

## Analysis of Mangrove Area and Density Using Multitemporal Satellite Imagery in 2014, 2019, and 2024 in Ujung Piring, Jepara Regency

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### ABSTRACT

Mangroves in Ujung Piring, Mlonggo District, Jepara Regency, which has experienced ecological pressure due to land conversion into aquaculture ponds and coastal abrasion. This research was conducted in October 2024 with the aim of assessing the community structure and spatial characteristics of mangroves, including land cover, area, and density, in Ujung Piring during 2014, 2019, and 2024. The method employed was descriptive-explorative. Information on the temporal condition of mangroves was obtained using Landsat 8 (2014) and Sentinel-2A (2019 and 2024) satellite imagery. The methods applied included the calculation of the Normalized Difference Vegetation Index (NDVI) to assess vegetation density and the Random Forest algorithm for land cover classification. The NDVI value in 2014 indicated sparse density, whereas in 2019 and 2024 the density increased to sparse to moderate, which was supported by field measurements showing an average NDVI of 0.41 (moderate) and canopy cover of 76.4% (dense). The mangrove area showed a continuous increase over the last decade, from 21.97 ha (2014) to 33.96 ha (2024), resulting in a net gain of 11.99 ha (17.45 ha gain and 5.46 ha loss). The increase indicates ongoing rehabilitation efforts and natural regeneration, while the loss of mangrove area was caused by land conversion into aquaculture ponds and coastal abrasion in several locations.

**KEY WORDS:** Hemispherical Photography, Mangrove Density, NDVI, Random Forest Classification, Ujung Piring Jepara

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### 1 INTRODUCTION

Mangrove ecosystems represent one of the most important coastal ecosystems, providing significant ecological and socio-economic functions. Mangroves serve as spawning, nursery, and feeding grounds for various aquatic organisms, while also protecting coastlines by attenuating wave energy, preventing coastal erosion, and supporting local economic activities and ecotourism (Arifanti et al., 2022). Indonesia possesses approximately 3.44 million ha of mangrove forests, accounting for around 21% of the global mangrove area, with the largest distribution located in Papua. Despite their ecological importance, mangrove ecosystems in Indonesia continue to experience significant pressure due to deforestation primarily driven by land-use conversion (FAO, 2023; KLHK, 2025). The conversion of mangrove areas into agricultural land, settlements, aquaculture ponds, and other economic activities has been identified as a major driver of mangrove ecosystem degradation (Sila & Wijayanti, 2025). On Java Island, mangrove forests cover approximately 63,740 ha, with Central Java contributing about 16,100 ha, making it one of the largest mangrove regions on the island (KLHK, 2025). However, mangrove ecosystems along the northern coast of Java have experienced considerable degradation due to land conversion into aquaculture ponds, agriculture, and settlements. These pressures are further exacerbated by coastal abrasion and habitat degradation, which limit the natural regeneration of mangroves (Debrot et

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al., 2022). Mangrove rehabilitation initiatives have been implemented by government institutions, local communities, and non-governmental organizations since 1998 (Poedjirahajoe et al., 2011). According to the National Mangrove Map, mangrove extent in Central Java increased by more than 1,000 ha during the 2021–2024 period (KLHK, 2021; KLHK, 2025). Nevertheless, the effectiveness of these rehabilitation programs still requires spatial and temporal evaluation to better understand mangrove ecosystem dynamics.

One of the mangrove ecosystems located along the northern coast of Java is the mangrove ecosystem in the Ujung Piring coastal area, Jepara Regency, which is distributed across several locations such as Jambu Village, Blebak Village, and Sekuro Village. This area has relatively high mangrove species diversity, with 23 mangrove species recorded in the Ujung Piring area (Kitamura et al., 1997), which is dominated by *Rhizophora apiculata*, while *Sonneratia alba* is only found in Jambu Village and Sekuro Village. The mangrove ecosystem in Ujung Piring is distributed across several zones, ranging from the shoreline, aquaculture ponds areas, to ecotourism areas. Despite the high mangrove species diversity, the ecosystem is experiencing serious pressure due to massive land conversion into aquaculture ponds, coastal abrasion, and habitat degradation that inhibits natural regeneration (Mauludin et al., 2018). Spatial data from Jambu Village show that aquaculture ponds land use reached 76 ha or about 12.8% of the total village area in 2021. Interpretation of Google Earth imagery from 2010 indicates that pond plot patterns had been clearly formed for a long time, indicating continuous aquaculture activities. Information regarding community structure and land conversion is important to assess the condition of mangrove ecosystems in terms of regeneration capacity, resilience, and ecosystem sustainability. Although rehabilitation efforts have been continuously carried out since 2017 by the government and local communities, the availability of systematic and time-series-based spatial data is still limited, which becomes an obstacle in evaluating management effectiveness and policy making.

Accurate mapping, monitoring, and modelling of mangrove ecosystems are important components in supporting sustainable coastal management. The use of satellite imagery enables the analysis of land cover changes over time as well as the estimation of ecological parameters such as mangrove area, density, and spatial dynamics (Roy et al., 2024). The limited availability of comprehensive ecological and spatial data regarding community structure, changes in mangrove extent, and vegetation density in the Ujung Piring area forms the basis for the necessity of this study. Therefore, this study aims to analyse changes in mangrove area and density in the Ujung Piring area, Jepara Regency, using a time-series approach based on satellite imagery from 2014, 2019, and 2024, as a basis for supporting sustainable coastal zone management.

## 2 METHODS

### 2.1 Study Area

This study was conducted in October 2024 in the Ujung Piring mangrove area located in Dusun Jambu, Mlonggo District, Jepara Regency, Central Java Province, Indonesia. The study area is part of the northern coastal region of Java Island and is geographically located at coordinates 6°30'17.40"–6°31'50.77" S and 110°39'54.14"–110°42'55.37" E (Figure 1). The area represents a coastal lowland with elevations ranging from 0–75 m above sea level. The coastal area of Jambu Village is dominated by mangrove ecosystems that develop on muddy to sandy substrates, with a recorded mangrove area of approximately 21.004 ha (Romadoni et al., 2023). In terms of composition, the area has relatively high mangrove diversity with a total of 23 species, of which six main species were found within the observation plots, namely *Rhizophora apiculata*, *Rhizophora mucronata*, *Sonneratia alba*, *Sonneratia caseolaris*, *Ceriops tagal*, and *Lumnitzera racemosa*, while other species were found outside the plots (Kitamura et al., 1997; Romadoni et al., 2023). The mangrove ecosystem in Ujung Piring is dominated by *Rhizophora apiculata* (Mauludin et al., 2018). The high diversity of mangrove species suggests that the Ujung Piring area represents a fringing mangrove forest or coastal fringe zone, where the vegetation is relatively protected from the influence of ocean wave energy, making the area favourable for mangrove growth (Purnama et al., 2020).

