Mapping of Mangrove Conditions Using Sentinel-2 Imagery

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A B S T R A K

Hutan mangrove menghadapi tekanan yang signifikan akibat aktivitas manusia seperti penebangan liar, konversi lahan, dan polusi. Dampak dari aktivitas manusia terhadap ekosistem ini telah menimbulkan kekhawatiran akan degradasi dan hilangnya hutan mangrove. Penelitian ini bertujuan untuk menganalisis kondisi ekosistem mangrove di Pulau Pannikiang melalui analisis kerapatan dan luasan. Data dikumpulkan dengan menggunakan metode penginderaan jauh, seperti citra satelit Sentinel-2 yang memiliki resolusi spasial 10 meter. Instrumen yang digunakan antara lain perangkat keras PC, ENVI, dan perangkat lunak ArcGIS untuk pengolahan citra. Jenis penelitian ini adalah penelitian deskriptif kuantitatif yang memanfaatkan teknologi penginderaan jauh. Subjek penelitian adalah seluruh hutan mangrove di sepanjang Pulau Pannikiang dengan luas total 1.042.261,12 m². Metode analisis yang digunakan adalah penerapan algoritma NDVI. Hasil utama dari penelitian ini adalah kondisi kerapatan mangrove di Pulau Pannikiang dimulai dari kelas kerapatan dangkal hingga kelas kerapatan sangat tinggi. Setiap kelas kerapatan memiliki luasan yang berbeda, masing-masing dimulai dari kerapatan sangat rendah dengan luasan 49137,98 m², kerapatan rendah dengan luasan 41947,12 m², kerapatan sedang dengan luasan 65916,9 m², kerapatan tinggi dengan luasan 175578,60 m², dan kerapatan sangat tinggi dengan luasan 749854,47 m². Penelitian ini menyimpulkan bahwa kondisi kerapatan mangrove di Pulau Pannikiang memiliki lima kelas kerapatan mulai dari kerapatan yang sangat rendah hingga kerapatan yang sangat tinggi. Penelitian ini memiliki implikasi penting bagi pengelolaan dan perlindungan kawasan mangrove.

A B S T R A C T

Mangrove forests face significant pressure due to human activities such as illegal logging, land conversion, and pollution. The impact of human activities on this ecosystem has raised concerns about the degradation and loss of mangrove forests. This study aimed to analyze the condition of the mangrove ecosystem on Pannikiang Island through density and area analysis. Data was collected using remote sensing methods, such as Sentinel-2 satellite imagery, which has a spatial resolution of 10 meters. The instruments used include PC hardware, ENVI, and ArcGIS software for image processing. This type of research is quantitative descriptive research that utilizes remote sensing technology. The research subjects were all mangrove forests along Pannikiang Island with a total area of 1,042,261.12 m². The analysis method used is the application of the NDVI algorithm. The main result of this research is that the condition of mangrove density on Pannikiang Island starts from the shallow density class to the very high-density class. Each density class has a different area, each starting from very low density with an area of 49137.98 m², low density with an area of 41947.12 m², medium density with an area of 65916.9 m², high density with an area of 175578.60 m², and very high density with an area of 749854.47 m². This research concludes that mangrove density conditions on Pannikiang Island have five density classes ranging from very low to very high density. This study has important implications for the management and protection of mangrove areas.

1. INTRODUCTION

Mangrove is a type of plant that can live between land and sea, therefore mangrove forests are often found at meeting locations between seawater and river estuaries (Azahra et al., 2024; Salamor & Yensy Lolita, 2020). Mangrove provides advantages or benefits such as habitat provision, coastal protection, and wave break (Fatimatuzzahroh et al., 2021; Prasetio et al., 2023). Ecologically, mangrove ecosystems function as spawning grounds and nursery grounds for various aquatic biota, besides that mangrove litter in the form of fallen leaves and branches will become a source of food in the aquatic environment after going through the decomposition process (Rumondang et al., 2023; Vincentius, 2020). The economic function of mangrove ecosystems is currently widely used to become ecotourism areas that can increase people's income and drive the economy of the surrounding area (Pakpahan & Kamilah, 2024; Parmawati et al., 2022). However, there are socio-economic factors in the community that cause damage

