottom is pale. Trident-like flowers with clusters of flowers (yellow) almost along the entire length of the bunch. The fruit is like a cone/chili/cashew, light yellowish green in color. It is a pioneer species in mangrove swamp habitats in protected coastal locations, also in saltier parts along river banks that are influenced by tides, and along coastlines. They generally like the bay front. In addition [37] reported that this species has a unique adaptation ability to be able to live and develop on muddy and acidic substrates, anoxic and always flooded, high salt water levels, less stable soil and the presence of tides. Avicennia is a type of mangrove that is able to live in habitats flooded by tides and anaerobic soil, with a complex root system.

[27, 28] explained that *Avicennia marina* is a mangrove that grow upright or spreading, the tree height reaches 30 meters. Having a complex, pencil-shaped (or asparagus-shaped) horizontal root system, the respiratory roots are upright with numerous lenticels. The bark is smooth with gray-green mottles and peels off in small sections. Young twigs and leaf stalks are yellow, hairless. The upper surface of the leaves is covered with concave glandular spots. The underside of the leaves is white to light grey. Trident-like flowers with clustered flowers appearing at the end of the bunch, pungent odor, lots of nectar. The fruit is slightly rounded, slightly grayish green in color. The surface of the fruit has smooth hair (like it has flour) and the tip of the fruit is slightly sharp like a beak. This species has the ability to occupy and grow in various tidal habitats, even in salty places. This type is one of the most common types of plants found in tidal habitats. In addition [38] reported that Avicennia marina usually grows or is found in the middle zone. This type of mangrove grows in areas with clayey sand substrates.

[27, 28] explained that *Bruguera gymnorrhiza* is an evergreen tree with a height sometimes reaching 30 m. The bark has lenticels, the surface is smooth to rough, dark gray to brown (color changes). Its plank-like roots spread to the sides at the base of the tree, and also have a number of knee roots. Leaves have skin, green on the top layer and yellowish green on the bottom with black spots (some don't). Hanging flowers with a flower stalk length of between 9-25 mm. Fruit spirally circular, transversely circular, 2-2.5 cm long. This species grows in areas with low salinity and dry, and well-aerated soil. This type is tolerant of protected areas and those that receive direct sunlight. They also grow on the land edges of mangroves, along ponds and tidal and brackish rivers.

Found on the coast only if there is erosion on the land in front of it. The substrate consists of mud, sand and sometimes black peat.

3.2 Mangrove community structure and importance value index

In general, the structure of the mangrove community and the IVI of mangroves can be seen in Table 4. In general, the *Sonneratia alba* type is the type of mangrove that has the highest frequency (F), density (K) and dominance (D) values compared to other types of mangroves. This had an impact on the high IVI value obtained by *Sonneratia alba* (147.07) followed by *Rhizopora mucronata* (96.71). These two types of mangroves always dominate or have high IVI values at each observation station compared to other types of mangroves (Table 5). [30] explained that the highest IVI indicates mangrove control in a place, where a high IVI will be proportional to high canopy cover, distribution and dominance. Several factors that cause differences in the IVI are the type of substrate, tides and sea water, competition between species in obtaining nutrients [39].

Table 4. Types, mangrove community structure and importance value index.

Type	**F**	**C**	**D**	**RF**	**RC**	**RD**	**IVI**
SA	1.89	33.67	3887.78	33.33	49.00	64.73	**147.07**
RM	1.78	23.11	912.90	33.33	36.16	27.22	96.71
AA	0.67	10.33	359.36	7.69	8.78	3.12	19.60
AM	0.67	2.67	85.81	12.82	5.43	3.95	22.21
RS	0.83	5.67	168.37	11.54	6.10	3.05	20.69
BG	1.00	3.33	117.38	11.54	2.83	1.02	15.39
RA	0.50	1.83	50.79	9.62	2.20	1.03	12.84

Where: Values of species frequency (F), relative frequency (FR), species density (K), relative density (KR), species dominance (D), relative dominance (DR) and important value index (IVI).

