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Satellite based analysis of mangrove cover and density change in mangroves of Tulang Bawang District, Lampung Province, Indonesia

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Abstract. *Kaskoyo H, Hartati F, Bakri S, Febryano IG, Dewi BS, Nurcahyani N. 2023. Satellite based analysis of mangrove cover and density change in mangroves of Tulang Bawang District, Lampung Province, Indonesia. Biodiversitas 24: 3019-3028.* Being a threatened ecosystem of the world, mangroves require regular monitoring to identify areas that need improvement in conservation measures. Considering this, the present study aimed to assess the mangrove cover and density change in mangrove forest of Tulang Bawang District, Lampung Province, Indonesia. Data was collected by remote sensing techniques using satellite imagery viz., Landsat 5 in 2000 and 2010 and Landsat 8 in 2020. It was then analyzed using remote sensing method, namely Object-Based Image Analysis techniques using the unguided classification method to obtain mangrove cover data; while mangrove density information was obtained using the Normalized Difference Vegetation Index algorithm. The results revealed the decrease in mangrove cover and density between 2000 and 2020. The mangrove cover decreased from 7529 ha in 2000 to 5551 ha in 2020. Furthermore, density of mangrove forest has also witnessed change from dense density class in 2000 to medium density class in 2020. From this result, it is evident that mangroves of East Rawajitu Sub-district are degrading and require focused efforts to prevent the degradation. Communities, entrepreneurs, and governments have different motives for utilizing mangrove forests that result in damage, so reasonable efforts are needed to manage mangrove forests sustainably.

Keywords: Anthropogenic, aquaculture, coastal, NDVI, shrimp farming

INTRODUCTION

Coastal areas are transitional areas that are highly volatile and dynamic and can maintain water productivity. Sectorally, the wealth possessed by this region can contribute significantly to the community's economy through fisheries, forestry, industry, tourism, mining, and other sectors (Suwarsih 2018). The region's transition between land and sea has formed an ecological chain that can provide various benefits in supporting life. The mangrove ecosystem is one of the most critical parts of the ecological chain in coastal areas (Tawanggian et al. 2022).

Mangrove ecosystems are dominated by terrestrial plant species that can invade and grow in a seawater environment. As a primary producer owned by this ecosystem, the strategic function can support and stabilize other ecosystems (Veetil et al. 2019). As a result, mangrove ecosystems have their charm and invite various parties to use them directly or regulate their use. The various benefits of mangrove ecosystems can be felt ecologically, socially, and economically, but these benefits can also have consequences for the threats to their existence and, therefore, their sustainability fate, especially in the area of study (Bakri et al. 2023).

Economic activities and population pressures associated with people's desire to improve their welfare will ultimately utilize the available spatial space (Hamuna et al. 2018). Such utilization affects land capability and land use. The mismatch between land capability and its use impacts degradation and decreased environmental quality, which can disrupt the balance of the ecosystem (Rizal et al. 2020; Jordan and Frohle 2022). The strong inter-ecosystem and inter-sectoral relationships in coastal areas will encourage the rate of damage to mangrove ecosystems (Tresiana et al. 2022). The extensive damage causes mangroves' spatial and temporal multifunctionality to shrink sharply. Agustin et al. (2018) stated that degraded mangroves could not maintain their relative surface height to seawater, so abrasion is increasing. The degraded mangrove also caused significant loss of carbon stock, coastal abrasion, seawater intrusion, a decline in fish capture, a reduction in juvenile shrimp and milkfish, and outbreaks of shrimp disease (Malik et al. 2017; Eddy et al. 2021)

The use of remote sensing technology is the right solution to detect the presence of mangroves over a large area. This technology provides an alternative to supporting the provision of data quickly and easily compared to field measurements (Dwiputra et al. 2019) and have been shown to be successful in mapping mangrove species, calculating biomass and carbon stock, as well as measuring changes in extent (Pham et al. 2019). Remote sensing provides the added benefit of giving historical data, such as validating the presence of mangroves in Peninsular Malaysia since 1853 and determining the gain/loss of mangrove systems over the last 74 years (Gopalakrishnan et al. 2021), as well as establishing the spatiotemporal characteristics of mangrove distribution in Guangdong Province over the past 30 years (Ma et al. 2019). Integration of satellite image data can describe vegetation density and changes in mangrove cover over time. Vegetation density can be identified by digital image interpretation using the Normalized Difference Vegetation Index (NDVI) transformation. Suwanto et al. (2021) stated that NDVI is a simple graphical indicator to describe vegetation index values from infrared and red channel satellite images that show the correlation between the level of leaf chlorophyll concentration and vegetation density. The information obtained can be used as an instrument for conducting integrated mangrove ecosystem management. Considering this, the present study aimed to assess the mangrove cover and density change in mangroves of Tulang Bawang District, Lampung Province, Indonesia, using satellite based imaginaries.

