Distribution changes of seagrass beds area using sentinel-2A imagery in lancang island, seribu island, Indonesia

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Abstract. Seagrass is a flowering plant (angiosperm) that inhabits shallow waters and plays a vital ecological role as a breeding ground, habitat, and food source for marine organisms. However, increasing human activities, including waste disposal, fishing, and coastal tourism, have contributed to the degradation of seagrass ecosystems. This study aims to map the spatial distribution and temporal changes of seagrass areas using Object-Based Image Analysis (OBIA) in the waters of Lancang Island, Seribu Islands, Indonesia. Image processing involved segmentation and multi-level classification (levels 1, 2, and 3) with optimal segmentation scales of 50, 10, and 1, respectively. The classification results identified three categories: non-seagrass, sparse seagrass, and dense seagrass. In 2016, seagrass covered 68.16 ha but declined to 42.37 ha by 2023, while non-seagrass areas expanded from 123.11 ha to 146.59 ha. Land-cover transitions revealed a conversion of 37.84 ha from seagrass to non-seagrass and 12.04 ha from non-seagrass to seagrass. Overall, seagrass experienced a net loss of 37.88 ha during the study period. The classification achieved an overall accuracy of 70%.

Keywords: Classification, seagrass, OBIA, area changes, Sentinel-2A

1 Introduction

Lancang Island is a small island located in the South Seribu Islands District, Seribu Islands, DKI Jakarta, Indonesia. Lancang Island is a residential island for fishing communities, with most of its area covered by shallow water ecosystems, such as seagrass, mangroves, and coral reefs, and possessing a sloping topography above sea level. The shallow water ecosystems found on Lancang Island have benefits for the coastal environment, such as protecting the beach from the threat of abrasion and becoming an attractive tourist destination. Reciprocal relationships also occur between shallow water ecosystems and abiotic components, plants, and animals on Lancang Island. This relationship can help maintain the balance and sustainability of aquatic ecosystems. One of the ecosystems that covers almost all the

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important roles for the environment and society on Lancang Island is the seagrass ecosystem.

According to [1], seagrass is a flowering plant (Angiospermae) that grows and develops well in shallow water. [1] Seagrass ecosystems in Indonesia are usually located between mangrove and coral reef ecosystems or near sandy beaches and coastal forests. [2] Seagrass ecosystems have both biological and ecological roles and benefits for coastal areas, for example, acting as fish spawning grounds, shelter, and food sources for many marine organisms such as green turtles (*Chelonia mydas*) and dugong (*Dugong dugon*). In addition, seagrass meadows can improve seawater quality and effectively sequester and bury carbon, which is very important for reducing the impact of global warming. [3] The many environmental benefits that seagrass ecosystems provide are not proportional to the community's efforts to maintain the quality of seagrass ecosystems.

Seagrass ecosystems in Indonesia have experienced a decline in quality, due to both natural processes and human activities such as conversion to port areas, making breakwaters, coastal reclamation, and dredging sediments in coastal areas. [4] Therefore, sustainable management of seagrass ecosystems is necessary. One way to do this is to provide information on the spatial and temporal distribution of seagrass beds. The availability of multitemporal information is important for understanding the dynamics that occur in seagrass ecosystems. One way to obtain this information is to utilize satellite imagery.

Satellite imagery is considered effective for obtaining object and environmental information without direct contact. [5] Sentinel-2A images can be used to map seagrass habitats in Lancang Island waters periodically as a basis for ecosystem management. The Object-Based Image Analysis (OBIA) method is superior to pixel classification because it considers the spectral and spatial aspects. [6] Research on mapping changes in seagrass areas using remote sensing technology has been widely conducted, such as on the coast of Malang Village with 63% accuracy [7], Tanjung Tiram Village with 60.28% accuracy [8], Banten Bay with 57.69% accuracy [9], and Pari Island using ALOS with 62.32% accuracy and ASTER with 60.87% accuracy [10]. Most previous studies have used low-resolution satellite imagery and pixel-based methods. As data resolution increases and classification methods such as OBIA are developed, mapping accuracy can be improved. Therefore, the aim of this study was to map changes in seagrass areas in the waters of Lancang Island and Seribu Island using the OBIA method.