[40] stated that *Sonneratia alba* has a large number of seeds and greater ability to survive, which influences dominance in a larger research area. This type develops on relatively coarser soil but in general is still classified as fine-textured soil [32]. Furthermore, [33] also stated that the *Sonneratia alba* species is also found in sand to sandy clay substrates. On the other hand, *Rizhopora mucronata* is usually found in the middle zone with clay sand substrates with low organic matter content. *Rizhopora sp*. is often found in areas with clay substrates because this type has supporting roots which are used to support the body of the plant itself and is able to adapt to unstable environments [34]. According to [41] *Rizhopora mucronata* is often found in areas that are always flooded with water.

Table 5. Types of mangrove and important value index (IVI).

Village	Type of Mangrove	IVI
Moneron (Station 1)	***Sonneratia alba***	**174,22**
	Rhizophora mucronata	**93,13**
	Avicennia marina	32,07
Total		**300**
Labuhan (Station 2)	***Sonneratia alba***	**156,81**
	Rhizophora mucronata	**65,24**
	Avicennia marina	9,53
	Avicennia alba	47,96
	Rhizophora stylosa	26,33
	Rhizopora Apiculata	7,10
	Bruguera gymnorrhiza	15,39
Total		**300**
Lembung Paseser (Station 3)	***Rhizophora mucronata***	**131,76**
	Sonneratia alba	**109,59**
	Rhizopora apiculata	18,58
	Avicennia marina	25,02
	Rhizophora stylosa	15,05
Total		**300**

3.3 Canopy cover and mangrove density

3.3.1 Normalized difference vegetation index and hemispherical photography

The NDVI algorithm is a vegetation index that is often used [42, 43, 44]. NDVI is generally used to differentiate vegetation areas from non-vegetation areas. The range of NDVI values is between -1 to 1. Minus values usually indicate non-vegetation which may be water bodies, ponds, people's houses and so on. NDVI has good qualities in explaining vegetation density. NDVI can also be used as time-series analysis. By recording NDVI over several years, changes in vegetation can be seen both spatially and temporally [45]. The map of the results of mangrove density processing using the NDVI vegetation index algorithm is presented in Figure 4. High NDVI values are represented in green while low NDVI are represented in red. The results show a max value of 0.88. This indicates that the mangrove ecosystem at the research location has a high level of density. The analysis results also show that the mangrove area is 110.18 ha with dense (89.14 ha), medium (8.73 ha) and sparse (5.2 ha) conditions.

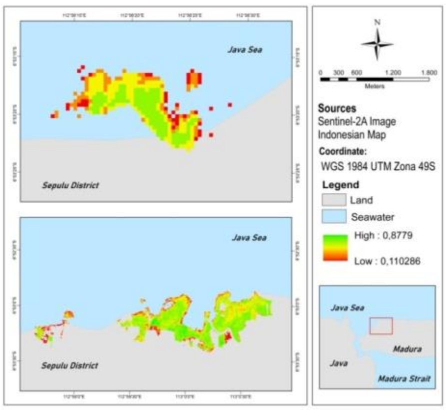

Fig. 4. Vegetation index classification map normalized difference vegetation index.

This method is used to take photos of mangroves. This method is simple to implement and gives more precise data. Figure 5 shows the results of taking field photos using hemispherical photography and the results of processing canopy cover using Image J software. The results of taking photos using hemispherical photography are processed using Image J software. This software is used to calculate the value of mangrove canopy cover. The percentage of mangrove canopy cover in each plot is presented in Table 6. In general, the condition of the mangrove ecosystem is in good/healthy condition. This is indicated by the average value of percent cover (% cover) which has a value between 50 – 75% (64.55% ± 9.31) and a density value of ≥ 1500 (2289 ± 1131 ind/ha) (Minister of Environment Decree No. 201, 2004).

a b

Fig. 5. Mangrove canopy cover processing (a) Photo of the original canopy (b) Photo of the canopy resulting from separating the sky pixel values and canopy cover.