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to mangrove forests where mangrove forests are used as land for making ponds and community settlements (Harefa et al., 2023; Naibaho et al., 2022). Mangrove scattered in several world country with an area of about 19.9 million hectares, of which Indonesia is one a country that has mangrove forests widest in the world. In addition, Indonesia has a high level of mangrove diversity highest in the world, with a total of 202 species mangroves (Haryanto et al., 2020; Pohos et al., 2021). Level high biodiversity make mangrove forests as assets which is very valuable not only seen from its ecological function, but also of function economical (Budiman et al., 2021; Togatorop et al., 2023). In the last three decades, Indonesia has lost around 40% of mangrove ecosystems and damage to mangroves in the world has reached around 46% (Darmawan et al., 2022; Rasyid et al., 2023). Another researcher said that, mangrove ecosystems around the world face a number of threats such as pollution, deforestation (forest cutting), and fragmentation (environmental change). South Sulawesi is one one province in Indonesia that experienced mangrove damage is quite severe. In 2009, only around 12,820 hectares were recorded of remaining mangrove area including mangrove forests that have been crashed and has been converted become a community aquaculture area (Damanik et al., 2022; Sribianti et al., 2021). Mangroves damage this will result in a decrease functions and benefits of mangrove forests. Therefore, it is necessary to monitor the mangrove ecosystem to improve the welfare of the local community while maintaining the sustainability of the ecosystem.

Mapping is one of the first steps in a study that can be carried out to observe the condition of mangrove forests which is more effective and efficient in obtaining an overview of the distribution of mangrove forest areas (Hanan et al., 2020; Saleha et al., 2023). Mangrove forest mapping by utilizing remote sensing technology can provide a map of the distribution of mangrove forest area (Asri, 2022; R. D. Putra et al., 2022). Remote sensing is a science of obtaining information through analyzing data without having direct contact with objects. Mapping can be used as an alternative solution for research that requires a fairly long period of time, considering that research on mapping the distribution of mangrove areas can be used to see conditions in previous and current years. Mangrove mapping has an important role to understand the characteristics, distribution and species of mangroves so that it can provide information related to environmental changes (Pham et al., 2019; Rahmadi et al., 2021). One of the remote sensing data that can be used for mangrove mapping is Sentinel-2A imagery. Sentinel-2 is a satellite launched in collaboration between the European Commission and the European Space Agency in the Global Monitoring for Environment and Security (GMES) program. The Sentinel-2A image has 13 multispectral channels, 13 spectral channels and is divided into 4 channels with a spatial resolution of 10 meters, 6 channels with a spatial resolution of 20 meters, and 3 channels with a spatial resolution of 60 meters (Rahmadi et al., 2021; Rosyid et al., 2019). This satellite was launched to monitor the condition of the earth's surface, so as to be able to provide information on the latest conditions of the earth from space for environmental and security applications. Other researchers' research suggested that Sentinel-2A images can provide maximum results for mangrove mapping in the tropics by using the NDVI method and the right combination. Furthermore, other researchers stated that using Sentinel-2A imagery for mapping mangrove areas provides an accuracy of up to 90% by utilizing short-wave infrared channels (Pham et al., 2019; Rahmadi et al., 2021).