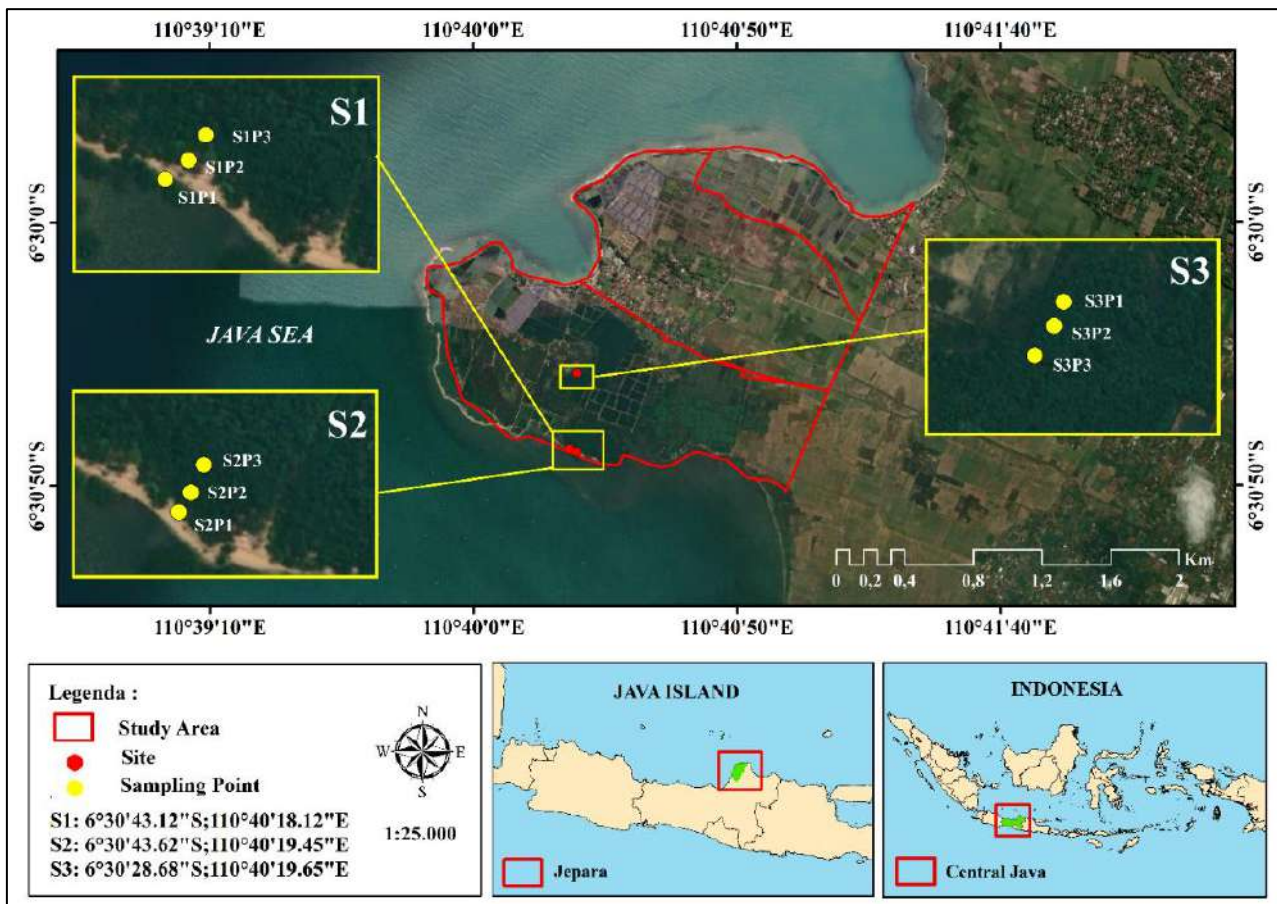


Fig. 1 Distributions of research data collection plots in Ujung Piring, Jawa Tengah, Indonesia

## 2.2 Data Source

This study employed an exploratory descriptive method, in which the research was not intended to test a particular hypothesis but rather to describe conditions based on observed variables, phenomena, or existing conditions (Negari et al., 2017). Field data were collected using a random sampling method with 10 × 10 m quadrat transects (Dharmawan and Pramudji, 2014). Sampling replication was conducted to ensure that the results obtained were representative and to reduce potential bias. The field variables measured included environmental parameters such as temperature, pH, and salinity, as well as mangrove species composition, the number of mangrove stands per quadrat, measurement of stem diameter at breast height (DBH), and canopy photographs for each plot. The field data were subsequently analysed to determine the mangrove community structure, including density, Importance Value Index (IVI), ecological indices, and percentage of canopy cover. In addition, remote sensing data analysis was conducted, which included satellite image processing and accuracy assessment.

## 2.3 Mangrove Community Structure Analysis

The analysis of mangrove vegetation density requires tree stem circumference data to determine the stem diameter or diameter at breast height (DBH). DBH measurements were conducted at a height of 1.3 m above the ground surface or at the observer's chest level. Trees were categorized as individuals with a height greater than 1.3 m and DBH ≥ 4 cm, whereas saplings were classified as individuals with DBH < 4 cm (Soeprobowati et al., 2024). The Importance Value Index (IVI) analysis was used to characterize and compare dominant species within each plot. Mangrove species with the highest IVI values were identified as the most important species within the plot and were considered dominant in the community. The Importance Value Index (IVI) is calculated as the sum of relative density (RD), relative frequency (RF), and relative dominance (RDo) (Sandaruwan et al., 2025). The importance value of a mangrove species in the tree category ranges from 0–300%, whereas in the sapling category it ranges from 0–200% (Rahman et al., 2025). The calculation formulas.

$$\text{Density (Di)} = \frac{\sum \text{individuals of species } i}{\sum \text{plots (total quadrat area)}} \times 10.000$$

$$\text{Relative Density (RD)} = \frac{\text{Density of a species}}{\text{Total density of all species}} \times 100\%$$

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$$\text{Frequency (Fi)} = \frac{\text{Number of plots where a species occurs}}{\text{Total number of plots}}$$

$$\text{Relative Frequency (RFi)} = \frac{\text{Frequency of a species}}{\text{Total Frequency of all species}} \times 100\%$$

$$\text{Dominance (Do)} = \frac{\sum \text{BA of species i}}{\sum \text{Plots (total quadrat area)}}$$

$$\text{Relative Dominance (RDo)} = \frac{\text{Dominance of a species}}{\text{Total dominance of all species}} \times 100\%$$

$$\text{Basal Area (BA)} = \frac{1}{4} \pi \text{DBH}^2$$

$$\text{IVI (Tree)} = \text{RDi} + \text{RFi} + \text{RDo}$$

$$\text{IVI (Sapling)} = \text{RDi} + \text{RFi}$$

Mangrove ecological indices provide a comprehensive quantitative description based on aspects of species diversity, evenness, and dominance. A well-structured community is indicated by high species diversity, a balanced distribution of individuals, and the absence of a single dominant species (Ashari et al., 2019). According to Sandaruwan et al. (2025), species abundance in a sampled community is defined as the number of individuals belonging to a particular species. This abundance is calculated using community structure formulas. The following equations were utilized:

$$H' = -\sum_{i=1}^s \{(Pi) \times \ln(Pi)\}$$

Where,  $H'$  = Shannon-Wiener Diversity Index;  $P_i$  = Proportion of individuals of the “i<sup>th</sup>” taxon of the community;

$s$  = Total number of taxa in the community;  $\ln$  = Natural logarithm (basis  $e$ )

$H'$  category :

$H' < 1$  : Low diversity

$1 \leq H' \leq 3$  : Moderate diversity

$H' > 3$  : High diversity

$$J = \frac{H'}{\ln(S)}$$

Where,  $J$  = Pielou’s Evenness Index;  $H'$  = Shannon-Wiener’s diversity index;  $\ln$  = Natural logarithm (basis  $e$ );  $S$  = Number of species in the community

$J$  category:

$J < 0,4$  : High evenness

$0,4 \leq J \leq 0,6$  : Moderate evenness

$J \geq 0,6$  : Low evenness

$$D = \sum(Pi)^2$$

Where,  $D$  = Simpson’s Dominance Index;  $P_i$  = Proportion of individuals of the “i<sup>th</sup>” taxon of the community.

$D$  category:

$D \rightarrow 1$  : Community dominated by one species

$D \rightarrow 0$  : Community evenly distributed with no dominant species

The percentage of mangrove canopy cover was calculated using the *hemispherical photography* method. The principle of this method is to compare the area of black pixels and white pixels obtained from the processed photograph. Black pixels represent canopy cover, whereas white pixels represent non-canopy areas or the sky. The percentage of mangrove canopy cover was calculated by dividing the number of canopy pixels ( $P_{255}$ ) by the total number of pixels within the plot ( $P_{plot}$ ) and multiplying by 100% (Dharmawan and Pramudji, 2014). The calculated canopy cover values were then analysed and classified according to the Indonesian Minister of Environment Decree No. 201 of 2004 concerning the Standard Criteria and Guidelines for Determining Mangrove Damage. The classification consists of three categories based on canopy cover percentage as presented in Table 1.

**Table 1. Standard Criteria for Mangrove Damage (Canopy Cover)**

Criteria	Density Class	Canopy Cover (%)
Good	Very dense	$\geq 75$
Good	Moderate	$\geq 50 - < 75$
Degraded	Sparse	$< 50$

**2.4 Magrove Area Change Analysis**

Satellite image data analysis to determine land cover was conducted using the *Random Forest Classification* method.

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Random Forest (RF) is a non-parametric ensemble machine learning algorithm that combines a large number of decision trees, particularly using the *Classification and Regression Tree* (CART) approach, to produce more accurate and stable classification results (Hidayah et al., 2024). This method is widely recognized for its ability to minimize generalization errors in classification and to simplify the design process of classification models (Saha et al., 2020).

