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Mapping of Mangrove Composition in Ratai Bay, Lampung Province Using Pleiades-1 Satellite Imagery

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ABSTRACT

Mangroves are vegetation that has important value in Indonesia's coastal areas. Ratai Bay in Lampung has an established natural mangrove ecosystem in a protected area, however information regarding the composition of vegetation types within it is still limited. Therefore, this research aims to map the composition of mangrove vegetation in Ratai Bay using Pleiades-1 satellite imagery. The mapping method involves image segmentation and unsupervised classification to categorize the study area into vegetation classes for field surveys. The final vegetation composition class was obtained through reclassification based on a main photo approach built from field data which produced six mangrove composition classes with a total accuracy level of 92%. The forest class dominated by the Rhizophora apiculata species is the largest class, covering an area of 203.19 hectares of the total mangrove area in Ratai Bay of 277.15 hectares. In addition, classes dominated by shrub life forms, mainly consisting of the species Rhizophora apiculata and Avicennia marina, are often found in mudflat areas at the mouth of the Ratai River.

ARTICLE INFO

Article History:
Submitted/Received 30 May 2023
First Revised 30 April 2023
Accepted 30 May 2023
First Available online 30 Oct 2023
Publication Date 30 Oct 2023

Keywords:
Mangrove Species Composition,
Lifeforms,
Pleiades-1 imagery

1. INTRODUCTION

Mangroves are one of the vegetation types that hold significant value in coastal ecosystems in Indonesia. Apart from having the largest area in the world, Indonesia protects mangroves due to their role in climate change mitigation, coastal disaster prevention, and as habitats for coastal biota (Alongi, 2008). The protection of mangrove ecosystems in Indonesia is manifested through recognizing mangroves as protected areas in spatial planning documents such as Forest Areas, coastal and small island zone plans, and regional spatial planning. Furthermore, Indonesia has also implemented a national mangrove rehabilitation program with a target of 600,000 hectares (Indonesia, 2020).

In the management of mangrove ecosystems, apart from the extent of mangrove vegetation coverage, information on mangrove vegetation composition is crucial in the aspect of mangrove ecosystem management (Heenkenda et al., 2014; Kamal et al., 2015; Maurya et al., 2021). Information on mangrove vegetation composition can depict biodiversity and ecosystem conditions (Duke, 1992). This is because the composition of vegetation species results from the reciprocal interaction between mangroves and their environmental conditions (Ahmed et al., 2022; Kodikara et al., 2018).

Remote sensing technology has emerged as one of the most effective alternatives for mapping mangrove vegetation composition and structure, as it minimizes the need for costly field surveys (Pham et al., 2019). Pleiades-1 satellite imagery is a type of remote sensing data currently available and serves as an alternative data source for mangrove mapping. Although it has limitations in terms of spectral resolution with only four bands, it excels in spatial resolution, ranging from 2-0.5 meters. The high spatial resolution capability of the Pleiades-1 imagery enables accurate mapping of mangroves at the family level (Anshah et al., 2021).