2 Methods

2.1 Location and data

The research was conducted from February to September 2023, which consisted of two stages. The first stage was a field survey conducted from February 13th, 2023 to February 18th, 2023, in the shallow waters of Lancang Island, Seribu Islands, DKI Jakarta province, Indonesia. The sampling area was located at coordinates position 5° 55' 30.00" S - 5° 56' 16.80" S; 106° 34' 51.60" E - 106° 35' 52.80" E. Field survey was conducted to obtain seagrass cover data for training area and image accuracy test. A total of 180 points of data were used for the training area and 80 points for the accuracy test; the results are presented in **Table 2**. The second stage involved data processing conducted at the Mapping and Spatial Modeling Laboratory, Department of Marine Science and Technology, Faculty of Fisheries and Marine Science, IPB University. The research location map is shown in **Fig. 1**.

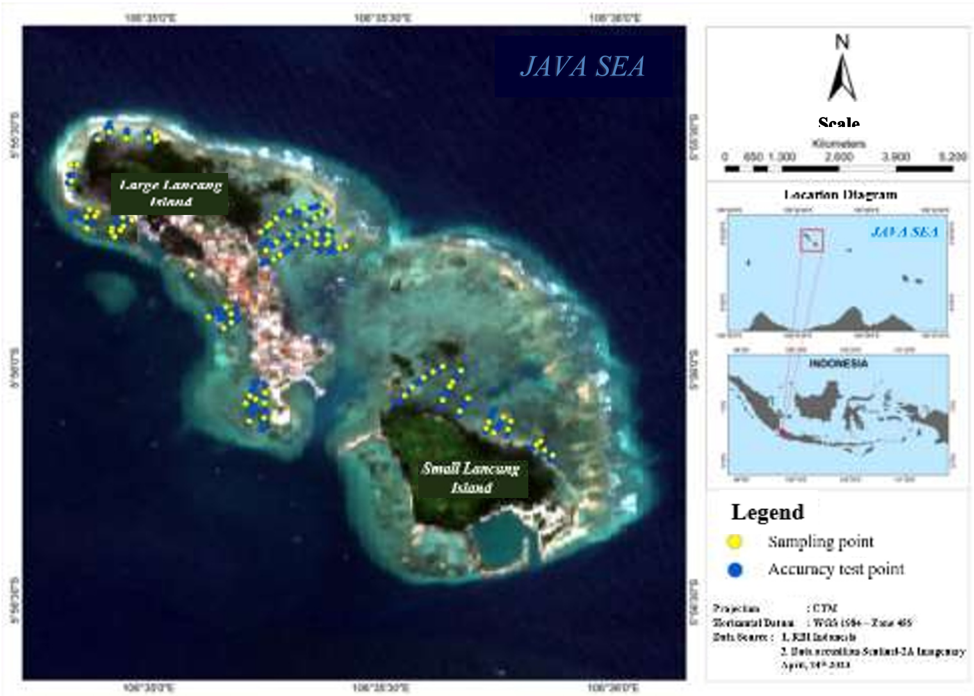


Fig. 1. Map of the research location on Lancang Island.

Field survey data collection in the seagrass area using a systematic sampling method. The number of sampling points was divided into two: sampling points for classification and accuracy test points. The materials used in this study were Sentinel-2A images acquired on October 7th, 2016, and April 24th, 2023, obtained from the scihub.copernicus.eu website and field survey data.

Digital number values from surveys using a spectro-radiometer and field observations were used as a reference for the classification of seagrass cover in Lancang Island Waters. Guidelines for observation and measurement of seagrass cover percentage refer to the seagrass-watch method by [11] This method is one of the most common methods in seagrass observation, conducted visually using quadratic transects of 10 m × 10 m. Observation results are classified into three density classes, as listed in **Table 1**.

Table 1. Seagrass cover precentage class.

Class		**Description**	***Digital Number Value***
Name	**Code**		
Dense Seagrass	DS	Percent seagrass cover > 70%	400 - 719
Moderate Seagrass	MS	Percent seagrass cover 30-70%	720 - 885
Sparse Seagrass/ Non-Seagrass	SS/NS	Percent seagrass cover 1-30%	> 885

Source : https://www.fgdc.gov/

The object-based classification (OBIA) method is used in data processing to map the extent of seagrass distribution. [12] In general, classification in OBIA consists of two stages: image segmentation and image classification. Segmentation is performed for each level. Image classification aims to classify objects based on the dark object subtraction (DOS) algorithm to segment objects such that they become defined objects [13].