In general, the dominant type of mangrove is *Sonneratia alba*. This type of mangrove has the ability to produce allelopathy which can inhibit the growth of new species in its growth area. This results in the distance between stands in the Sonneratia zone being farther than in Rhizophora [46]. Apart from the number and type of species, the size of the tree trunk circumference can also influence the percent canopy cover [47]. *Sonneratia alba* dominantly has a large trunk circumference (>30 cm) so that the greater the circumference of the mangrove tree trunk, the smaller its density (rare). On the other hand, Rhizophora can be close to each other because they have small tree trunk circumference values (< 30 cm). Furthermore, [20, 41] stated that the type Rhizophora sp. has wide and large leaves and is old in age, making the canopy more perfect. The greater the area of leaf overlap, the denser the mangrove canopy cover [48].

Table 6. Percentage of Canopy Cover.

Station	Point	Plot	Mangrove canopy cover (%)	Density (ind/ha)	Category
Maneron	1	1	54.98	3100	Good/ Healthy
		2	58.60	2800	Good/ Healthy
		3	61.40	4600	Good/ Healthy
	2	1	54.45	2400	Good/ Healthy
		2	61.44	1300	Moderate
		3	51.85	1500	Good/ Healthy
Average			**57.12 ±3.95**	**2617± 1202**	**Good/ Healthy**
Labuhan	1	1	56.39	3100	Good/ Healthy
		2	51.86	1000	Moderate
		3	59.99	4100	Good/ Healthy
	2	1	65.22	2500	Good/ Healthy
		2	57.14	1900	Good/ Healthy
		3	57.00	4400	Good/ Healthy
	3	1	55.65	600	Bad/ Damage
		2	53.65	1900	Good/ Healthy
		3	66.49	1600	Good/ Healthy
	4	1	56.98	3100	Good/ Healthy
		2	72.74	2500	Good/ Healthy
		3	83.55	3800	Good/ Healthy
	5	1	72.19	1900	Good/ Healthy
		2	72.85	800	Bad/ Damage
		3	69.33	2100	Good/ Healthy
Average			**63.40 ±9.18**	**2353± 1167**	**Good/ Healthy**
Lembung Paseser	1	1	75.50	1800	Good/ Healthy
		2	74.97	1700	Good/ Healthy
		3	72.77	2500	Good/ Healthy
	2	1	77.01	200	Bad/ Damage
		2	72.90	3100	Good/ Healthy
		3	75.87	1500	Good/ Healthy
Average			**74.84 ±1.69**	**1800± 984**	**Good/ Healthy**
General Average			**64.55 ±9.31**	**2289± 1131**	**Good/ Healthy**

4 Conclusion

At the research location, 7 types of mangroves were found, including *Sonneratia alba, Rhizopora mucronata, Rhizophora stylosa, Avicennia alba, Avicennia marina, Rhizophora apiculata*, and *Bruguera gymnorrhiza*. The condition of the mangrove ecosystem has a canopy cover of 64.55 ± 9.31 (%) and the density was 2289 ± 1131 (ind/ha) which indicates that the mangrove ecosystem in Sepulu District, Bangkalan, is in good condition. This condition will have a positive impact on local communities, biodiversity and environmental health in general. Apart from that, this condition will greatly support conservation efforts and sustainable resource management as well as existing mangrove ecotourism. This research has achieved its aim, namely understanding the condition of the mangrove ecosystem in Sepulu District. Further research from the other side is very necessary to support the formation of new mangrove ecotourism and support existing mangrove ecotourism. This research also provides an overview of how the condition of the mangrove ecosystem in Sepulu District can support mangrove ecotourism on Madura Island. To maintain this condition, community involvement is very necessary for sustainable ecotourism. Healthy mangroves contribute to biodiversity, act as carbon sinks, and provide numerous ecosystem services. Therefore it is important to preserve and manage this ecosystem sustainably. With the existing conditions and positive efforts that continue to be made as well as support from many parties, the mangrove ecosystem in Sepulu District will increasingly provide many benefits for the community and the environment.

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