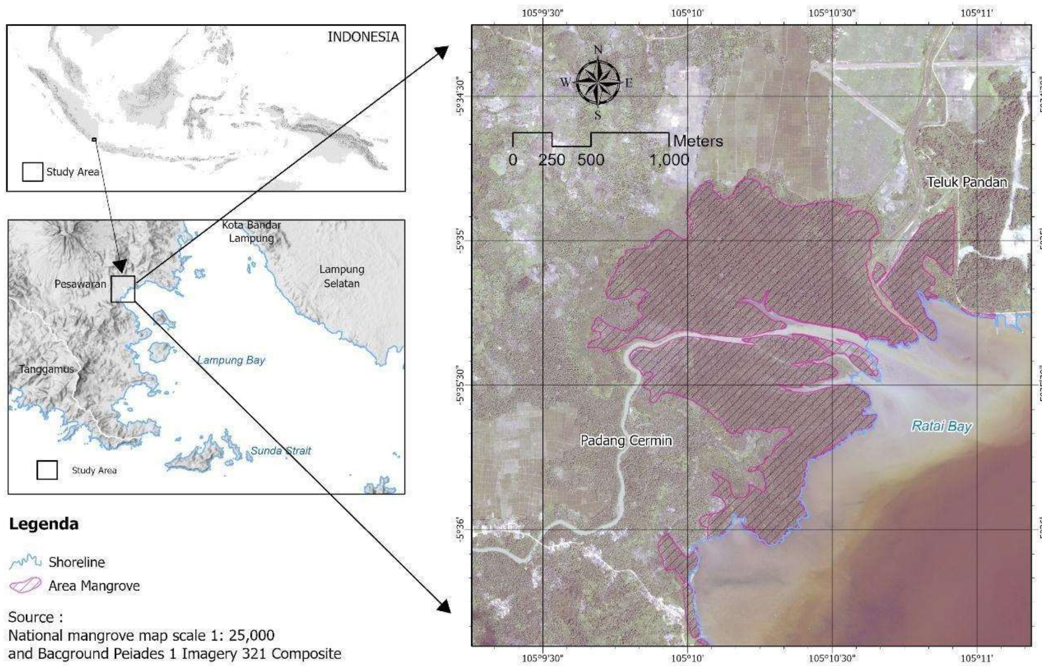
One of the mangrove ecosystems in Indonesia is located in Ratai Bay, Lampung Province. Mangroves in this area thrive naturally, making it part of the protected coastal and small island areas. Ratai Bay's mangroves also exhibit high carbon stocks, as indicated by the high leaf area index values (Juniansah et al., 2018). On the other hand, information related to mangrove vegetation composition in Ratai Bay is still not available, either in the form of work reports or scientific publications. In order to complete scientific references related to the distribution of mangrove composition in the study area, this research focuses on 2 research objectives which include: 1) assessing the performance of Pleiades-1 satellite imagery in mapping mangrove composition and 2) inventorying the distribution of vegetation composition in the mangrove forest of Ratai Bay, Lampung Province using Pleiades-1 satellite imagery.

2. METHODS

2.1 Study Area

This study focuses on the study area located in Teluk Ratai, Lampung Province. The research area is positioned between the coordinates of 105º 09' 40" E - 105º 10' 55" E and 05º 34' 45" S - 05º 36' 04" S **(Figure 1)**. The selection of this study area is based on the fact that Teluk Ratai is a coastal and small island conservation zone within the Coastal and Small Island Zoning Plan of Lampung Province. Information regarding the composition and structure of mangrove vegetation serves as one of the crucial datasets required for managing this area.

DOI: https://doi.org/10.17509/gea.v23i2.59612
p- ISSN 1412-0313 e- ISSN 2549-7529



Source: Data analysis (2021)

Figure 1. Study Area

2.2 Materials

The main primary data used in this research is Pleiades-1 satellite imagery. Additionally, field survey plot data acquired in 2022 are also available. The field survey plot data are used to develop interpretation keys and test the accuracy of mangrove vegetation mapping. Detailed information regarding the data and its specifications used in this study can be found in **Table 1**.

Table 1. Data used and its specification

No	Data	Source and Specification
1	Pleiades-1 Satellite Imagery	• Multispectral Bands • Pixel size 2 meters • Acquisition February 23, 2020 • Source from Geospatial Information Agency (BIG)
2	Field Survey Data	• Total 61 plots • Survey conducted in November 2022
3	Ground Control Points Data	• A total of 4 GCP points

Source: Data source from BIG

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p- ISSN 1412-0313 e- ISSN 2549-7529

3. METHODOLOGY

In order to achieve the objectives of this research, there were several methodological stages that were followed **(Figure 6)**. These stages include data preparation, field data acquisition, reclassification of mangrove composition, and accuracy assessment.

3.1 Data Preparation

Data preparation generally involves preprocessing the data through geometric correction of the images. Geometric correction is necessary because Pleiades-1 satellite imagery is at the sensor processing level. This means the pixel geometry needs to be optimized using ground control point (GCP) data (Perko et al., 2019). The geometric correction process is carried out through image orthorectification using 4 GCPs (Ground Control Points) with the Toutin model. The Toutin model for orthorectification is considered capable of producing vertically aligned images with more optimal positional accuracy, as it is based on a physical model that utilizes satellite orbital data (Toutin and Schauer, 2006).