The SVM algorithm was applied at the classification stage by setting the kernel type parameter, that is, Radial Basis Function (RBF) with C and Gamma parameters. The purpose of using the kernel is to group the initial dimensions of the dataset, that is, lower dimensions to relatively high dimensions. [14] The kernel function is often called the kernel trick. The RBF SVM function (Vapink 1982) was performed using equation (1), [15]

$$K(x_i, x_j) = exp\,(-\frac{||xi-xj||^2}{2\sigma^2}) \quad (1)$$

Remarks:
$K(x_i,x_j)$ = Kernel value
x_i,x_j = Data points
σ = Constant used to set the number of kernels

2.2 Data analyses

Image classification was an advanced stage after segmentation in object-based processing, where each segment was classified based on its characteristics. The classification scheme helps define shallow marine habitats and consists of three levels such as level 1 consits of land, shallow water, deep sea, level 2 consists of seagrass and non-seagrass, and level 3 consist of percent seagrass cover for instance dense, moderate, rare/sparse. [16] The sparse seagrass class was classified as non-seagrass along with sand, coral, rubble and macroalgae.

The accuracy test aims to investigate the correctness of the image classification results by comparing them with field survey data. The analysis was conducted using a confusion matrix [17], which yielded the overall accuracy, user accuracy, producer accuracy values, and kappa coefficients. The overall accuracy indicates the total agreement between the classification and the field data, user accuracy indicates the accuracy of the classification against the reference points, and producer accuracy shows the class distribution of the classification results in the field. An accuracy test was conducted using the following equation:

$$\textit{Overall accuracy}\ (OA) = \frac{\Sigma_{i=1}^{k} n_{ii}}{n} \times 100\% \quad (2)$$

$$\textit{Producer accuracy}\ (PA) = \frac{n_{jj}}{n+j} \times 100\% \quad (3)$$

$$\textit{User Accuracy}\ (UA) = \frac{n_{ii}}{n_{i+}} \times 100\% \quad (4)$$

$$KC = \frac{[(\Sigma_{i=1}^{k} nii)xn]-AxB}{(n^2-AxB)} \quad (5)$$

Remarks:
OA = *Overall Accuracy*
PA = *Producer Accuracy*
UA = *User Accuracy*
KC = *Kappa Coefficient*
n = Total number of observations
nii = Number of observations in column i and row i
njj = Number of observations in the jth column and jth row
n+j = Total column
ni+ = Total marginal of the i-th row

The process of detecting changes in the seagrass area will obtain the seagrass cover percentage in the field, which will be analyzed to determine alterations in the seagrass area that occurred in the research location. The post-classification comparison method was used to detect seagrass changes. This method detects changes by comparing the classification maps obtained by classifying them independently between two images of the same area but at different times. [9] This comparison method produces a comparison matrix between two categories that shows the changes that occurred in each category or year being compared.

3 Result and discussion

3.1 Research site conditions

Lancang Island is one of the small island villages of the South Seribu Islands in DKI Jakarta, Indonesia. This island is a fishing settlement with shallow water ecosystems such as seagrass beds, coral reefs, and mangroves. These ecosystems play an important role in maintaining the coastal environmental balance. Seagrass beds are one of the main ecosystems that support marine life and contribute to the fishery and tourism sectors.


(a)


(b)

Fig. 2. (a) seagrass cover (b) study site scene; Source: direct photograph taken.

Benthic habitats on Lancang Island consist of seven types: seagrass, sand, rubble, algae, live coral, sand mixed with rubble, and dead coral. Seagrass species found like *Enhalus acoroides*, *Thalassia hemprichii*, *Syringodium isoetifolium*, and *Cymodocea serrulata*. An example of a seagrass cover and study site is shown in **Fig. 2**. The island is divided into two: the inhabited Large Lancang Island and the uninhabited Small Lancang Island with more preserved seagrass beds. Lancang Island possesses a rich marine ecosystem, dense mangrove forests, and has great potential for fisheries, marine tourism, and coastal conservation. Communities also utilize natural resources by cultivating seaweed.