MATERIALS AND METHODS

Study area

This research was conducted in February-September 2022, examining coastal areas in East Rawajitu Sub-district, Tulang Bawang District, Lampung Province, Indonesia (Figure 1). The location selection was based on the consideration that a mangrove forest directly opposite the East Coast is used for various purposes, but spatial information on changes in density and area is still limited. The mangrove ecosystem in Tulang Bawang District, Lampung Province is one mangrove habitat that is now being damaged and needs special attention (Bakri et al. 2023). The area has long been used for the aquaculture sector, especially shrimp ponds, which has implications for changes in the ecological system of the local area. In addition, spatial information on changes in the area and the distribution of mangrove cover in the area has never been comprehensively studied. Therefore, continuous monitoring is required to detect threats to the mangrove ecosystem to optimize the use of coastal areas for shrimp farming without any compromising environmental quality deterioration (Bakri et al. 2023). Monsef and Smith (2017) revealed that mangrove monitoring is needed to measure growth rates and identify improvement areas. Such monitoring can be done effectively and efficiently using remote sensing technology (Ghorbanian et al. 2021).

Data collecting

Fieldwork

Fieldwork was conducted to determine vegetation type and mangrove zonation. Mangrove vegetation types were divided into minor, major, and associated vegetation. Mangrove zonation was divided into open, mid, brackish, and inland zones.

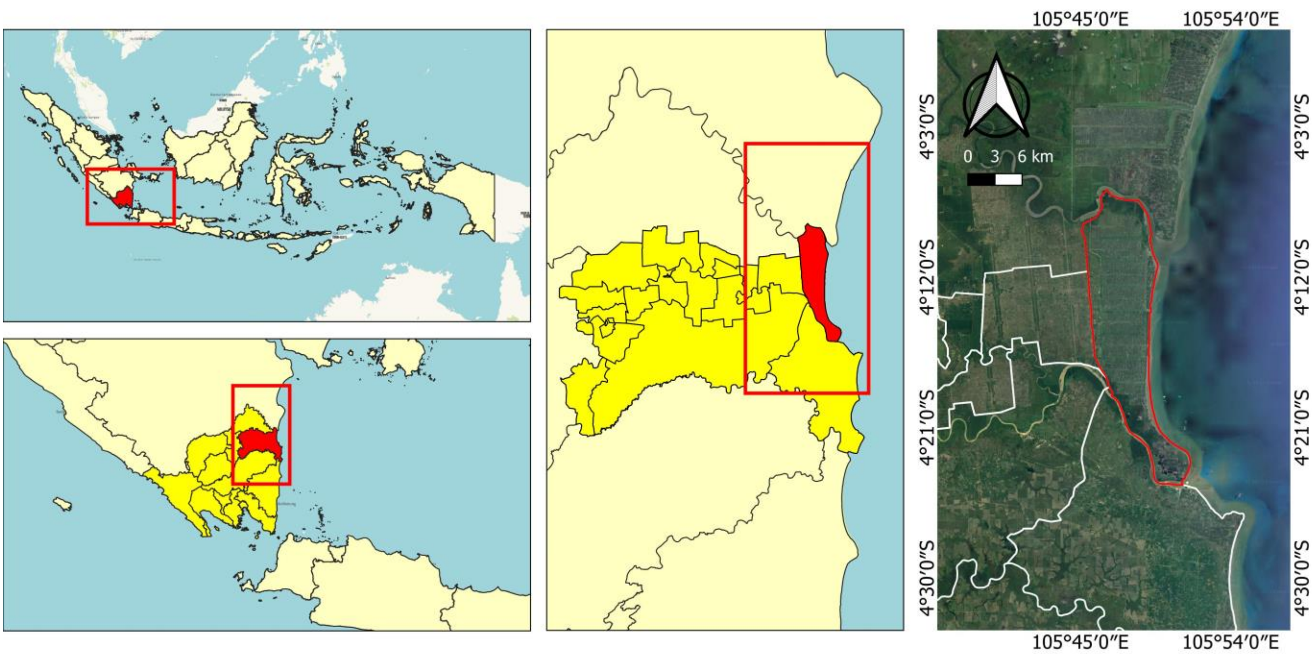

Figure 1. Research location in East Rawajitu Sub-district, Tulang Bawang District, Lampung Province, Indonesia

Remote sensing

Administrative maps of the East Rawajitu Sub-district obtained through the Geospatial Information Agency (BIG), Landsat 5 TM satellite images (acquisitions 11 July 2000 and 7 July 2010), and Landsat 8 OLI satellite images (acquisitions 9 February 2020) obtained using remote sensing techniques through the United State Geological Survey (USGS) Global Visualization View (Glovis) page, as well as research-related articles obtained through the internet, books, and journals.

Identification of mangrove species

Mangroves found at the research site were identified based on fruit, leaves, stems, roots, and seeds. The identification used a guidebook of mangrove types (Noor et al. 1999), which were then analyzed descriptively based on the type, component, and zone.

Atmospheric correction

Atmospheric correction was analyzed using the Dark Object Subtraction (DOS) method. This method assumes that the minimum pixel value is zero, while values other than zero are assumed to be atmospheric disturbances. The method uses an approach where the reflectance value of pixels in the image is reduced by the reflectance value of the darkest object pixel (Muhtar et al. 2019).