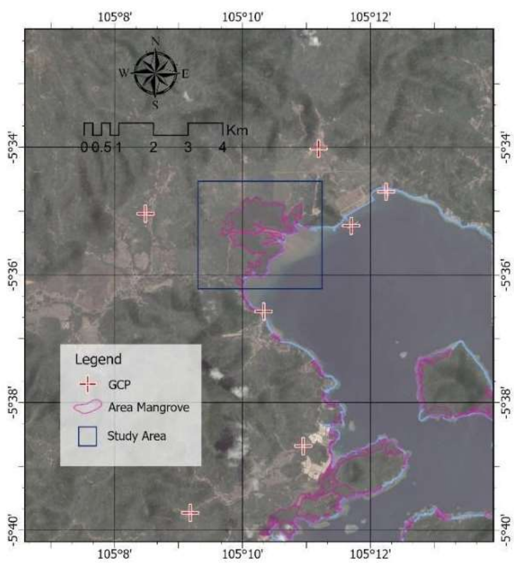

Figure 2. GCPs distribution

After the geometric correction, the Pleiades-1 satellite imagery undergoes a classification process to separate mangrove and non-mangrove objects. The approach used in this classification is object-based (Geographical Object Image Analyst/GEOBIA). The GEOBIA analyst employed is a multi-level classification based on knowledge encapsulated in a classification rule set. The rule set consists of hierarchical classification rules based on the interpreter's knowledge, implemented as a decision tree (Almeida et al., 2020; Hidayatullah, 2022; Kamal et al., 2015). The object-based approach has been proven effective in distinguishing mangrove and non-mangrove vegetation in high-resolution remote sensing imagery (Hidayatullah and Kamal, 2023). The results of the classification for mangrove-non-mangrove separation can be seen in **Figure 3**. The classification is generated using multiresolution segmentation (scale: 20, shape: 0.2, and compactness: 0.5), along with the

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p- ISSN 1412-0313 e- ISSN 2549-7529

utilization of a multi-level classification that optimizes the use of the four channels of Pleiades-1 satellite imagery.

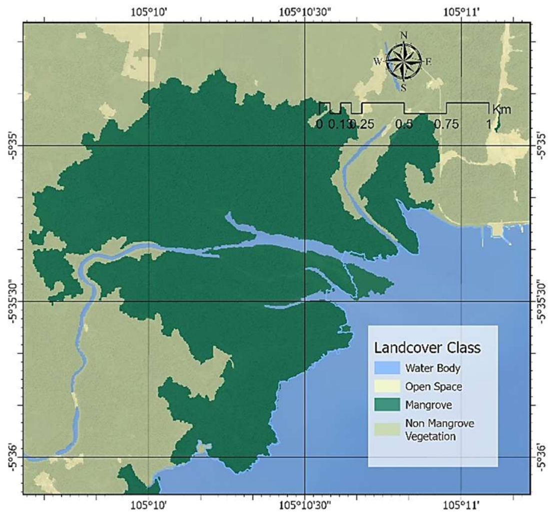

Figure 3. Result mangrove-non mangrove classification

After successfully separating mangrove and non-mangrove objects, an unsupervised classification process is performed for the mangrove area. This unsupervised classification serves as an initial approach to classifying segments based on pixel value similarity to prioritize the classification of similar objects (McCarthy et al., 2015). The algorithm used is k-means clustering, with the mapping units being the results of multiresolution segmentation (scale: 8, shape: 0.2, and compactness: 0.5). The use of k-means clustering is intended to create classifications that minimize the variability of values within each class and maximize the variability of values between classes (Zharikov et al., 2005). This process aims to divide the mangrove area into classes that exhibit similar pixel values within each segment. The resulting classes from the unsupervised classification **(Figure 4)** will serve as the basis for field survey determination. The distribution of field samples **(Figure 3)** is carried out purposively, considering the variation in classes from the unsupervised classification as well as accessibility to the observation locations.