3.2 Image pre-processing

The initial stage of image processing included image cropping in order to focus the study area on Lancang Island, Seribu Island, followed by geometric correction using the image-to-map method based on Rupa Bumi Indonesia (RBI) maps through a georeferencer in QGIS. Thirty ground checkpoints (GCP) were employed. Atmospheric correction was performed using the dark object subtraction (DOS) method. The DOS method produces a reflectance value of zero in each band of the Sentinel-2A imagery because the DOS method reduces the reflectance value of the entire image by the reflectance value of the darkest object, where the minimum value other than zero is considered as atmospheric disturbance. [18] The correction results in an image that is sharper and brighter than the initial image, as shown in **Fig. 3**.

(a) (b)

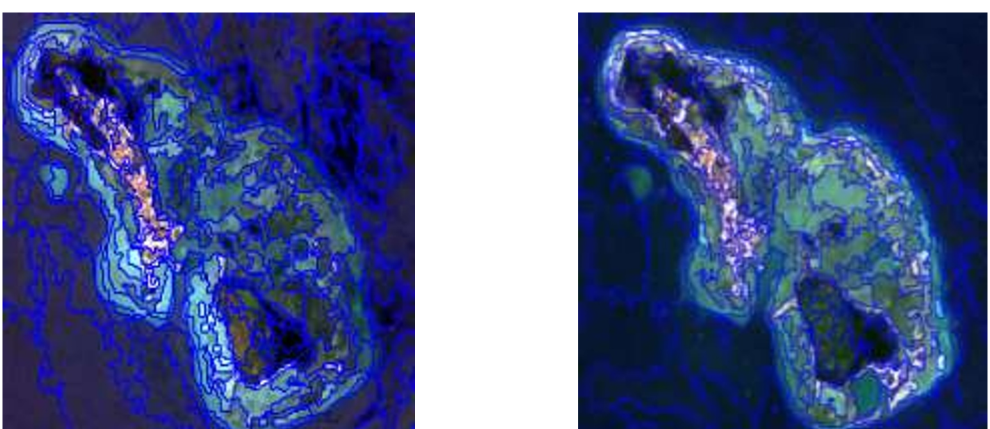
Fig. 3. Image 2023 (a) before and (b) after atmospheric correction.

3.3 Classification scheme

The classification scheme was determined based on 260 field observation points on Lancang Island. seagrass and non-seagrass were identified as rubble, coral, sand, and sparse seagrass. This scheme was adapted to the dominant composition of shallow water habitats observed in the field, as there is no standardized classification of shallow marine habitats and each site has different complexities. [19] The classification scheme consists of three levels: Level 1 consists of land, shallow water, and deep water; Level 2 consists of seagrass and non-seagrass; and Level 3 consists of rich/healthy and less rich/healthy seagrass, based on Decree No. 200 of 2004. Of all the points, 70% were used as classification training data and 30% were used for accuracy testing.

3.4 Segmentation

Segmentation is the first step in object-based classification. A multiresolution segmentation (MRS) algorithm was used in this process. The outcomes of the 2016 and 2023 image segmentation process level 1 are presented in **Fig. 4**.



(a) (b)

Fig. 4. Level 1 segmentation result of image (a) acquisition year 2016 (b) acquisition year 2023.

After trial-and-error, three levels of segmentation were conducted using different scale values at each level. Level 1 used a scale value of 50, Level 2 used a scale of 10, and Level 3 used a scale value of 1. Each level uses the default shape and compactness parameters of 0.1 and 0.5. Objects generated from the segmentation process are classified based on the classification scheme created. Level 1 segmentation aims to build segments from pixels into the same segment; level 2 segmentation focuses on benthic areas; and level 3 focuses on the research area, namely seagrass, for further classification and accuracy testing.

3.4.1 Level 1 classification

At the same time, the Level 1 classification (reef level) produces three classes, namely land, shallow water, and deep sea (**Fig. 5**). Level 1 classification results were used as a boundary and reference for the research study area while conducting level 2 classification, namely shallow marine habitats. Contextual editing was applied, in which the threshold value was adjusted based on the spatial and spectral characteristics of the relevant features for all classes. [20] The threshold value for the 2016 image used a blue/red (B/R) band ratio of 0-0.8 for the terrestrial class, blue/green (B/G) band ratio of 0.8-1 for the terrestrial, shallow water class and 1-5 for the deep sea classes, respectively. The threshold value for the 2023 image uses a blue/red (B/R) band ratio of 0-0.6 for the terrestrial class and 0.6-2.2 for the shallow water class, a blue/green (B/G) band ratio of 0.9-3.7 for the deep sea class.