Band composite

Band composites are a combination of three different bands to represent RGB colors, resulting in colors in the image that match the combination of these bands. The arrangement of colors from the three bands in satellite imagery at least has a Near Infrared Radiation (NIR) band to sharpen the colors for the overall appearance of vegetation in the image (Hendrawan et al. 2018). The Landsat 5 TM RGB satellite image band composite uses band 453, while the Landsat 8 OLI RGB satellite image uses band 564, where the composite image on each satellite is a composite for vegetation visualization. The composite of false-colored images of the object's color will not appear as it should (Dwiputra et al. 2019). Then, an image cropping process is carried out to reduce the coverage of the initial large image area, which can facilitate further image data processing.

Image classification

The image classification process is carried out with Object-Based Image Analysis (OBIA) based classification techniques using eCognition Developer software. This image classification technique considers not only spectral aspects but also the spatial aspects of objects simultaneously. Objects are formed by segmenting adjacent pixels with homogeneous quality (spectral similarity) according to their parameters (Hossain and Chen 2019). The land cover classification was analyzed using the unsupervised classification method by separating mangrove and non-mangrove objects. The classification results were then exported into a shapefile format. Then processed using ArcGIS 10.3 software to obtain information like the mangrove cover area.

Density classification

The mangrove vegetation index was analyzed using the NDVI algorithm to determine the level of mangrove density based on the object's response to red and NIR band radiation (Chamberlain et al. 2021; Bakri et al. 2022). The working principle of NDVI is that radiation from the red band is absorbed by chlorophyll, so the leaf structure reflects it through its mesophyll tissue (Hanan et al. 2020). According to Latifah et al. (2018), the formula used to calculate the NDVI value is as follows:

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

Where:

NIR : band 4 of Landsat 5 TM satellite imagery and band 5 of Landsat 8 OLI satellite imagery

Red : band 3 of the Landsat 5 TM satellite image and band 4 of the Landsat 8 OLI satellite image.

The resulting NDVI values range from -1 to +1. The classification of the mangrove density index was determined based on the range of NDVI values, referring to the book "Guidelines for Inventory and Identification of Critical Mangrove Land" published by the Ministry of Forestry (Table 1). Mangrove density was classified into three classes: sparse, moderate, and dense.

Table 1. Classification of mangrove density based on NDVI value

Classification	NDVI value
Sparse	-1 ≤ 0,32
Moderate	0,33 ≤ 0,42
Dense	0,43 ≤ 1

Source: Departemen Kehutanan (2005)

RESULTS AND DISCUSSION

Mangrove zoning and vegetation types

The mangrove forest in East Rawajitu Sub-district stretches as a greenbelt around the settlements of thousands of families of Bumi Dipasena farmers. The existence of this ecosystem is managed independently by the local community because it realizes that mangrove ecosystems play an important role in supporting life. In addition to being a breaker of waves and wind, millions of mangrove stems are also useful as a biofilter for water sources for shrimp farming. Various animal species such as fish, mammals, reptiles, primates, and aquatic birds, inhabit this ecosystem. In addition, the types of vegetation that make up the mangrove ecosystem are also very diverse. Ravi et al. (2020) revealed that the types of plants that can live in mangrove ecosystems are halophytes, which can invade and survive in areas with high salinity levels. Various types of mangroves can thrive in the coastal areas of East Rawajitu Sub-district. The types of mangroves found in the area are presented in Figure 2.