Many studies related to mangrove ecosystems have been conducted, including community structure, monitoring, and detection of mangroves using remote sensing. But no one has conducted such research on Pannikiang Island. Pannikiang Island is one of several small islands in Barru Regency which were designated as reserves for a marine conservation area based on the Decree of the Governor of South Sulawesi Number 2944 of 2018. The designation of this island is a strategic and important step as an effort to protect the natural resources that are still relatively natural with a variety of functions. Pannikiang Island has several ecosystems, one of which is a fairly extensive and dense mangrove ecosystem with a complete diversity of mangrove species which are generally dominated by types of *Rhizophora apiculata*, *Rhizophora mucronata* and *Sonneratia alba*. The island quite representative because it has conditions mangrove ecosystem which is classified as still natural and also about 85% of Panikiang Island covered by mangroves (Hapsari et al., 2022; Masud et al., 2020). The purpose of this study was to analyze the condition of the mangrove ecosystem on Pannikiang Island through density and area analysis. This analysis is important to understand the distribution of mangrove density on the island. Understanding the density and area of mangroves can help us utilize this natural resource optimally. This knowledge is also very important for countermeasures against damage to mangrove ecosystems. Damage mitigation efforts will be more effective if they are based on accurate data on the condition of the ecosystem. Therefore, the results of this study will serve as a solid basis for future mangrove management and protection on Pannikiang Island. Thus, the sustainability of the mangrove ecosystem can be maintained, and its benefits for the environment and society can be optimized.

2. METHOD

Field Data Collection

This research activity was carried out from October 03rd to December 03rd 2022 which is located in Mangrove Ecotourism at Pannikkiang Island, Madello Village, Balusu District, Barru Regency, South Sulawesi Province. The research subject was the entire mangrove forest along Pannikiang Island with a total area of 1,042,261.12 m². This type of research is quantitative descriptive research that utilizes remote sensing technology to map and classify mangrove conditions on Pannikiang Island. The location map can be seen in Figure 1.
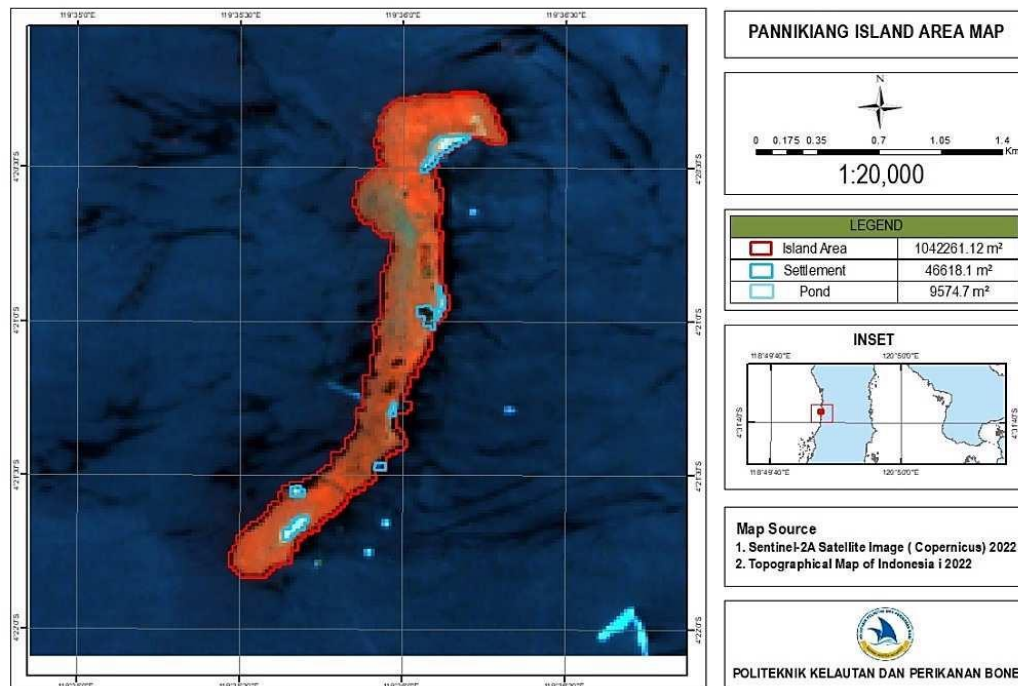

Figure 1. Map of mangrove area on Pannikiang Island

Image Processing

The image data processing tools used are hardware, namely PC and software, namely ENVI and ArcGIS. The material used is Sentinel-2 satellite imagery data with a medium spatial resolution of 10 meters which was acquired on September 1st 2022 by selecting the best cloud-free imagery and obtained free of charge on the European Space Agency (ESA) website with the specified wavelength used as in Table 1.