The accuracy assessment of the classification results was calculated using the kappa coefficient. Accuracy evaluation is essential in remote sensing image classification. Kappa-based indices and overall accuracy are widely used to assess classification accuracy and demonstrate the validity of classification algorithms. The kappa coefficient is derived from the confusion matrix. The accuracy indices include Producer's Accuracy (PA), User's Accuracy (UA), Overall Accuracy (OA), and the Kappa Coefficient (k) (Chowdhury and Hafsa, 2022). These indices were calculated using the following formulas:

$$\text{Overall Accuracy (OA)} = \frac{\sum C_{Pii}}{N}$$

Where:  $C_{Pii}$  = Total observed pixels classified correctly;  $N$  = Total number of pixels observed.

$$\text{Producer's Accuracy (PA)} = \frac{R_{Pii}}{R_i}$$

Where:  $R_{Pii}$  = Accurately classified observation in a specific row  $i$ ;  $R_i$  = Total observation in the same row  $i$ .

$$\text{User's Accuracy (UA)} = \frac{C_{Pij}}{C_j}$$

Where:  $C_{Pij}$ : Accurately classified observation in a specific column  $j$ ;  $C_j$ : Total observation in the same column  $j$ .

$$\text{Koefisien Kappa (k)} = \frac{N \sum_{i=1}^n O_{ii} - \sum_{i=1}^n (R_{Pi} \times C_{Pi})}{N^2 - \sum_{i=1}^n (R_i \times C_i)}$$

Where:  $N$ =Total number of pixels observed;  $O_{ii}$  = Number of pixels observed in row  $i$  and column  $i$ ;  $n$  = Total number of rows/columns (Classes) in confusion matrix;  $R_{Pi}$  = Total number of pixels in row  $i$ ;  $C_{Pi}$  =Total number of pixels in column  $i$ .

## 2.5 NDVI Analysis

Mangrove density was assessed using the NDVI (*Normalized Difference Vegetation Index*) method. NDVI has been widely used for mapping and monitoring mangrove ecosystems due to its broad spatial coverage, capability for multitemporal analysis, and high spectral sensitivity to vegetation conditions (Sofue et al., 2025). The NDVI values derived from vegetation index transformation range from  $-1$  to  $+1$  (Iqbal et al., 2018). The classification of mangrove density values in this study followed the criteria established by the Ministry of Environment and Forestry Decree No. 105 of 2018. Based on NDVI values, mangrove density was categorized into three classes:  $NDVI < 0.35$  (sparse),  $0.35 \leq NDVI \leq 0.60$  (moderate), and  $NDVI > 0.60$  (dense) (Hidayah et al., 2024). Prior to image processing, satellite imagery was corrected to improve visual quality and to standardize spatial resolution. The images were then cropped to the study area. The workflow of satellite image processing is presented in Fig. 2.

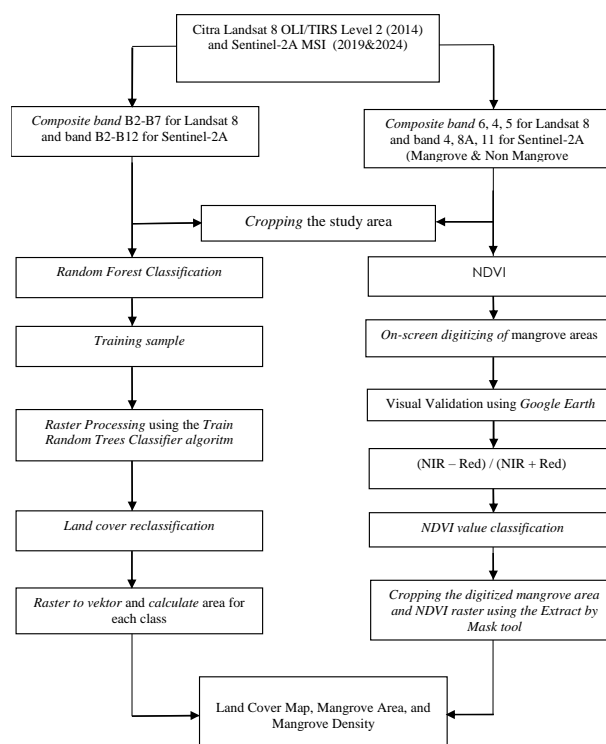


Fig. 2 Flowchart of Landsat and Sentinel-2A satellite image analysis for mangrove forest detection in Ujung Piring, Jepara

### **3 RESULT AND DISCUSSION**

#### **3.1 Mangrove Ecological Conditions**

Environmental parameters at the study site showed variations among stations. The recorded temperature ranged from 33.6°C to 39°C, which exceeded the standard range of 28°C–32°C. Drastic temperature fluctuations may induce thermal stress in mangroves, potentially affecting their growth and survival (Akbar et al., 2024). Salinity values ranged from 32–35‰, with two stations exceeding the maximum standard value of 34‰, although these levels remain tolerable for mangrove ecosystems. The elevated salinity is likely associated with increased temperatures during the dry season, which intensifies evaporation and consequently raises salt concentrations. In addition, limited freshwater input, aquaculture runoff, and seawater intrusion may also contribute to higher salinity levels (Farhaby et al., 2020). Meanwhile, the measured pH ranged from 7.8 to 8.1, indicating neutral to slightly alkaline conditions that remain within the acceptable range for supporting marine biota (7.0–8.5). Stable pH conditions play an important role in maintaining nutrient availability and supporting microbial activity within mangrove ecosystems (Romadhony et al., 2023).

#### **3.2 Mangrove Community Structure**

A total of five mangrove species were recorded within the study area, namely *Sonneratia alba*, *Aegiceras corniculatum*, *Rhizophora apiculata*, *Lumnitzera racemosa*, and *Excoecaria agallocha*. Among these species, *Rhizophora apiculata* was the most dominant and was distributed across all sampling stations. The analysis of mangrove vegetation density in the Ujung Piring area indicated that all observation stations were classified as dense according to the criteria of the Ministerial Decree of Environment No. 201 of 2004 (Table 1). Station 1 (S1) recorded a density of 2700 ind/ha (dense). Although species composition at this station was relatively diverse, most species occurred at low densities per hectare. The dominant species was *R. apiculata* at the tree stage, with a density of 900 ind/ha. Station 2 (S2) had a density of 1900 ind/ha (dense) and was dominated by saplings of *R. apiculata* with a density of 633.33 ind/ha, indicating that regeneration processes are currently occurring at this station, although mature tree stands have not yet developed optimally. Station 3 (S3) exhibited the highest density, reaching 3833.33 ind/ha (dense), largely composed of *R. apiculata* in the sapling stage (2300 ind/ha) and tree stage (1433.33 ind/ha). The high density of saplings in S3 indicates an active regeneration process and successful natural recruitment of mangroves in this area.

Substrate conditions varied among stations. Stations S1 and S2 were characterized by sandy silt substrates directly influenced by tidal dynamics, whereas S3 was dominated by muddy substrates. Substrate characteristics play an important role in mangrove regeneration as they provide suitable media for propagule establishment and influence vegetation density. According to Rifanjani et al. (2024), species of the genus *Rhizophora* possess propagules with high adaptability due to their viviparous reproductive strategy, in which propagules begin germinating while still attached to the parent tree, thereby increasing the probability of successful establishment. Mangrove density at the tree stage is an important indicator for assessing the level of mangrove forest degradation (Sahami, 2018). Based on tree-stage density across all observation stations, the mangrove ecosystem in Ujung Piring can be categorized as sparse and degraded. This condition is likely influenced by environmental pressures such as elevated temperature and salinity. However, the dominance of sapling density, particularly from *R. apiculata*, indicates the presence of active natural regeneration processes. This condition is further supported by mangrove rehabilitation programs carried out by local communities and government institutions since 2017, suggesting that the ecosystem still has significant potential for recovery.

The Important Value Index (IVI) analysis indicated that *Rhizophora apiculata* was the most dominant species across most observation stations, both at the sapling and tree stages (Fig. 3). This dominance suggests that *R. apiculata* possesses strong adaptability to local environmental conditions and may function as a pioneer species in the natural regeneration process (Kusumahadi et al., 2020). Other species, such as *Sonneratia alba* and *Excoecaria agallocha*, also played important roles, particularly in certain locations where environmental conditions may be more favorable for their growth. High IVI values may indicate ecosystem stability and reflect the competitive advantage of particular species in responding to environmental factors and interspecific competition (Sandaruwan et al., 2025). However, excessive dominance by a single species, such as *R. apiculata*, may lead to community homogenization. Such homogenization can reduce species diversity and decrease ecosystem resilience to environmental disturbances (Calipayan et al., 2024). This condition highlights the importance of species enrichment-based rehabilitation to promote a more diverse and stable mangrove ecosystem in the Ujung Piring area.