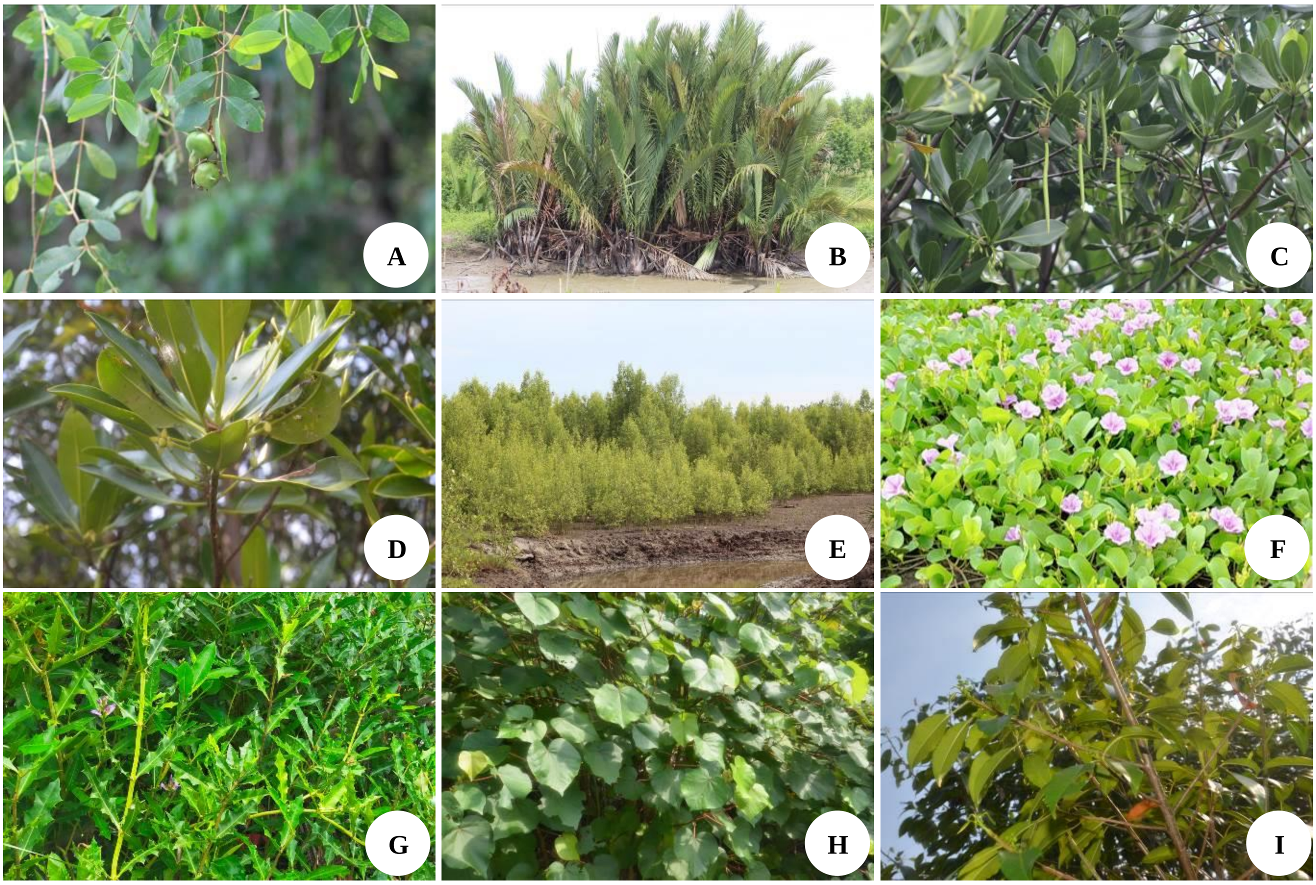

Figure 2. A. *Sonneratia caseolaris*; B. *Nypa fruticans*; C. *Rhizophora mucronata*; D. *Rhizophora stylosa*; E. *Avicennia marina*; F. *Ipomoea pes-caprae*; G. *Acanthus ilicifolius*; H. *Thespesia populnea*; I. *Excoecaria agallocha*

Mangrove species found in East Rawajitu Sub-district consist of major, minor, and associated mangrove components. Mangrove forests in the area are dominated by major mangrove components, which include *Avicennia marina* (Forssk.) Vierh., *Sonneratia caseolaris* (L.) Engl., *Rhizophora mucronata* Lam., *Rhizophora stylosa* Griffith, and *Nypa fruticans* Wurmb. According to Rofi'i et al. (2021), major mangroves are a group of plants consisting of true mangroves that can form morphological specializations such as distinctive roots and other special physiological mechanisms to secrete salt to adapt to their environment. Mangroves belonging to the major mangrove component have the potential to form pure stand groups more quickly (Oktavian 2021). This provides an opportunity for natural mangrove rehabilitation.

Minor mangroves are true mangrove components whose lives are not directly in contact with tides and are usually found in marginal areas (Ginantra et al. 2018). Minor mangrove species in the East Rawajitu mangrove forest include *Acanthus ilicifolius* L., *Ipomoea pes-caprae* (L.) R.Br., and *Xylocarpus granatum* J.Koenig. The minor component usually does not form a conspicuous vegetation element and rarely forms a pure stand. Associated mangroves found in East Rawajitu include *Thespesia populnea* (L.) Sol. ex Corrêa, *Excoecaria agallocha* L, and *Terminalia catappa* L.. Associated mangroves are vegetation that grows landward behind the true mangrove zone and is tolerant of seawater salinity. These vegetation types are not found exclusively in mangrove forests and are only transitional vegetation to land or sea, but they can interact with true mangroves (Pereira et al. 2016; Soares et al. 2017). The diverse types of mangrove vegetation in East Rawajitu Sub-district are influenced by the adaptation process of each mangrove type to its environmental conditions. According to Irsadi et al. (2019), the adaptation process will run well if environmental conditions such as solar energy, nutrients, and water content can support the growth and development of mangrove vegetation.

Mangrove plant groups live based on their zones. The distribution of mangroves shows the zonation of the dominant species. In large mangrove forests, there is a pattern of zonation of dominant species parallel to the coastline. This zonation generally depends on the gradient of sharp changes in ecological properties from sea to land. Mangrove zonation is divided into four parts: the open zone, the middle zone, the brackish zone, and the inland zone. The open zone is the area closest to the sea and is the foremost zone dominated by the mangrove groups *Avicennia* sp. and *Sonneratia* sp. This zone generally has a muddy substrate with a stable intensity of inundation levels (high salinity levels). In the middle zone are mangrove species such as *Rhizophora* sp. and *Bruguiera* sp. These mangroves live in a zone with soft, muddy substrate conditions, but the salinity levels are rather low, so that the mangroves will be inundated during high tide conditions. The brackish zone contains the mangrove species *N. fruticans*. The zone shows hard, muddy soil substrate conditions and is usually inundated during the highest tide conditions.