Table 1. Sentinel 2A wavelength specification

Sentinel-2 Band	Wavelength (nm)	Band Name	Spatial Resolution (m)
Band 2	0.490	Blue (B)	10
Band 3	0.560	Green (G)	10
Band 4	0.665	Red (R)	10
Band 8	0.865	Near Infrared (NIR)	10

The steps that must be taken in processing the image are download, image stacking, radiometric correction, image sharpening, cropping, land and sea separation (masking) image composites and classification. Download Sentinel-2A satellite imagery from http://sentinel-pds.s3-website.eu-central-1.amazonaws.com/ with T50 MQV and T50 MRU tiles, which consist of 13 bands. The choice of wavelength is based on the need for NDVI analysis so that the wavelengths in bands 4 and 8 are selected and the need for composite images for land cover data extraction so that bands 2 and 3 are selected (Semedi et al., 2021). Radiometric correction is a correction aimed at improving pixel values by considering atmospheric disturbances as the main source of error. Atmospheric effects cause the reflection value of objects on the earth's surface recorded by the sensor to not be the original value, but to become larger or smaller due to the absorption process. Image sharpening is used to clarify the

appearance of objects contained in the image so that informative images can be obtained. The purpose of image sharpening is to sharpen the visual interpretability of images, either to obtain beautiful images or for image analysis. This sharpening is done before displaying the image with the aim of increasing the information that can be interpreted digitally. The process involves sharpening the contrast that appears in the form of the image recorded in the image, so that it can improve the appearance of the image and increase the differences that exist between objects in the image (R. D. Putra et al., 2022). Furthermore, cropping or cutting the image area is a technique used to determine which part of the image contains the Pannikiang Island object area to be processed. Masking is the process of separating the object of study from those that are not included in the observation area. The masking process is carried out in the land area by making the Digital Number (DN) in that area zero (0), so that during the classification process it is not affected by the radiance value from the land. The image composite is the process of combining three remote sensing images from different image channels or bands so as to provide a color combination with the aim of highlighting the appearance of mangrove that is the object of study. In the composite image process, bands will be used based on the wavelength specifications and also the color channels used, namely channel 432 in red, green and blue (RGB). Image classification using Unsupervised-ISODATA which refers to the clustering of spectral values by value average. The results of image classification produce a closing class land in the form of mangroves and non-mangrove (settlement and pond) (Faizal et al., 2023). The method used in mangrove is the application of the NDVI algorithm. Normalized Difference Vegetation Index (NDVI) analysis is an algorithm used to determine the greenness index of plants (vegetation). The NDVI index itself is generated through a combination of two channels (bands) of satellite imagery namely red (red) and Near-Infrared Radiation (NIR), from the results of the algorithm it will produce a value of -1 to 1.

3. RESULT AND DISCUSSION

Result
Mangrove Area

The distribution of mangroves on Panikiang Island using Sentinel-2 imagery produces a mangrove area of 1042261.12 m^2. The mangrove area map can be seen in Figure 2. The results of image classification using the unsupervised ISODATA classification method to separate mangrove and non-mangrove (settlement and pond) cover, with automatic data subtraction, 6 spectral clusters are obtained, which are then simplified into 3 data clusters based on spectral reflection as shown in Figure 2. All pixels are classified to the nearest class. This process continues until the maximum number of iterations is reached. The results of the classification in this study indicate that there are 6 spectral classes that are obtained from the system automatically from all image pixels. Then identify and group the same objects with the combine class method. There are 3 types of colors and different hues of pixels. The combination and grouping of pixel value groups is used to separate mangrove and non-mangrove land cover based on the similarity of spectral reflections.

Mangrove Density

Mangrove density classification data obtained based on NDVI calculations using ENVI software. The NDVI calculation used in this processing uses Band 8 and Band 4 Sentinel-2A satellite imagery, the results can be seen in Figure 3. The combination of these two channels will produce data that is sensitive to the greenness of the vegetation. The results were obtained using the NDVI method which separated mangrove vegetation and obtained results ranging from very low to highest values of -0.59 to 0.77. The NDVI classification range of absorption of solar radiation results is always in the range of -1 to +1. The greater the NDVI value, the higher the density level. NDVI will produce new images with a value range of -1 to +1 and vegetation is marked with a high NDVI value, otherwise water bodies are marked with negative NDVI values due to electromagnetic absorption by water. The results of NDVI values can be seen in Table 2 below.