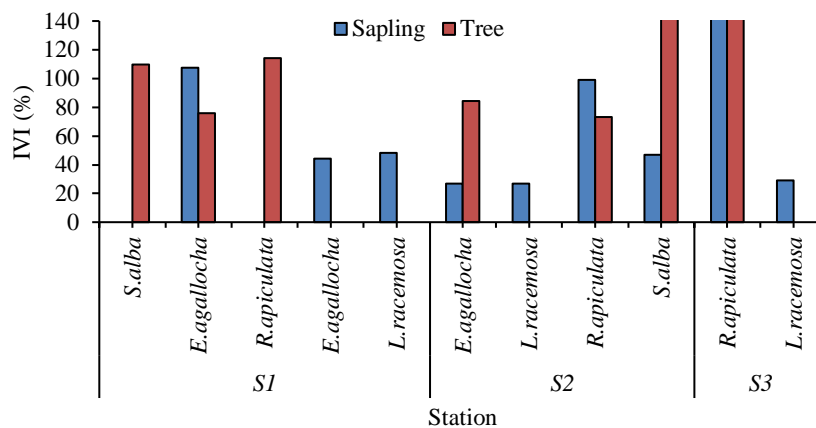
The analysis of mangrove ecological indices revealed differences in community structure among the observation stations (Fig. 4). Station 1 (S1) exhibited a Shannon diversity index ( $H'$ ) of 1.35, categorized as moderate, with an evenness index ( $J$ ) of 0.84 and a dominance index ( $D$ ) of 0.30, indicating low dominance. Station 2 (S2) showed a similar condition with a Shannon diversity index ( $H'$ ) of 1.20, which also falls within the moderate category. This station recorded the highest evenness value ( $J$ ) of 0.87 and a dominance index ( $D$ ) of 0.33, suggesting a relatively even distribution of individuals among species with no strong dominance. In contrast, Station 3 (S3) exhibited a more stressed or degraded community condition, with a very low Shannon diversity index ( $H'$ ) of 0.12 and an evenness index ( $J$ ) of 0.17, both categorized as low. The dominance index ( $D$ ) was relatively high at 0.95, indicating low species diversity and uneven distribution of

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individuals, with strong dominance by a single species. The results of this ecological index analysis are consistent with the findings of Rifanjani et al. (2024) in Nipah Panjang Village, Kubu Raya Regency, where 11 mangrove species were recorded with Shannon diversity values ( $H'$ ) ranging from 0.70 to 1.43 (low to moderate), relatively even distribution indicated by the evenness index ( $J$ ), and generally low dominance values ( $D$ ). In that study, *Rhizophora apiculata* was also found to dominate across different growth stages. High species dominance is often observed in areas experiencing ecological pressure or exploitation. Similarly, the high dominance observed at S3 is consistent with the findings of Zakia et al. (2024) in the coastal area of Tanjungpiayu, Batam City, where two mangrove species were recorded with low Shannon diversity values ( $H'$ ) ranging from 0 to 0.45, evenness values ( $J$ ) ranging from 0 to 0.65 (low to moderate), and relatively high dominance values ( $D$ ) between 0.73 and 1. In that area, *Rhizophora apiculata* was the dominant species, and in one station only a single mangrove species was recorded. This condition indicates significant ecological pressure, resulting in uneven mangrove population distribution and dominance by a single species.

**Table 2** Density of mangrove species based on tree and sapling growth stages in Ujung Piring, Jepara.

Stasiun	Species	Growth Stage	Number of Individuals	Density (ind/ha)	Density Category
S1	<i>S. alba</i>	Tree	10	333,33	Sparse
	<i>E. agallocha</i>	Sapling	15	500	Sparse
		Tree	18	600	Sparse
	<i>A. corniculatum</i>	Sapling	5	166,67	Sparse
	<i>R.apiculata</i>	Tree	27	900	Sparse
	<i>L. racemosa</i>	Sapling	6	200	Sparse
<b>Total</b>			<b>81</b>	<b>2700</b>	<b>Dense</b>
S2	<i>S. alba</i>	Sapling	4	133,33	Sparse
		Tree	10	333,33	Sparse
	<i>E. agallocha</i>	Sapling	3	100	Sparse
		Tree	11	366,67	Sparse
	<i>R. apiculata</i>	Sapling	19	633,33	Sparse
		Tree	7	233,33	Sparse
	<i>L. racemosa</i>	Sapling	3	100	Sparse
<b>Total</b>			<b>57</b>	<b>1900</b>	<b>Dense</b>
S3	<i>R. apiculata</i>	Sapling	69	2300	Dense
		Tree	43	1433,33	Moderate
	<i>L. racemosa</i>	Sapling	3	100	Sparse
<b>Total</b>			<b>115</b>	<b>3833,33</b>	<b>Dense</b>



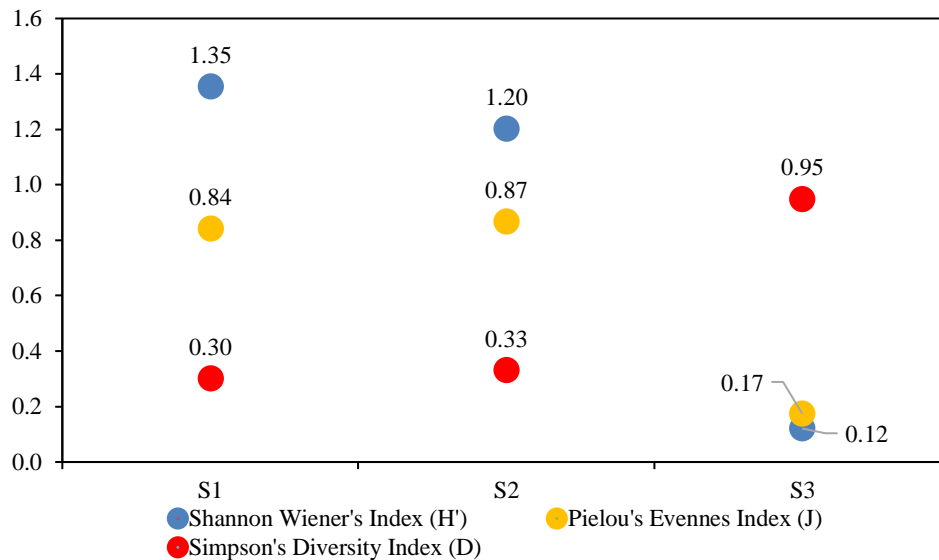
**Fig. 3** Important Value Index (IVI) of mangrove species at sapling and tree stages in Ujung Piring, Jepara.

The analysis of mangrove ecological indices revealed differences in community structure among the observation stations (Fig. 5). Station 1 (S1) exhibited a Shannon diversity index ( $H'$ ) of 1.35, categorized as moderate, with an evenness index ( $J$ ) of

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0.84 and a dominance index (D) of 0.30, indicating low dominance. Station 2 (S2) showed a similar condition, with a Shannon diversity index (H') of 1.20, which also falls within the moderate category. This station recorded the highest evenness value (J) of 0.87 and a dominance index (D) of 0.33, indicating a relatively even distribution of individuals among species and low dominance. In contrast, Station 3 (S3) exhibited a more stressed or degraded community condition, with a very low Shannon diversity index (H') of 0.12 and an evenness index (J) of 0.17, both categorized as low. The dominance index (D) was high at 0.95, indicating low species diversity and uneven distribution of individuals, with strong dominance by a single species.

These findings are consistent with those reported by Rifanjani et al. (2024) in Nipah Panjang Village, Kubu Raya Regency, where 11 mangrove species were recorded with Shannon diversity values (H') ranging from 0.70 to 1.43 (low to moderate), relatively even distribution indicated by the evenness index (J), and generally low dominance values (D). In that study, *Rhizophora apiculata* was also dominant across all growth stages. High species dominance is often observed in areas experiencing ecological pressure or disturbance. Similarly, the high dominance observed at S3 is in line with the findings of Zakia et al. (2024) in the coastal area of Tanjungpiayu, Batam City, where two mangrove species were recorded with low Shannon diversity values (H') ranging from 0 to 0.45, evenness values (J) ranging from 0 to 0.65 (low to moderate), and high dominance values (D) between 0.73 and 1. In that area, *Rhizophora apiculata* was the dominant species, and in one station only a single species was recorded. This condition indicates significant ecological pressure, leading to uneven species distribution and dominance by a single mangrove species.