Furthermore, mangroves in the inland zone are in the brackish or almost freshwater area behind the green mangrove belt. This zone is the habitat for the associated mangrove component. The species richness in this zone is higher than in other zones because it is directly adjacent to the mainland.

The adaptability of each species to environmental conditions results in differences in mangrove forest composition with distinct boundaries. Although there is zoning in mangrove vegetation, many vegetation formations and zones overlap, so the structures and correlations that appear in one area cannot always be applied in other areas. The distribution of mangroves in East Rawajitu Sub-district does not show a fixed pattern. *A. marina* and *S. caseolaris* are not only found in the open zone, but some also penetrate the middle and brackish zones. In addition, *R. mucronata* mangroves were growing in the open zone, although the frequency was not too high. The presence of mangrove species that do not fit the situation should be due to the influence of the spread of seeds assisted by wind and tides and planting efforts without knowing the suitability of mangrove species to their zone. This is in line with the research of Mughofar et al. (2018), which states that the irregular zoning of mangrove forests is caused by natural factors and errors in rehabilitation techniques that ignore the suitability of mangrove species to the zone where they grow. Substrate, salinity, tidal currents, sedimentation, and the relative heights of land and water determine mangrove forest zoning. These environmental factors will shape the distribution of mangrove species and dominate each habitat.

Changes in mangrove cover from 2000 - 2020

Initially, the East Rawajitu area was an expanse of shrubs and mangrove forests, which were then packaged by one company into the largest aquaculture area in Southeast Asia. The land clearing was carried out in 1987 and followed standard operating procedures to maintain the existing mangrove forest. Over time, the state of mangrove cover always changes. These changes are indicated by the increase or decrease in mangrove areas within a certain period. Mangrove cover will increase if there is natural or non-natural mangrove growth, while mangrove cover will decrease if there is mangrove death or another cover replaces it. Based on the interpretation of Landsat satellite images in the period 2000-2020, it is evident that there have been changes in mangrove cover in East Rawajitu Sub-district (Figure 3).

Changes in mangrove cover between 2000 and 2020 showed a significant decline. The area of mangrove forest in East Rawajitu Sub-district in 2000 was 7,529 ha, but in 2010 the area of mangrove forest decreased by 1,641 ha, leaving only an area of 5,888 ha. The decline in mangrove cover has implications for the decline in water quality. According to Matatula et al. (2019), mangroves are declining in quality and quantity at an alarming rate worldwide. Natural factors, along with anthropogenic factors, are the causes of mangrove cover loss on a global scale (Almahasheer 2018). This needs to be addressed intensively to restore the function and role of mangrove ecosystems as stabilizers for other surrounding ecosystems.

Since the company's transition in 2007, managing mangrove forests in East Rawajitu Sub-district has become undirected. The company only prioritizes economic benefits without paying attention to its environmental aspects. The decline in the mangrove cover area in 2010 was due to the company's failure to carry out coastal revitalization techniques. At that time, the revitalization technique was carried out by dredging the canal (main inlet) and dumping the mud using a grader into the mangrove forest. The resulting sludge contains ammonia, which slowly kills mangrove forest life. In addition, the cutting down of trees by the community was also one of the triggers for the damage. At that time, massive abrasion resulted in large waves and tides penetrating until seawater submerged some of the community's pond plots. As a result, some lines could not function and be utilized for cultivation anymore. Seawater became a threat to smallholder farmers.

The company has tried to reduce the community's concern about the threat of seawater by encouraging the community to plant mangrove seedlings and build barriers, but these efforts have not yet yielded results. The company has not prioritized environmental improvement because it faces a financial crisis. After many conflicts, in 2012, the company was sold cheaply to the government. In the meantime, mangrove destruction became rampant and difficult to overcome. This prompted the community to make efforts to improve the environment independently.

The people living in East Rawajitu Sub-district are migrants from various regions in Indonesia, thus consisting of various ethnicities and cultures. Based on the research, most people come from Java and Sumatra. The community comprises Javanese, Palembang, Lampung, Batak, Semendo, Sundanese, Padang, Bugis, and Komering tribes. Although they consist of various ethnicities and cultures, the local community has a high sense of mutual assistance. According to Barusman et al. (2018), social relations between residents in one of the villages in the East Rawajitu Sub-district are unique because they are full of togetherness, homogeneity, kinship, discipline, mutual trust, and cooperation.

Handling mangrove damage in East Rawajitu Sub-district was carried out in stages by the local community. This activity began with *gelugu* (coconut wood) planting because no mangrove seedling assistance from any party existed. The planting funds came from community contributions, so the planting was carried out little by little until finally, the community received mangrove seedling assistance from various environmental care communities. Herawati and Hermansah (2020) revealed that mangrove rehabilitation by replanting is one of the right steps to restore ecosystem functions.