Table 2. NDVI values of mangrove density class on Pannikiang Island

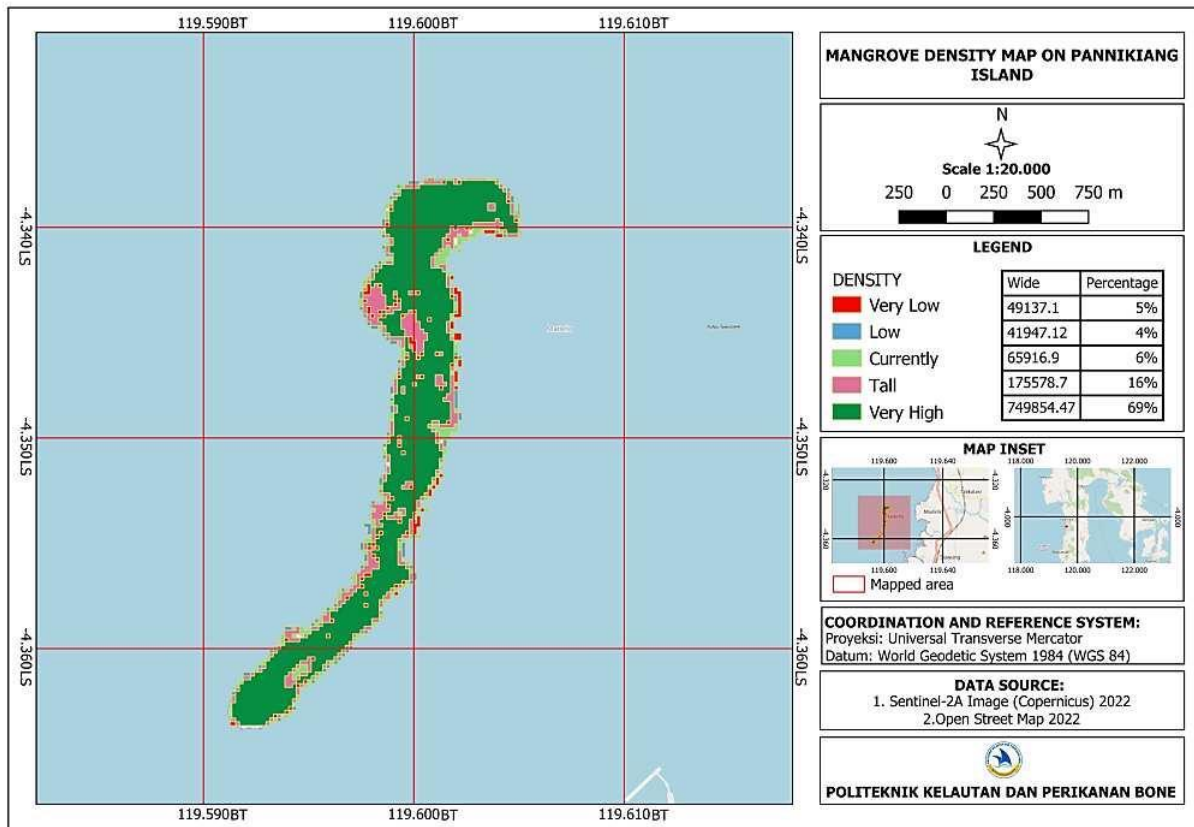| Density Class	NDVI Value
Very low	-0,59 – 0
Low	0 – 0,20
Medium	0,40 – 0,21
High	0,41 – 0,60
Very high	0,61 – 0,77

Figure 3. Mangrove density map on Pannikiang Island

Based on data processing, the broad categories and density conditions of mangroves were divided into five density classes, namely very low, low, medium, high and very high density classes. It can be seen in Figure 3 that the very high density class is spread almost throughout Pannikiang Island, while the high density class is spread on the West side of the island, the medium density class is spread along the coast, while the low and very low density class is spread on the East side of the island. The area of each density class can be seen in Table 3 below.