**Fig. 4 Ecological indices (H', J, and D) of mangrove communities at each observation station in Ujung Piring, Jepara**

Mangrove canopy cover percentage was analyzed using the *hemispherical photography* method. The average canopy cover across the three observation stations was 76.4%, which falls into the dense category based on the criteria of the Ministerial Decree of Environment No. 201 of 2004 (Table 3). According to Romadoni et al. (2023), the average mangrove canopy cover in Ujung Piring, measured using the same method, was 60.72% (moderate category) across three observation stations. This indicates an increase in canopy cover over the past year, suggesting potential success of rehabilitation efforts or natural regeneration processes in the mangrove ecosystem. The dominance of *Rhizophora apiculata* is one of the main factors contributing to the high canopy cover in Ujung Piring. Kuncahyo et al. (2020) reported that *R. apiculata* has relatively broad leaves, ranging from 9 to 20 cm in size. This morphological characteristic contributes to higher canopy cover, as the tree crown functions like an umbrella that reduces the penetration of sunlight and rainfall beneath the canopy. In addition, canopy cover is also influenced by the distribution of tree diameter and height. In this study, all observation stations exhibited relatively well-developed mangrove stands, which supports the high canopy cover values observed.

**Table 3. Mangrove canopy cover percentage at each observation station in Ujung Piring, Jepara**

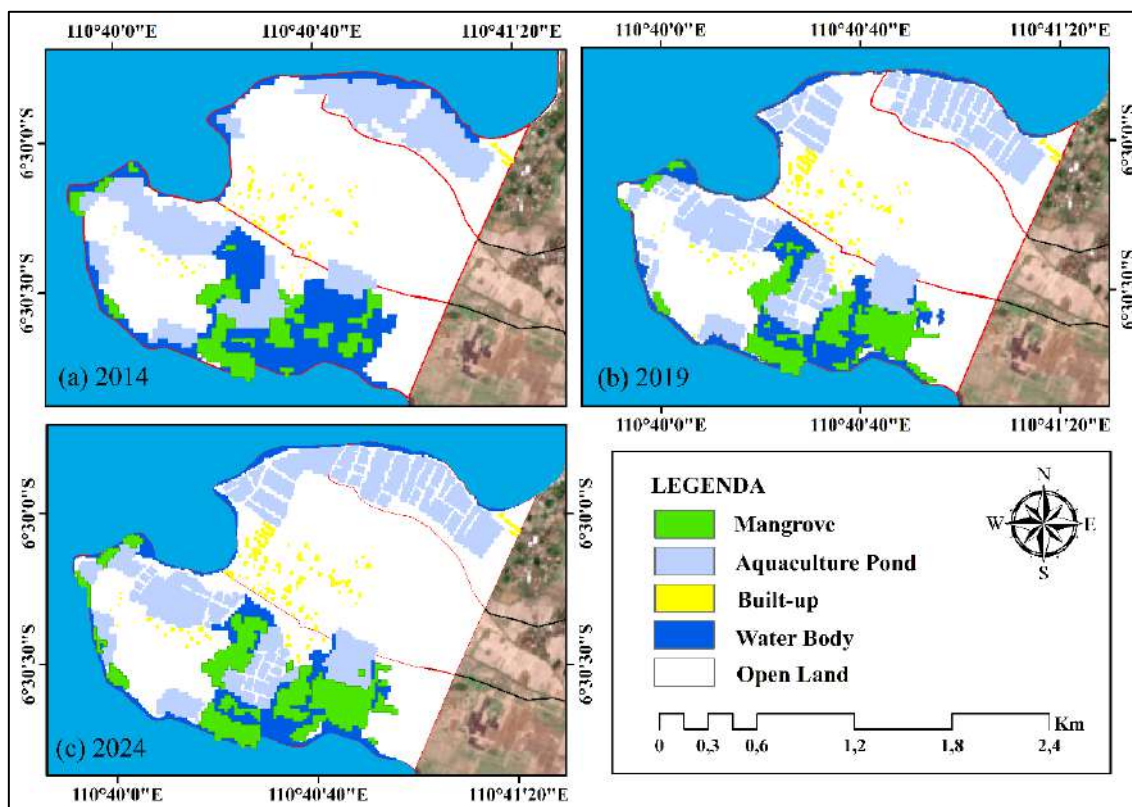
Station	Mean Canopy Cover (%)	Category
1	74	Moderate
2	77	Dense
3	78,4	Dense
Overall mean	76,4	Dense

### 3.3 Spatial Change in Land Cover, Mangrove Area, and Density

The analysis of multitemporal satellite imagery revealed significant land cover dynamics within the study area over the past decade. These changes are influenced by both anthropogenic activities and natural ecological processes, particularly within aquaculture ponds, mangrove areas, and water bodies. Aquaculture ponds represent one of the dominant land uses in the area, alongside mangrove vegetation. Based on satellite image interpretation, the extent of aquaculture ponds increased by 13.37 ha between 2014 and 2024, indicating a substantial expansion of aquaculture activities over the past decade. Mangrove cover also exhibited a significant increase of 11.99 ha, expanding from 21.97 ha in 2014 to 33.96 ha in 2024. This increase was accompanied by a notable reduction in water bodies by 24.13 ha, which can be interpreted as a consequence of aquaculture expansion and coastal morphological changes. According to Romadoni et al. (2023), the mangrove area in Ujung Piring was estimated at 21.004 ha. Based on this reference, the mangrove extent in the study area has increased by approximately 12.96 ha in recent years. Spatial changes in land cover are illustrated in Figure 5, while the magnitude of changes across two time intervals (2014–2019 and 2019–2024) is presented in Table 4. This pattern reflects both ecological recovery and anthropogenic pressure within the study area. These trends indicate a complex interaction between mangrove rehabilitation efforts and ongoing land conversion, particularly driven by aquaculture expansion.

**Table 4. Land cover changes in Ujung Piring from 2014 to 2024**

Class	Area (ha)			Change Δ (ha)		
	2014	2019	2024	2014-2019	2019-2024	2014-2024
Mangrove	21,97	27,64	33,96	5,67	6,32	11,99
Aquaculture Ponds	68,02	73,07	81,38	5,05	8,32	13,37
Built-up Areas	2,76	4,40	5,25	1,64	0,85	2,49
Water Bodies	50,96	31,41	26,83	-19,55	-4,58	-24,13
Open Land	209,26	216,46	205,55	7,19	-10,91	-3,72



**Fig. 5 Spatial distribution of land cover in Ujung Piring, Jepara for (a) 2014, (b) 2019, and (c) 2024, derived from Random Forest classification.**

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The accuracy assessment of land cover classification in Ujung Piring, Jepara for 2024 was conducted using a *confusion matrix*, as presented in Table 5, based on the Random Forest classification method. The results indicate a high Overall Accuracy (OA) of 94%, while the Kappa coefficient (k) reached 0.93, reflecting a strong agreement between classified and reference data. According to Romadoni et al. (2023), a confusion matrix evaluates classification accuracy by comparing correctly classified pixels with the total number of validation samples to derive the overall accuracy. The minimum acceptable OA recommended by the United States Geological Survey is above 85%. The Kappa coefficient ranges from -1 to 1, where values closer to 1 indicate stronger agreement (KLHK, 2020). Chopade et al. (2023) stated that kappa values greater than 0.75 indicate high accuracy, whereas values below 0.40 reflect poor classification performance. Based on the obtained OA and kappa values, the land cover classification results can be considered highly accurate and reliable for further land cover change analysis in the Ujung Piring area.

**Table 5 Accuracy assessment of land cover classification in 2024 using Random Forest**

Class	User Accuracy	Producer Accuracy	Overall Accuracy	Kappa Accuracy
Mangrove	100%	100%	94%	0,93
Aquaculture Ponds	100%	91%		
Built-up Areas	90%	90%		
Water Bodies	90%	100%		
Open Land	90%	90%		

Changes in mangrove extent based on overlay analysis are presented in Fig. 6. During the period 2014–2019 (Fig. 6a), a substantial mangrove gain of 11.7 ha was observed, accompanied by a loss of 6.03 ha. The increase in mangrove area was likely driven by early rehabilitation efforts initiated around 2017, particularly in areas close to the coastline, as well as in central and eastern parts of Ujung Piring, including abandoned aquaculture ponds. In addition, natural regeneration may have contributed, as propagules from mature trees were transported by tidal currents and successfully established in suitable areas. Meanwhile, mangrove loss, mainly occurring in the southwestern and eastern coastal zones, was likely associated with aquaculture expansion and coastal abrasion. A similar pattern has been reported in the coastal area of Tanggul Tlare, Jepara, where mangrove degradation due to land conversion and abrasion has led to subsequent rehabilitation efforts (Utomo et al., 2017).