Most communities have supported mangrove rehabilitation efforts, although community participation in some villages is still meagre. In addition, some people still carry out illegal logging. People outside Rawajitu Timur Sub-district also carry out mangrove logging activities. Because there are no official norms or stringent fines governing mangrove ecosystem management, people are more spontaneous in how they use their resources (Bakri et al. 2023). According to Rusdi et al. (2020), the availability of formal regulations is crucial for all stakeholders, including the community, to have strong guidelines in mangrove ecosystem management. In line with the research of Kaskoyo et al. (2017), environmental policies will result in better decisions because the community has information that can be used to make decisions. Formal regulations function as policies that can determine the direction and answer various community interests, so that people will be more courageous to act in preserving their resources (Widarmanto 2018).

Between 2010-2020, the area of mangrove forests decreased by 337 ha, so currently, the area of mangrove cover in East Rawajitu Sub-district is only 5,551 ha. This is due to the actions of people converting land and logging mangroves to fulfil their interests. Mangrove planting that the community has attempted has not increased in the area. However, the previously lost coastline has begun to be covered by various types of mangrove vegetation. However, much of the mangrove vegetation in the eastern part has been lost and damaged. Mangrove damage due to logging is presented in Figure 4.

Environmental degradation, policy changes, and socioeconomic dynamics have led to a decline in the function of mangrove ecosystems. The community uses wood from mangrove logging to build bridges. In addition, some mangroves are deliberately cut down because they cover the road where people pass. In the south, some mangrove land has been converted into ponds. Meanwhile, aggressive abrasion in the area is eating away at the mangroves. Several key stakeholders, such as the government, businessmen, and communities, play a role in developing coastal areas and have different motives for utilizing the ecosystem. If the utilization policy is not following the agreement between stakeholders, then the damage to this ecosystem may continue (Marasabessy et al. 2018). This extreme condition is a serious problem and must be addressed immediately to maintain mangrove forests properly. Therefore, an agreement between stakeholders and an appropriate management strategy is needed to build a sustainable mangrove forest.

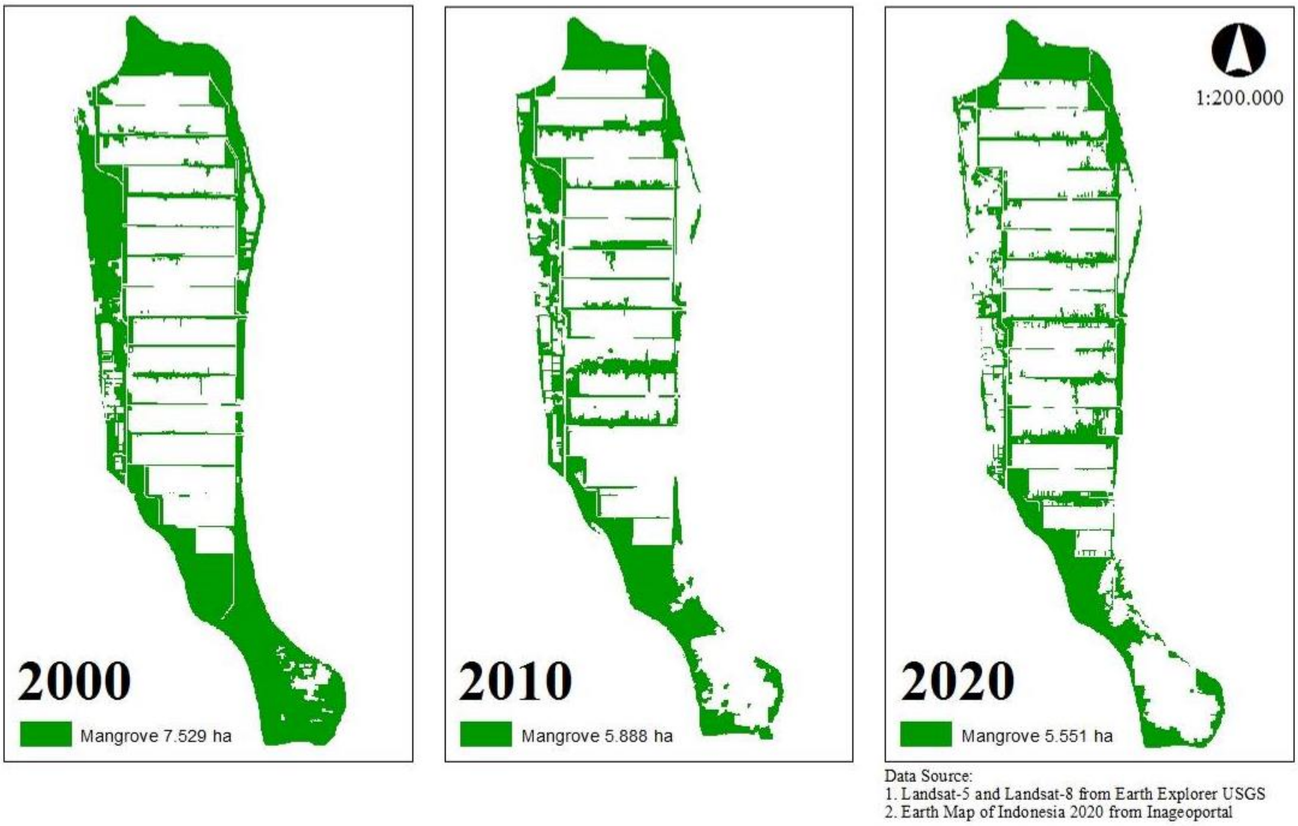

Figure 3. Map of changes in mangrove cover area for 2000-2020 in the East Rawajitu Sub-district, Tulang Bawang District, Lampung, Indonesia