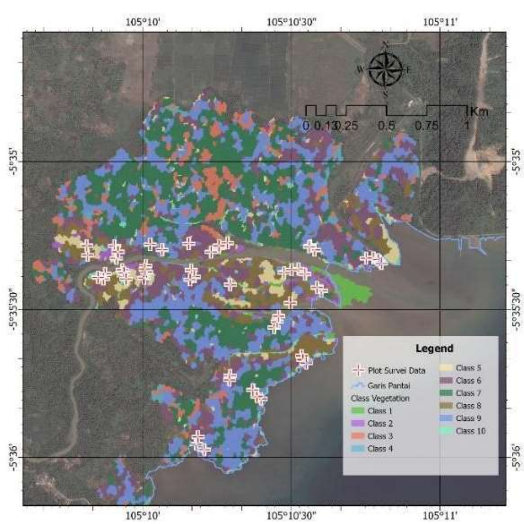

Figure 4. Vegetation Class from unsupervised classification and survey plot distribution

DOI: https://doi.org/10.17509/gea.v23i2.59612
p- ISSN 1412-0313 e- ISSN 2549-7529

3.2 Field Survey

Field surveys will be conducted using the plot sampling method adopted from SNI 7717-2020, which specifies the geospatial information requirements for mangroves. The observation area in the field will take the form of a 10 x 10-meter square, capturing the lifeforms and species dominance. Additionally, data on vegetation structure, such as canopy cover percentage and tree height, will also be collected to supplement the information. As shown in **Figure 5**, GPS positioning measurements are taken at the center of each plot, coinciding with the position for capturing hemispherical photos. These hemispherical photos are used as a measurement tool to estimate canopy cover percentage in the field. Tree height within the plots is measured using a laser finder device.

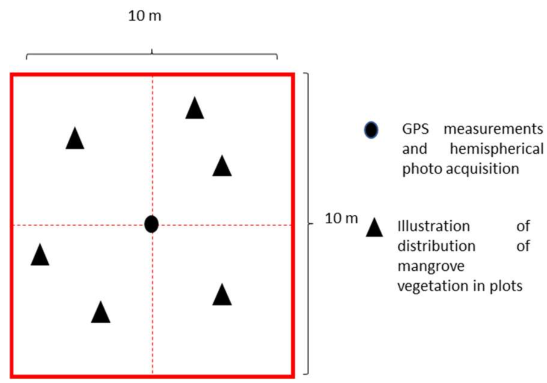

Figure 5. Illustration of field data acquisition

3.3 Reclassification of Mangrove Composition

In classifying the composition and structure of mangrove vegetation, this study employs visual interpretation. Visual interpretation is a well-established approach commonly used for mangrove object interpretation (Heenkenda et al., 2014). The visual method is particularly suitable for relatively small study areas, such as the study area in this research (Snook et al., 1987). On the other hand, visual interpretation is considered superior to digital interpretation for classifying objects that are not overly complex (with a limited number of classes) (Husson et al., 2016). To enhance the accuracy of visual interpretation, field observations will be used to develop the key for interpreting objects in the Pleiades-1 satellite imagery. During this stage, classification is performed on the segments obtained from the image segmentation process in the previous stage. At this stage, classification is performed on the segments obtained from the image segmentation process in the previous stage. The stages of reclassification are as follows:

- Identification of mangrove zonation based on image appearance, unsupervised classification results, and field observations.
- Identification of mangrove vegetation composition based on the dominance of lifeforms and species in the field.
- Developing Pleiades-1 imagery interpretation keys for each mangrove zonation class.
- Re-classification of each segment of unsupervised classification results based on the visual appearance of Pleiades-1 imagery.

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3.4 Mapping Accuracy Assessment

Accuracy testing was conducted as a form of assessment of the ability of Pleiades-1 satellite imagery for mangrove vegetation composition mapping. Accuracy assessment is done using confusion matrix **(Table 2)**. Confusion matrix is one of the evaluation techniques to measure the extent of the truth of the classification results of remote sensing data. The reference data used for accuracy assessment consists of 61 sample plot points spread throughout the study area. In general, the accuracy variables measured in the confusion matrix are producer accuracy, user accuracy, and total accuracy **(Table 2)**. Producer accuracy represents the degree to which objects in the field are mapped on the classification results, while user accuracy represents the level of correctness, and finally total accuracy represents the overall level of accuracy in the classification results (Congalton, 1991, 2001; Story and Congalton, 1986).