During the period 2019–2024 (Fig. 6b), mangrove gain was relatively smaller (9.09 ha) compared to the previous period, with a corresponding loss of 2.77 ha. The expansion was mainly observed along the coastline and in previously open areas near aquaculture ponds. The reduced gain may indicate a decline in available open land for rehabilitation, as many suitable areas have already been colonized by mangroves, suggesting that restoration efforts have reached a more mature stage. The lower mangrove loss during this period may reflect improved community awareness and increased land stability in rehabilitated areas.

Over the entire period (2014–2024; Fig. 6c), total mangrove gain reached 17.45 ha, representing the cumulative outcome of rehabilitation over the past decade. Mangrove loss amounted to 5.46 ha, largely attributed to earlier land conversion (2014–2019) and ongoing coastal abrasion in certain locations. Overall, the mangrove area in Ujung Piring shows a net increase, where gains exceed losses, indicating a positive outcome of rehabilitation efforts despite ongoing pressures from human activities and natural processes. This finding is consistent with Candraningtyas et al. (2025), who reported significant spatial and temporal variations in mangrove cover across five estuaries along the northern coast of Central Java. While some estuaries experienced substantial declines due to aquaculture expansion and coastal erosion, others showed notable increases driven by intensive rehabilitation programs, highlighting the importance of effective management strategies at the regional scale.

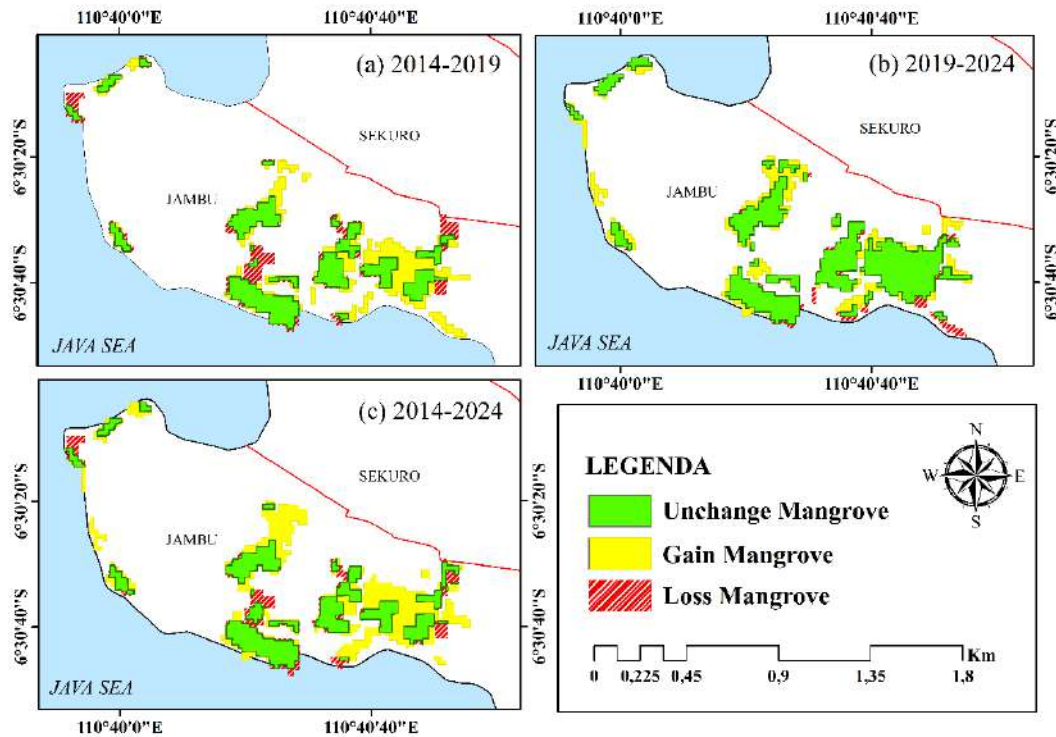


Fig. 6 Spatial distribution of mangrove gain and loss in Ujung Piring, Jepara based on overlay analysis for (a) 2014–2019, (b) 2019–2024, and (c) 2014–2024.

The analysis of mangrove density changes based on NDVI values is presented in Table 6. In 2014, NDVI values ranged from 0.04 to 0.33, corresponding to a sparse category. This increased in 2019 to 0.05–0.56, indicating sparse to moderate density, and remained relatively stable in 2024 at 0.05–0.53, also within the sparse to moderate range. The spatial distribution of mangrove density is illustrated in Fig. 7. The increasing NDVI trend over time suggests ongoing mangrove rehabilitation and vegetation growth in the study area. NDVI values at each sampling site (Table 7) show an average of 0.316 at S1 (sparse), 0.423 at S2 (moderate), and 0.493 at S3 (moderate). Overall, the mean NDVI value for the study area was 0.410, which falls into the moderate density category. The relatively low NDVI value at S1 may be associated with the dominance of mature trees with more open canopy structures, as well as the presence of species with smaller leaves or less compact canopies, such as *Sonneratia alba*. In contrast, the higher NDVI values observed at S2 and S3 are likely influenced by the presence of younger stands or active mangrove regeneration, particularly *Rhizophora apiculata*, which is characterized by dense canopies and dark green leaves that strongly reflect near-infrared (NIR) wavelengths. This pattern indicates that NDVI effectively captures variations in mangrove structural conditions across different growth stages.

Table 6. Changes in mangrove density based on NDVI values in Ujung Piring, Jepara

Year	NDVI Range	Category Density
2014	0,04 - 0,33	Sparse
2019	0,05 - 0,56	Sparse - Moderate
2024	0,05 - 0,53	Sparse - Moderate

Table 7. NDVI values at mangrove sampling sites in Ujung Piring, Jepara

Station	Point			Mean	Category
	1	2	3		
S1	0,251	0,251	0,445	0,316	Sparse
S2	0,262	0,503	0,503	0,423	Moderate
S3	0,511	0,533	0,435	0,493	Moderate
<b>Mean</b>				<b>0,410</b>	<b>Moderate</b>

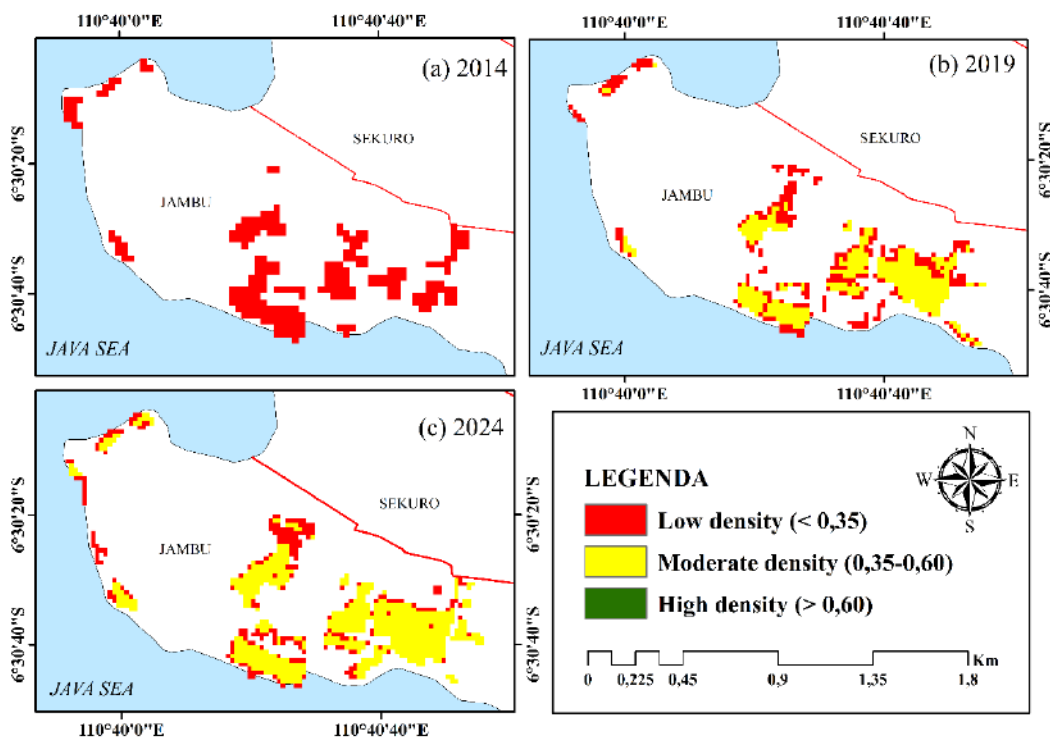


Fig. 7 Spatial distribution of mangrove density in Ujung Piring based on NDVI for (a) 2014, (b) 2019, and (c) 2024.