Figure 4. Mangrove damage in East Rawajitu Sub-district, Tulang Bawang District, Lampung, Indonesia due to logging

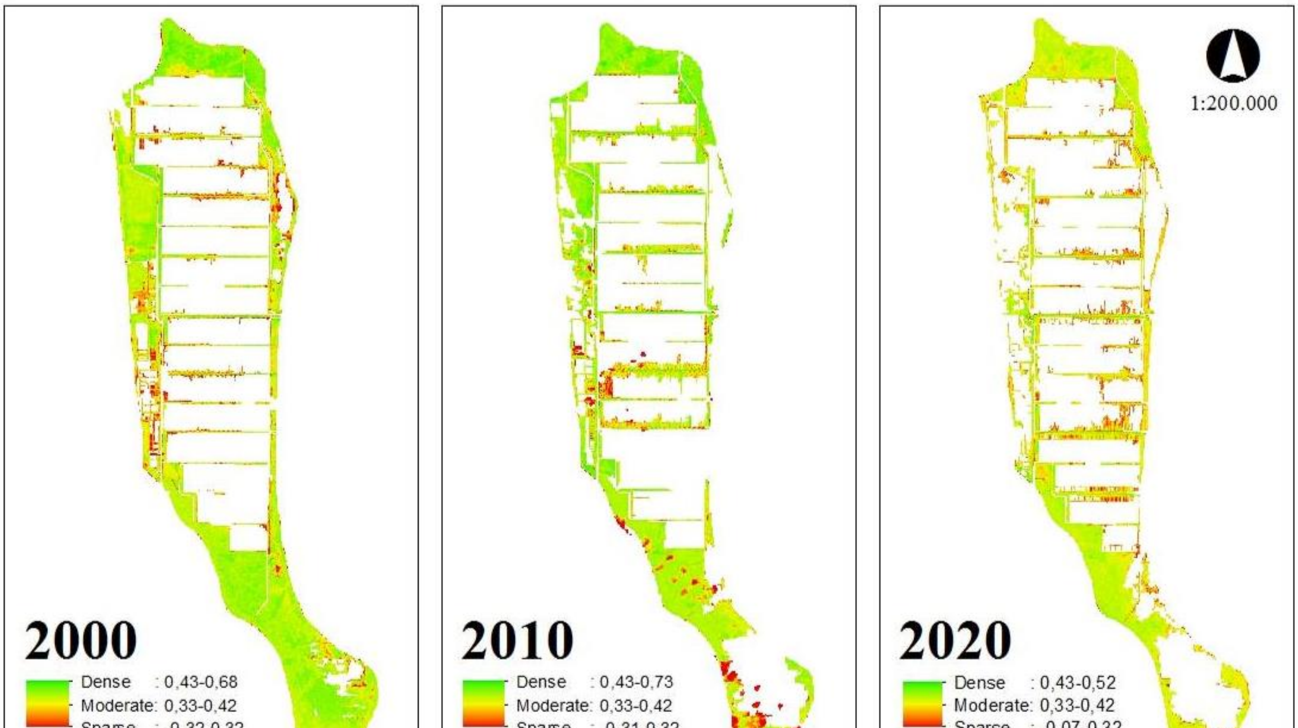

Figure 5. Map of mangrove density in East Rawajitu Sub-district, Tulang Bawang District, Lampung, Indonesia based on NDVI transformation in 2000-2020

Table 2. NDVI values and mangrove cover area based on the density level

Classification	2000		2010		2020	
	NDVI value	Area (ha)	NDVI value	Area (ha)	NDVI value	Area (ha)
Sparse	-0.32-0.32	646	-0.31-0.32	665	0.07-0.32	2,133
Moderate	0.33-0.42	771	0.33-0.42	537	0.33-0.42	3,217
Dense	0.43-0.68	6,112	0.43-0.73	4,686	0.43-0.52	201

Change in mangrove density from 2000 to 2020

A vegetation index image is a type of spectral transformation performed to multichannel photographs to highlight elements of vegetation density, such as mangrove forests. Mangrove density is obtained by overlaying the mangrove class from the land cover classification with images applied to the NDVI formula. The results of the NDVI transformation on the distribution of mangrove forest density in East Rawajitu Sub-district in 2000, 2010, and 2020 are presented in Figure 5.