Table 3. Mangrove density class on Pannikiang Island

Density Class	Area (m^2)	Precentage (%)
Very low	49137.98	5
Low	41947.12	6
Medium	65916.89	6
High	175578.60	16
Very high	749854.47	69

Discussion
Mangrove Area
From Figure 2 below, the distribution area of mangroves is 1042261.12 m^2, residential area is 46618.1 m^2 and pond area is 9574.7 m^2. This shows that the mangrove ecosystem is extensive and dominant compared to residential areas and ponds. In addition, the wide distribution of mangroves also reflects the high ecological potential in maintaining environmental balance and biodiversity. This data processing uses the method of observing the mangrove vegetation index density through remote sensing approaches. The vegetation index is a systematic transformation that involves several channels at once and produces new and representative images in presenting vegetation phenomena (Hardianto et al., 2021; Mukhlisin & Soemarno, 2020). Analysis using the vegetation index with a remote sensing approach provides accurate and representative data on the condition of mangrove vegetation, which is very useful in planning and managing this area. Mangrove ecosystems are objects that can be identified with remote sensing technology, because the location of the ecosystem is in the transitional area of land and sea so that it produces a distinctive recording effect compared to other terrestrial vegetation objects. Mangroves

grow in land and sea transition areas, so there are three main features that greatly affect object recognition through remote sensing, namely vegetation, soil and water (Ahmad et al., 2021; Andakke & Tarya, 2022; Cahyo et al., 2022; Pasaribu et al., 2022), these three features greatly affect the spectral reflection received by the sensor remote sensing, so density identification requires special transformation. In identifying the density of vegetation, various transformations of the vegetation index are often used. Other researchers argue that the mangrove on Pannikiang Island, which is in the Spermonde Islands cluster, is still relatively natural and has a diversity of mangrove species. It can be seen on the map that the area of mangroves still dominates on Pannikiang Island, but parts of the area have been cleared for settlement. The condition of the Pannikiang Island mangrove ecosystem is currently in a good category with a large area (A. W. Putra et al., 2023; Rusdi et al., 2020). The condition of the mangroves has not changed much since 2011 with the condition of the mangrove ecosystem on Pannikiang Island being in the medium to dense category and still in the good category. In addition, there are several associated trees that grow around mangroves such as *Hibiscus tiliaceus, Pandanus amaryllifolius*, and *Terminalia catappa*, especially those close to residential areas (Damsir et al., 2023; Masud et al., 2020). Overall, the mangrove ecosystem on Pannikiang Island grows thickly with a basic sedimentary structure in the coastal area, generally fine sand to coarse blackish and muddy.

Mangrove Density

Mangroves on Pannikiang Island also have high species diversity and are still classified as natural, which is an essential asset for scientific research and ecotourism. It can be seen in the map below that the density level of mangroves is dominated by green color, which means that the resulting NDVI value is very high and the condition of the mangroves on Pannikiang Island is quite good with a resulting density percentage of 69%. The high mangrove density with an NDVI value of 69% indicates a healthy and fertile vegetation condition, which functions as a habitat for various biota and as a coastal protection from abrasion. NDVI density analysis can also be used to monitor changes in mangrove density, species, and total cover (Akbar et al., 2020; Singgalen et al., 2021). The ecological potential of the mangrove ecosystem on Pannikiang Island can be seen from the mangrove density distribution. Based on Figure 3 it can be seen that the distribution of mangrove density spreads in every part of the island. The distribution of density is classified as very high with the largest area of 749854.47 m^2 compared to other density category classes, so that it can become a potential tourist attraction and natural potential for the survival of the biota in it. In line with the results of other researchers who argue that, the density of mangroves in the tree category on Pannikiang Island is categorized as moderate to very dense based on the criteria for mangrove damage issued by the Minister of Environment in Ministerial Decree Number 201 of 2004 (Gultom et al., 2024; Masud et al., 2020). As a whole the mangrove ecosystem on Pannikiang Island grows thickly with a basic sedimentary structure in the coastal area, generally fine sand to coarse blackish and muddy. This makes most of the Pannikiang Island area overgrown with mangroves with a very high density. Besides, mangrove density is important in showing that existing mangrove ecosystem communities grow in fertile waters (Kuncahyo et al., 2020; Masud et al., 2020). Mangrove density is one of the ecological parameters of the mangrove ecosystem which shows the fertility of mangrove vegetation. The density of mangroves in some areas has a high density compared to some other areas, because it has a large number of tree stands and the characteristics of dense stilt roots that function as sediment traps. Dense roots are very effective for capturing and retaining mud (Mahmuda et al., 2023; Widiawati et al., 2021). The trapped sediment is rich in organic matter content so that it can expand mangrove habitat and can increase the growth and development of mangroves (Furukawa & Wolanski, 1996; Kurniasih, 2023).