The polynomial regression analysis between NDVI and mangrove canopy cover showed a coefficient of determination ( $R^2$ ) of 0.8331 (Fig. 8), indicating a strong correlation between the two variables. An increase in canopy cover contributes directly to higher NDVI values up to a certain threshold. As canopy cover increases from sparse to dense conditions, NDVI values rise sharply. However, beyond a certain level (approximately 83.31%), NDVI tends to reach saturation, as the reflectance signal approaches its maximum. A similar pattern was reported by Pietersz et al. (2024), who found a strong positive correlation between NDVI and mangrove canopy cover. Canopy cover is considered one of the most influential vegetation parameters affecting NDVI, as it is directly related to the photosynthetic surface area that reflects near-infrared (NIR) wavelengths.

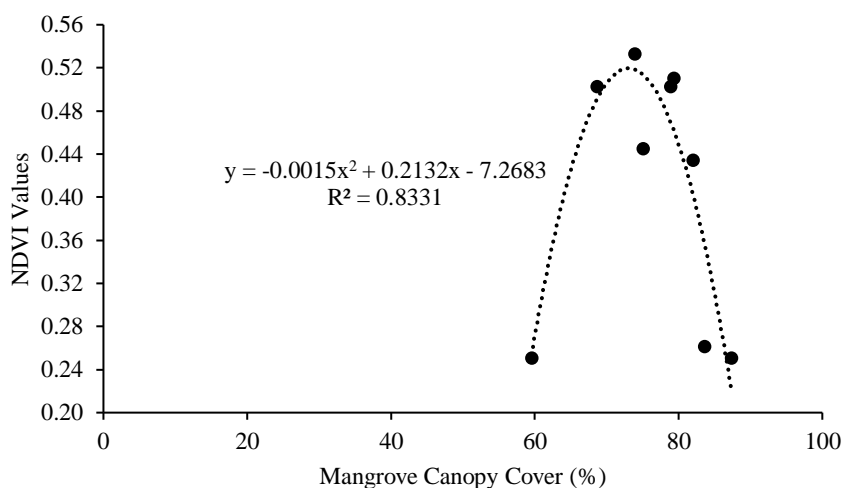


Fig. 8 Polynomial relationship between mangrove canopy cover (%) and NDVI values.

#### 4 CONCLUSIONS

The results of this study indicate that mangrove cover and density in the Ujung Piring area, Jepara, have undergone significant changes over the past decade (2014–2024). Land cover is predominantly dominated by aquaculture ponds, which

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increased by 13.37 ha. Mangrove area also showed a notable increase of 11.99 ha, with total gains reaching 17.45 ha and losses of 5.46 ha. Mangrove density improved from sparse to sparse–moderate conditions (NDVI: 0.05–0.53). These findings suggest that mangrove rehabilitation efforts and natural regeneration in Ujung Piring have been effective, contributing positively to the recovery of mangrove cover and density. This improvement also plays an important role in limiting the expansion of aquaculture ponds. Therefore, maintaining and strengthening sustainable mangrove management strategies in the area is highly recommended.

### REFERENCES

1. Akbar LFA, Idrus AA, Mahrus, Santoso S (2024) *Mangrove Structure and Composition Analysis in Teluk Jor, East Lombok Regency*. *Jurnal Biologi Tropis* 24(2b): 411-421. <https://doi.org/10.29303/jbt.v24i2b.8253>
2. Arifanti VB, Sidik F, Mulyanto B, Susilowati A, Wahyuni T, Subarno, Yulianti, Yuniarti N, Aminah A, Suita E, Karlina E, Suharti S, Pratiwi, Turjaman M, Hidayat A, Rachmat HH, Imanuddin R, Yeny I, Darwiati W, Sari N, Hakim SS, Slamet WY, dan Novita N (2022) *Challenges and Strategies for Sustainable Mangrove Management in Indonesia: A Review*. *Forest* 13(5): 1-18. <https://doi.org/10.3390/f13050695>
3. Ashari DS, Muhammad F, dan Utami S (2019) Struktur Komunitas Hutan Mangrove Di Sungai Donan Kabupaten Cilacap, Jawa Tengah. *Bioma*, 21(1): 65-71. <https://doi.org/10.14710/bioma.21.1.65-71>
4. Calipayan MM, Bello P, Aloquin RD, Aculan MC, dan Brillantes SGA (2024). *Diversity, Stand Structure, Biomass and Carbon Storage Potential of Natural and Planted Mangrove Forests in Samar, Philippines*. *Journal of Biodiversity and Environmental Sciences (JBES)* 24(1): 92-104.
5. Candraningtyas CF, Hafiffah AS, Widowati D, Mardiyanto MB, Saputri AB, dan Setyawan AD (2025) *Spatial and Temporal Dynamics of Mangrove Cover Change in Five Estuaries Along the North Coast of Central Java, Indonesia (2014-2024)*. *INTL J BONOROWO WETLANDS* 15(1): 49-60. <https://doi.org/10.13057/bonorowo/w150106>
6. Chopade MR, Mahajan S, dan Chaube N (2023) *Assessment of Land Use, Land Cover Change in the Mangrove Forest of Ghogha area, Gulf of Khambhat, Gujarat*. *Expert Systems With Applications* 212: 1-10. <https://doi.org.proxy.undip.ac.id/10.1016/j.eswa.2022.118839>
7. Chowdhury MS, dan Hafsa B (2022). *Multi-Decadal Land Cover Change Analysis Over Sundarbans Mangrove Forest of Bangladesh: A GIS and Remote Sensing Based Approach*. *Global Ecology and Conservation* 37: 1-15. <https://doi.org.proxy.undip.ac.id/10.1016/j.gecco.2022.e02151>
8. Debrot AO, Plas A, Boesono H, Prihantoko K, Baptist MJ, Murk AJ, dan Tonneijck FH (2022) *Early Increases in Artisanal Shore-Based Fisheries in a Nature-Based Solutions Mangrove Rehabilitation Project on the North Coast of Java*. *Estuarine, Coastal and Shelf Science* 267: 1-12. <https://doi.org/10.1016/j.ecss.2022.107761>
9. Dharmawan IWE dan Pramudji (2014) *Panduan Monitoring Status Ekosistem Mangrove*. Sarana Komunikasi Utama, Jakarta.
10. FAO (2023) *The World's Mangroves 1980-2005*. Rome: Food and Agriculture Organization of United Nations.
11. Farhaby AM, Abdullah A, Carmila, Arnanda E, Nasution EA, Feriyanto, Mustofa K, Putri LL, Mahatir M, Santia N, Susanti S, Simamora S, dan Lestari Y (2020) Analisis Kesesuaian Ekosistem Mangrove Sebagai Kawasan Ekowisata di Pulau Kelapan Kabupaten Bangka Selatan. *Jurnal Enggano* 5(2): 132-142. <https://doi.org/10.31186/jenggano.5.2.132-142>
12. Hidayah, Z., A. R. As-syakur, dan H. A. Rachman. 2024. *Sustainability Assessment of Mangrove Management in Madura Strait, Indonesia: A Combined Use of the Rapid Appraisal for Mangroves (RAPMangroves) and the Remote Sensing Approach*. *Marine Policy*, 163: 1-17. <https://doi-org.proxy.undip.ac.id/10.1016/j.marpol.2024.106128>
13. Iqbal MN, Mahmudi M, dan Risjani Y (2018) Pemetaan Sebaran Hutan Mangrove dengan Teknologi Penginderaan Jauh dan Sistem Informasi Geografis di Kecamatan Bangkalan Kabupaten Bangkalan Provinsi Jawa Timur. *JFLS* 2(2): 101-113.
14. Kementerian Lingkungan Hidup dan Kehutanan (KLHK) (2021) *Peta Mangrove Nasional*. Direktorat Jenderal Planologi Kehutanan dan Tata Lingkungan, Kementerian Lingkungan Hidup dan Kehutanan, Jakarta.
15. Kementerian Lingkungan Hidup dan Kehutanan (KLHK) (2025) *Keputusan Menteri Kehutanan Republik Indonesia Nomor 594 Tahun 2025 tentang Peta Mangrove Nasional Tahun 2024*. Direktur Jenderal Pengelolaan Daerah Aliran Sungai dan Rehabilitasi, Menteri Kehutanan Republik Indonesia, Jakarta.
16. Keputusan Menteri Negara Lingkungan Hidup (2004) *Keputusan Menteri Negara Lingkungan Hidup Nomor 201 Tahun 2004 tentang Kriteria Baku Kerusakan Mangrove*. Kementerian Lingkungan Hidup, Jakarta.
17. Kitamura S, Anwar C, dan Chaniago C, dan Baba S (1997) *Buku Panduan Mangrove di Indonesia (Bali dan Lombok)*. Denpasar.
18. Kuncahyo I, Pribadi R, dan Pratikto I (2020) Komposisi dan Tutupan Kanopi Vegetasi Mangrove di Perairan Bakauheni, Kabupaten Lampung Selatan. *Journal of Marine Research* 9(4): 444-452. <http://dx.doi.org/10.14710/jmr.v9i4.27915>
19. Kusumahadi KS, Yusuf A, dan Maulana RG (2020) Analisis Keanekaragaman Jenis Vegetasi Mangrove di Kawasan Hutan Lindung Angke-Kapuk dan Taman Alam Angke-Kapuk Muara Angke Kota Jakarta Utara. *Ilmu dan Budaya* 41(69): 8123-8134. <https://doi.org/10.47313/jib.v41i69.890>