Table 2. Confusion matrix for mapping accuracy assessment

		Reference		**Total**	**User's Accuracy**
		A	**B**		
Classification	**A**	AA	AB	AA+AB+AC	AA/(AA+AB+AC)
	B	BA	BB	BA+BB+BC	BB/(BA+BB+BC)
	Total	AA+BA+CA	AB+BB+CB	Sample totals	
	Producer's Accuracy	AA/(AA+BA+CA)	BB/(AB+BB+CB)		
	Overall Accuracy	AA+BB+CC/Sample totals			

Source: Congalton, 1991

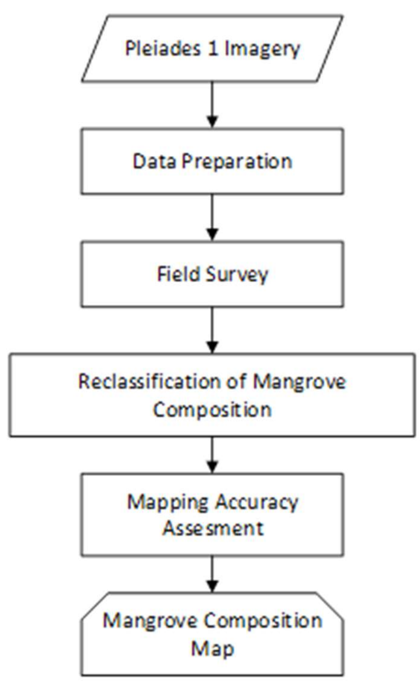

Figure 6. Research flowchart

DOI: https://doi.org/10.17509/gea.v23i2.59612
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4. RESULTS AND DISCUSSION

4.1 Performance for Mangrove Composition Mapping

In this study, the composition of mangrove vegetation is mapped based on vegetation community categorized by the dominant lifeforms and species. Lifeforms refer to the physical characteristics used to classify plants based on their shape and lifestyle (Plumb, 1991). In mangrove vegetation, lifeforms can be divided into several classes, including trees, shrubs, palmae, and ground ferns (Duke, 1992; Duke et al., 1998). In the study area, all four types of lifeforms were found. However, considering their distribution and mapping purposes, the classification of lifeforms can be simplified into three classes: tree dominance, shrub dominance, and palmae plant dominance (Field documentation can be seen in **Figure 7**).

Ground ferns, represented by the species Acrostichum aureum (AA), form the second layer of vegetation under the mangroves, with lifeforms resembling trees. Due to the limitations of optical remote sensing data in identifying the second vegetation layer, ground ferns were excluded from the mapping classification. The lifeforms and mangrove species in the study area exhibit a structured hierarchical relationship (Duke, 1992). One lifeform may consist of different species and vice versa (Kamal et al., 2015).

Areas dominated by tree lifeforms are dominated by mangrove species Rhizophora apiculata (RA), Sonneratia alba, and Avicennia marina (AM). Although other species, such as Ceriops tagal (CT), Xylocarpus granatum (XG), and Rhizophora stylosa (RS), were also found, they do not dominate specific zonation formations. On the other hand, shrub dominance is characterized by mangrove species AM and RA, while palmae like plant dominance is associated with Nypa fruticans (NF) species. To assist in the classification of mangrove vegetation based on lifeform and species, a hierarchical classification system was developed, as shown in Figure 8.

Figure 7. Lifeforms mangrove vegetation in the study area (a) Palmae (b) Trees (c) shrubs

Source: Field Documentation, 2022

DOI: https://doi.org/10.17509/gea.v23i2.59612
p- ISSN 1412-0313 e- ISSN 2549-7529

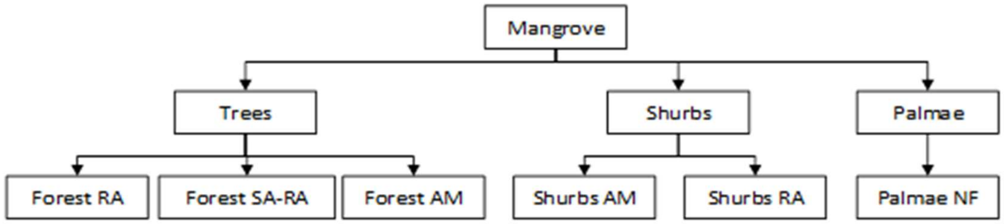

Figure 8. Hierarchical classification mangrove composition in Ratai Bay

Source: Data analysis, 2023

The six mangrove composition classes can be identified by interpreting the Pleiades-1 satellite imagery using a key interpretation built on field data. As seen in Figure 9, the tree dominance class is marked in red (false colour standard composite) and appears darker compared to the dominant shrub class. Additionally, some locations with dominant trees exhibit a slight blue hue. This color variation is due to the difference in species dominance, where locations with a red color dominance are predominantly occupied by the species RA (Forest RA), while locations with a blue color dominance are typically a mixture of SA species with some presence of RA (Forest SA-RA).