The mangroves found on Panikiang Island are scattered with different densities. The existence of these differences is highly dependent on environmental factors. Tides indirectly control the depth of the water table (water table), water and soil salinity related to species tolerance to salt content, soil type which determines the level of soil aeration, water table height and drainage, fresh water supply and flow, and the amount of light affected the growth of tillers of several intolerant mangrove species such as *Rhizophora, Avicennia* and *Sonneratia*. Then, differences in mangrove density in each area are also influenced by several factors, including the adaptation of mangroves to the habitat environment, substrate conditions and so on. The condition of mangroves is influenced by several factors, one of which is human activity. Meanwhile, there are three main factors causing damage to mangroves, namely pollution, conversion of mangrove forests and excessive logging (Farhaby & Anwar, 2023; Jaelani et al., 2023; Maolani & Nuryati, 2021; Rahmadi et al., 2020; Yuniar et al., 2023). There are several limitations to the management of this mangrove area. Logging of mangroves for firewood, house construction, and land clearing activities carried out by local communities and those outside the island pose a severe threat to mangrove sustainability. In addition, low public understanding of the importance of maintaining mangrove ecosystems and the lack of adequate facilities and infrastructure trigger uncontrolled

utilization. This is exacerbated by human activities such as bat trapping and land conversion that cause ecosystem damage. To overcome these limitations, solutions that can be applied are increasing public awareness through environmental education and campaigns and providing adequate facilities and infrastructure to support conservation efforts. Applying the ecotourism concept can also be an effective solution by involving the community in managing mangrove areas so that they feel direct economic benefits. In addition, rehabilitating damaged mangrove areas by planting mangrove seedlings can increase the density and health of these ecosystems. This study has important implications for the management and protection of mangrove areas. Information on mangrove distribution and density can be used to plan effective rehabilitation and conservation programs. This data is also helpful in monitoring changes in the condition of mangrove ecosystems over time so that corrective measures can be taken promptly. The implementation of remote sensing technology to monitor mangrove vegetation allows area managers to identify areas that require conservation interventions, such as planting mangrove seedlings in locations that have been degraded using MH or other approaches. In addition, this research can help develop a holistic ecosystem-based management strategy that focuses on not only conservation aspects but also the socio-economic aspects of the surrounding community. Thus, the results of this research can make a real contribution to the protection of sustainable mangrove ecosystems.

4. CONCLUSION

Based on the study's results, mangrove density conditions on Pannikiang Island have five density classes ranging from very low to very high density. Each density class has a different area. These classes include very low density, low density, medium density, high density, and very high density. The results showed a significant variation in density along the mangrove forest area of Pannikiang Island. The area occupied in the high-density class is more critical than in other courses. This condition indicates that regions with very high density have great potential to be used as a reference in continuing conservation programs. In addition, these areas are also crucial for protection programs and sustainable management of mangrove ecosystems on Pannikiang Island. Thus, management strategies should consider these density differences to ensure the region's sustainability and health of mangrove ecosystems.

5. ACKNOWLEDGE

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