Figure 5 shows the visualization of mangrove distribution in the East Rawajitu Sub-district with different densities. Based on the NDVI transformation results, there were changes in mangrove density levels in 2000, 2010, and 2020. Mangrove density is divided into three classes, namely sparse, medium, and dense density classes. In 2000 and 2010, the distribution of mangroves was dominated by dense canopy density, indicated by green symbols on the map, while in 2020, mangrove density was dominated by yellow, which stated that mangrove density was moderate. According to Rahman (2022), the NDVI transformation is based on the principle that green leaves absorb visible red radiation, thus making their reflectance low, while the leaf structure will reflect higher NIR radiation.

The dominance of colors obtained at each mangrove density class level can represent the area of mangrove cover. The larger the area at a given density level, the more dominant the color will be. Areas with high green saturation (dark green) are areas that are still heavily vegetated, as the Vegetation Index itself actually represents the extent of vegetation greening (Lagomasino et al. 2015; Landeros et al. 2018). The area of mangrove cover and NDVI values in each image that include mangrove vegetation area objects based on 2000, 2010, and 2020 density levels are presented in Table 2.

The condition of mangrove forests in 2000 was dominated by a dense density class of 6,112 ha with NDVI values ranging from 0.43-0.68. NDVI values increased in 2010, which showed that the level of mangrove density was getting higher, with NDVI values of dense density classes ranging from 0.43-0.73. The area of mangrove cover included in this category only remained at 4,696 ha. Furthermore, a very significant change occurred in 2020. Mangrove cover that falls into the dense density category in that year only leaves an area of 201 ha with NDVI values ranging from 0.43 to 0.52, and the rest is dominated by a medium density class of 3,217 ha and a sparse density class of 2,133 ha. The density of the mangroves increases with increasing NDVI values. Based on the opinion of Snyder et al. (2019) and Rahmat et al. (2022), the NDVI method compares the greenness of vegetation in satellite imagery data standards used the index as a mathematical blend of the red band (Red) and the NIR (Near Infrared Radiation). This is consistent with the study by Hartoyo et al. (2021), which found that vegetation cover will be denser if the NDVI value is close to 1. Conversely, if the NDVI score is close to -1, the vegetation cover will be more sparse.

The decline in mangrove forest density is due to the many pressures on coastal areas. This has resulted in changes in the structure and community of mangrove ecosystem constituents, the loss of flora and fauna habitat, and high levels of sedimentation and abrasion. The community has carried out mangrove rehabilitation efforts in Tulang Bawang District, spearheaded by the Pelangi Sentosa Mangrove Group. The group is engaged in mangrove seedling procurement, planting, and maintenance activities. The type of seedlings cultivated is *R. mucronata*. Although rehabilitation efforts have been carried out, these efforts have not produced significant results. According to Hai et al. (2020), mangrove rehabilitation in various places often fails because it does not pay attention to the suitability of the species to the place where it grows. The success of mangrove forest rehabilitation needs to consider the ability of natural regeneration and environmental conditions that affect the growth of mangrove seedlings (Azman et al. 2021). These activities can be carried out by coastal community groups so that the concept of community-based management, or the community as the main component driving mangrove conservation, will be created. Community-based management can work well if people with the initiative to protect and conserve mangrove forests have the skills to rehabilitate, conserve, and manage mangrove forests. Changes in land area happened as a result of environmental parameters that supported and human activity elements that carried out rehabilitation (Rosalina et al. 2023). In addition, engaging local communities early on, promoting social learning, laying the foundation for social capital development, and providing communities with access to sufficient geographic data can further improve local mangrove management (Damastuti and de Groot 2019). A participatory strategy engaging the community is a more sustainable way to restore and maintain mangroves since empowered local communities are better at managing forests (Agaton and Collera 2022; Tresiana et al. 2022).

In conclusion, it is note that mangroves in East Rawajitu Sub-district, Tulang Bawang district, Lampung Province, consist of major, minor, and associate mangrove components. The *A. marina*, *S. caseolaris*, *R. mucronata*, *R. stylosa*, and *N. fruticans* are dominated as major mangrove component. Minor mangrove species in the East

Rawajitu mangrove forest include *A. ilicifolius*, *I. pes-caprae*, and *X. granatum*. Associated mangroves in the study area include *T. populnea*, *E. agallocha*, and *T. catappa*. The analysis of changes in the mangrove cover in the East Rawajitu Sub-district from 2000 to 2020 showed a significant decline, from 7,529 ha to 5,551 ha. The decline in the mangrove cover area in 2010 was due to the company's failure to carry out coastal revitalization techniques. Then decline of mangrove cover in 2020, caused by the local community, carried out mangrove damage in the study area in stages. The condition of mangrove forests in 2000 was dominated by a dense density class of 6,112 ha with NDVI values ranging from 0.43-0.68. In 2010, there was an increase in the NDVI value in the dense density class to 0.43-0.73, but the area decreased. In 2020, there was a decrease in the NDVI value (0.43-0.52) and a drastic decrease in the area for the dense density class. The decline in mangrove forest density is due to the many pressures on the study area. Since the national government of Indonesia committed to rehabilitate 600,000 ha of mangrove between 2020 and 2024, it is proposed that mangroves of East Rawajitu Sub-district may be given priority and focused efforts to prevent the degradation.

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