However, it is important to note that in the field, it is very difficult to find areas consisting of only one mangrove species. For example, in the Forest-RA zone, other species such as RS, CT, and XG are also found. However, the distribution of these other species is less dominant than the presence of the RA species, which is found almost throughout the study area. Their preferred habitat influences the distribution of these other species; CT and XG are often found in the Forest-RA area located in the backward zone, closer to the terrestrial vegetation. Another example is the Forest-SA class, which coexists with the RA species, but the dominance of the SA species is slightly higher. In some locations, especially in the front part of the Forest-SA class, there is also the presence of the AM species, although it is not dominant.

The most distinguishing feature between the tree dominance and shrub dominance classes is that the tree dominance class is associated with tall mangroves that create a sense of height due to the shadows in the canopy gaps. Regarding color, mangroves with a dark reddish-brown color are generally associated with the RA species, while mangroves with a lighter pink color are associated with the AM species. Additionally, the shrub lifeforms occur in the seaward zone, which is the mouth of the river, characterized by flat muddy areas with high tidal inundation. What is unique is that in some locations, the shrub-dominated mangrove areas are open mangrove areas where the color is influenced by the background soil.

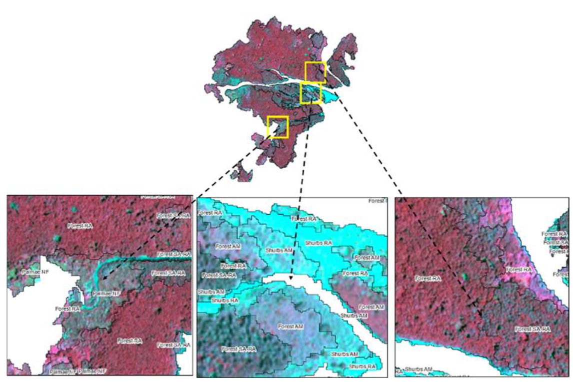

Figure 9. Visual appearance of mangrove vegetation composition in Pleiades-1 composite imagery (Infrared (R) Red (R) Green (G))

DOI: https://doi.org/10.17509/gea.v23i2.59612
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Finally, the lifeforms of the Palmae-dominated mangroves are associated with the NF species, which is characterized by a pinkish color mixed with blue (Figure 7a). In terms of texture, this class tends to have a smooth appearance, but the main distinguishing factor is its location at the back, following the course of the river towards the upstream. This area can be categorized as the back zone with slightly higher ground, resulting in relatively low tidal inundation intensity. The mangrove composition map is generated by reclassifying the classified image segments, as shown in Figure 10. The use of visual interpretation approach in classifying each segment of the classification result, although uncontrolled, resulted in a mangrove composition map with a total accuracy of 92% (Table 3). This accuracy is considered high as the classification was done using high spatial resolution imagery. The use of high spatial resolution imagery has proven to be effective in producing maps of mangrove distribution with higher accuracy, even up to the level of species dominance (Kamal et al., 2015; Wang et al., 2019). Additionally, in this study, a classification approach based on object-based analysis was employed, which is considered more optimal in mapping mangrove zonation (Kamal and Phinn, 2011; Kumar et al., 2019).

However, it should be noted that in this study, the distribution of samples was not ideal, as some classes, such as the Palmae NF class, Shrub AM class, and Shrub RA class were only tested using four samples. Furthermore, there is a significant imbalance in the accuracy of each class. As seen in Table 3, the user's accuracy for the Forest AM class, Shrub AM class, and Shrub RA class are not very high. For example, the user's accuracy for the Shrub RA class is 50%, indicating a 50:50 probability of correctly classifying objects in that class compared to the field data (Congalton, 2001; Story and Congalton, 1986). The indication of the low accuracy in these three classes lies in the influence of the dominant background soil on the visual appearance of the image, leading to errors in object classification. These three classes are located in the front zone, which is situated in the tidal flat area at the mouth of the Ratai River. This area is dominated by sparsely distributed mangroves, and the background soil significantly affects the visual appearance of that area.