**Sigit Febrianto et al, Analysis of Mangrove Area and Density Using Multitemporal Satellite Imagery in 2014, 2019, and 2024 in Ujung Piring, Jepara Regency**

20. Mauludin MR, Azizah R, Pribadi R, dan Suryono (2018) Komposisi dan Tutupan Kanopi Mangrove di Kawasan Ujung Piring Kabupaten Jepara. *Buletin Oseanografi Marina* 7(1): 29-36. <http://dx.doi.org/10.14710/buloma.v7i1.19039>
21. Negari CAS, Triarso I, dan Kurohman F (2017) Analisis Spasial Daerah Penangkapan Ikan dengan Alat Tangkap *Gill Net* di Perairan Pasir, Kabupaten Kebumen, Jawa Tengah. *Indonesian Journal of Capture Fisheries* 1(3): 1-7.
22. Peraturan Menteri Lingkungan Hidup dan Kehutanan Republik Indonesia (2018) Peraturan Menteri Lingkungan Hidup dan Kehutanan Republik Indonesia Nomor P.105/MENLHK/SETJEN/KUM.1/12/2018 tentang Penetapan Peta Mangrove Nasional Tahun 2018. Kementerian Lingkungan Hidup dan Kehutanan, Jakarta.
23. Pietersz JH, Pribadi R, Pentury R, dan Ario R (2024) Estimasi Tutupan Kanopi Berdasarkan NDVI dan Kondisi Tutupan Tajuk pada Ekosistem Mangrove Negeri Passo, Teluk Ambon Dalam. *Jurnal Kelautan Tropis* 27(2): 197-208. <http://dx.doi.org/10.14710/jkt.v27i2.22090>
24. Poedjirahajoe E, Widyorini R, dan Mahayani NPD (2011) Kajian Ekosistem Mangrove Hasil Rehabilitasi pada Berbagai Tahun Tanam Untuk Estimasi Kandungan Ekstrak Tanin di Pantai Utara Jawa Tengah. *Jurnal Ilmu Kelautan* 5(2): 99-107. <https://doi.org/10.22146/jik.1854>
25. Purnama MB, Pribadi, dan Soenardjo N (2020) Analisa Tutupan Kanopi Mangrove Dengan Metode *Hemispherical Photography* di Desa Betahwalang, Kabupaten Demak. *Journal of Marine Research* 9(3): 317-325. <http://dx.doi.org/10.14710/jmr.v9i3.27577>
26. Rahman R, Bramana A, Suharti R, dan Irawan H (2025) Analisis Vegetasi Mangrove Berdasarkan Faktor Lingkungan Perairan di Kawasan Pesisir Kabupaten Pati. *Buletin Oseanografi Marina* 14(1): 49-60. <https://doi.org/10.14710/buloma.v14i1.62083>
27. Rifanjani S, Effendi FS, dan Wulandari RS (2024) Tingkat Kerusakan Berdasarkan Zonasi Hutan Mangrove Di Desa Nipah Panjang Kecamatan Batu Ampar Kabupaten Kubu Raya. *Jurnal Hutan Lestari* 12(3): 577-594. <https://doi.org/10.26418/jhl.v12i3.51480>
28. Romadhony MY, Hartoko A, dan Muskananfolo MR (2023) Kesuburan Perairan Berdasarkan Kandungan Nutrien pada Ekosistem Mangrove di Kawasan Hutan Mangrove Pasar Banggi, Rembang - Jawa Tengah. *Jurnal Pasir Laut* 7(1): 32-41. <https://doi.org/10.14710/jpl.2023.52274>
29. Romadoni AA, Ario R, dan Pratikto I (2023) Analisa Kesehatan Mangrove di Kawasan Ujung Piring dan Teluk Awur Menggunakan Sentinel-2A. *Journal of Marine Research* 12(1): 71-82. <https://doi.org/10.14710/jmr.v12i1.35040>
30. Roy AD, Arachchige PSP, Watt MS, Kale A, Davies M, Heng JE, Daneil R, Galgamuwa GAP, Moussa LG, Timsina K, Ewane EB, Rogers K, Hendy I, Jones AE, Miguel SD, Burt JA, Ali T, Sidik F, Asbullah M, Selvam PP, Jaavar WSWM, Alawatte I, Doaemo W, Cardil A, dan Mohan M. 2024. *Remote Sensing-Based Mangrove Blue Carbon Assessment in the Asia-Pacific: A Systematic Review. Science of The Total Environment* 938(3): 173240-173257. <https://doi-org.proxy.undip.ac.id/10.1016/j.scitotenv.2024.173270>
31. Saha S, Sahab M, Mukherjee M, Arabamerid A, Ngoe PTT, Paul GC (2020) *Predicting the Deforestation Probability Using the Binary Logistic Regression, Random Forest, Ensemble Rotational Forest, REPTree: A case Study at the Gumani River Basin, India. Science of the Total Environment* 730: 1-20. <https://doi-org.proxy.undip.ac.id/10.1016/j.scitotenv.2020.139197>
32. Sahami F (2018) Penilaian Kondisi Mangrove Berdasarkan Tingkat Kerapatan Jenis. *Nike: Jurnal Ilmiah Perikanan dan Kelautan* 6(2): 33-40. <https://doi.org/10.37905/v6i2.5185>
33. Sandaruwan R, Badullage HS, Perera IJJUN, Jayapala HPS, Udayanga KAS, dan Bellanthudawa BKA (2025) *Unveiling the ecological wealth: Species diversity, conservation impact, and carbon sequestration in mangrove ecosystems. Regional Studies in Marine Science* 84 :1-12. <https://doi-org.proxy.undip.ac.id/10.1016/j.rsma.2025.104083>
34. Soeprbowati TR, Sularto RB, Hadiyanto H, Puryono S, Rahim A, Jumari J, dan Gell P (2024) *The Carbon Stock Potential of the Restored Mangrove Ecosystem of Pasarbanggi, Rembang, Central Java. Marine Environmental Research* 193(10): 1-11. <https://doi-org.proxy.undip.ac.id/10.1016/j.marenvres.2023.106257>
35. Sofue Y, Quevedo JMD, Lukman KM, dan Kohsaka R (2025) *Identifying Changes in Mangrove Landscapes in the Philippines and Indonesia using Remote Sensing and Community Perceptions: Towards Ecosystem Services Management. Regional Studies in Marine Science* 82: 1-13. <https://doi.org/10.1016/j.rsma.2025.104023>
36. Tosiani A (2020) Akurasi Data Penutupan Lahan Nasional Tahun 1990-2016. Kementerian Lingkungan dan Kehutanan, Jakarta.
37. Utomo B, Budiastuti S, dan Muryani C (2017) Strategi Pengelolaan Hutan Mangrove di Desa Tanggul Tlare Kecamatan Kedung Kabupaten Jepara. *Jurnal Ilmu Lingkungan* 15(2): 117-123. <https://doi:10.14710/jil.15.2.117-123>
38. Zakia R, Lestari F, Azizah D, dan Raza'I TS (2024) Analisis Indeks Ekologi Ekosistem Mangrove di Kawasan Pesisir Tanjungpiayu Kota Batam. *Jurnal Akuatiklestari* 7(2): 164-170. <https://doi.org/10.31629/akuatiklestari.v7i2.6704>