Table 3. Confusion matrix accuracy assessment of the mangrove composition map

			Field check							
			A	**B**	**C**	**D**	**E**	**F**	**Total**	**User Accuracy**
Image classification	A	Forest AM	2				1		3	67%
	B	Forest RA		28				1	29	97%
	C	Forest SA-RA			19			1	20	95%
	D	Palmae NF				4			4	100%
	E	Shrubs AM					2	1	3	67%
	F	Shrubs RA					1	1	2	50%
		Total	2	28	19	4	4	4	61	
		Producer Accuracy	100%	100%	100%	100%	50%	25%		
		Overall Accuracy								**92 %**

Source: Data analysis, 2023

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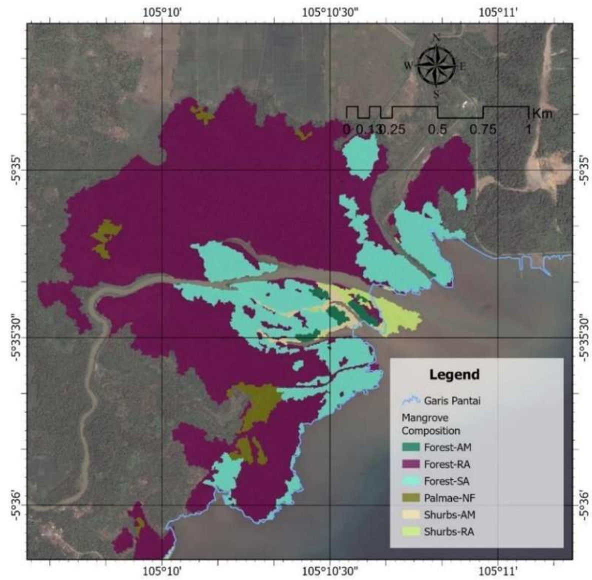

Figure 10. Mangrove Composition Map in Ratay Bay

4.2 Distribution of Mangrove Composition in Ratai Bay

In terms of area **(Table 4)**, the mangroves in the study area are dominated by the Forest RA mangrove zone, covering an area of 203.19 hectares or nearly 74% of the total mangrove area depicted in the mangrove composition map **(Figure 8)**. With the dominance of the RA species, the study area has the potential to be a source of various medicinal raw materials (Baishya et al., 2020). Based on the field survey plot data **(Table 5)**, the Forest RA mangrove area consists of mature mangroves with heights ranging from 2.6 meters to 25.5 meters, with an average mangrove height of 14.06 meters. The mangrove area dominated by the RA species is associated with deep fine mud substrate and moderate tidal inundation intensity. The Forest RA area represents well-preserved mangroves, as indicated by an average canopy cover percentage of 79.64% in that area. Some spots in the Forest RA mangrove area are naturally open due to lightning strikes, indicating that human disturbance to the mangrove ecosystem in Ratai Bay is minimal.

In the seaward zone of Ratai Bay, the dominant class is Forest SA-RA. The presence of the RA species indicates that this area has a mixture of mud and sand substrates and is located in the seaward zone close to the coastline. This class represents a mangrove zone dominated by SA and RA species, with heights ranging from 6.6 to 17 meters **(Table 5)**. This class covers an area of 55.94 hectares with an average canopy cover percentage of 78.95% **(Table 4)**. Some locations directly adjacent to the coastline have open areas resulting from the influence of sea waves. In addition to the SA and RA species, several locations in this zone also contain the AM species.

The shrub lifeforms class is commonly found in the muddy flats at the mouth of Ratai River. It has deep mud substrate and high tidal inundation intensity, which prevent mangroves in this area from growing to their maximum potential (Ahmed et al., 2022; Irsadi et al., 2019). Overall, the areas classified as Shrubs AM and Shrubs RA have heights of less than 6 meters **(Table 5)**. In addition to their limited height, these classes also have relatively sparse density, with a maximum canopy cover percentage of 76.98%. Despite the unfavorable conditions for mangrove growth, many mangrove planting activities have been carried out in the open areas of this zone.

DOI: https://doi.org/10.17509/gea.v23i2.59612
p- ISSN 1412-0313 e- ISSN 2549-7529

Table 4. Mangrove area in each composition class

Lifeforms	Lifeform-species Composition	Area (Hectare)
Palmae		**7.64**
	Palmae NF	7.64
Shrubs		**7.59**
	Shrubs AM	2.62
	Shrubs RA	4.98
Trees		**261.92**
	Forest AM	2.78
	Forest RA	203.19
	Forest SA-RA	55.94
	Total	277.15

Source: Data analysis, 2023

The NF species, on the other hand, inhabits the back zone and is characterized by having slightly higher ground surface elevation compared to other mangrove species (Widodo et al., 2020). Although NF species have a shrub-like lifeform and differ from typical mangrove species, they are still classified as true mangroves. This is also evident in the distribution of the Palmae-NF class in the study area, where this class is located in the back zone if we draw a vertical line perpendicular to the coastline parallel to the river. This zone has a total area of 7.65 hectares with relatively high density, with an average canopy cover percentage of 79.95%. The NF species in the study area have an average height of 7 meters. Unlike other zones, areas dominated by the NF species have very few occurrences of other mangrove species. This is because NF species have high dispersal ability and fast growth. On the other hand, this species can disrupt the physical conditions of its habitat, making it rare for other species to coexist with it (Nwobi et al., 2020).

Table 5. Description of mangrove composition classification

NO	Composition Class	Cover (%)			Height (Meters)			Species
		Min	Max	Mean	Min	Max	Mean	
1	Forest SA-RA	12,51	88,31	78,95	6.6	17.4	12.33	Dominated by RA and SA species, several RS and AM species were found.
2	Forest AM	69.37	82.08	75.58	8.2	8.2	7.5	Dominated by AM species, several RA and SA species were found.
3	Forest RA	29.16	90.82	79.64	2.6	25.5	14.06	Dominated by RA species, many species from the genus Rhizophora

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								sp. were also found, such as RS and RM. In the backward zone, RA species were mixed with species AA, CT, XG.
4	Shrubs AM	46.07	70.09	60.58	2.9	5,6	4,2	Dominated by AM species, several RA and SA species were found.
5	Shrubs RA	70.09	76.98	73.53	3.9	5.6	4.75	Dominated by RA species, many species from the genus Rhizophora sp. were also found, such as RS and RM.

Source: Data analysis, 2023

5. CONCLUSION

Mangrove composition mapping using Pleiades-1 satellite imagery was able to divide into six zoning classes (RA Forest, SA-RA Forest, RA Shrubs, AM Shrubs, and NF Palmae) representing the lifeforms and species dominance in Ratai Bay with 92% mapping accuracy. The Forest RA class dominates the area of Ratai Bay with a total area of 203.19 hectares out of the total mangrove area of 277.15 hectares. Generally, this class represents mature mangroves with an average height of 14 meters and a canopy density of 79%. The dominant species in this class are RA and several species from the Rhizophora family. On the other hand, the classes dominated by shrub lifeforms, namely shrubs RA and shrubs AM, are found in the muddy flat areas at the mouth of the Ratai River. These shrubs, dominated by species AM and RA, have an average height of 4 meters and a canopy cover percentage of around 70%.

6. RECOMMENDATIONS

To obtain a detailed map of mangrove composition with a higher level of class information, it is highly recommended to use digital classification methods. The visual interpretation approach has limitations in separating numerous object classes within a relatively large area.

7. ACKNOWLEDGMENTS

This paper is a part of the first author's master thesis. The research was funded by the Higher Education Applied Research grant (PTUPT) in 2022 from the Ministry of Education, Culture, Research and Technology of the Republic of Indonesia (contract number 1670/UN1/DITLIT/Dit-Lit/PT.01.03/2022 assigned to Muhammad Kamal). We want to express our gratitude to (1) the Master Program in Remote Sensing for providing access to the equipment and laboratory, (2) the Geospatial Information Agency for their assistance in providing the research materials, and (3) Mulyanto, Lucky Rakananda Hasandy, Garda Kalari, Fransisca Widyastuti, and Ratu Aqilah Arsy for the assistant during the fieldwork.

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