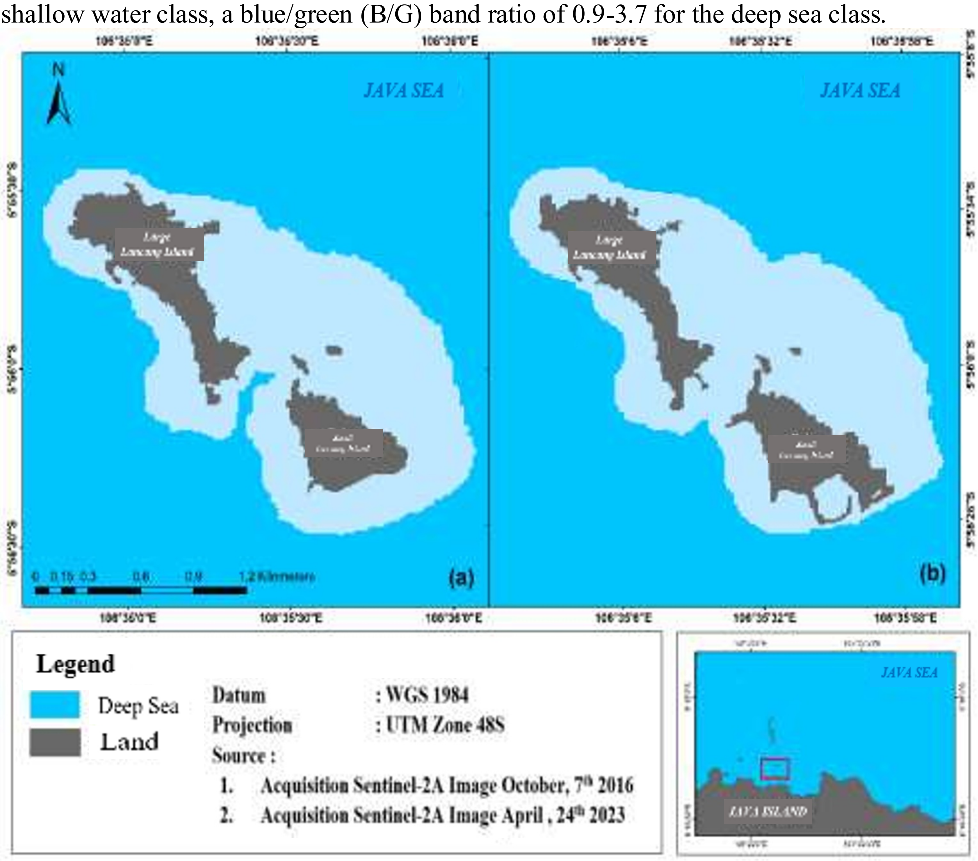


Fig. 5. Level 1 classification of Lancang Island shallow waters (a) year 2016 and (b) year 2023 acquisition image.

The results of level 1 classification on the 2016 and 2023 acquisition images produced the same 2 (two) classes but possessed different areas. The year 2016 yielded in a land class area about 59.13 hectare and shallow water about 191.24 hectare, while the year 2023 resulted in a land class area of 62.81 hectare and shallow water of 188.96 hectare. The difference in area might be caused by the segmentation process between the two images producing different total objects that could affect the difference in the class area. Other factors could be caused by misinterpretation of a class, such as a shallow water class that should be a deep-sea class, which could cause differences in the area of a class.

3.4.2 Level 2 classification

The level 2 classification was the result of field identification using visual observation and analysis based on the OBIA classification. At this stage, it may be classified using a guided method that applies the SVM algorithm. The thematic layer uses classification scheme data in the form of a Region of Interest (RoI) data measure from direct observations in the field study. The input features used in the level 2 classification process were the layer values (mean and standard deviation) of all bands. The seagrass and non-seagrass classification results maps for Lancang Island in 2016 and 2023, employing the SVM classification method shown in **Fig. 6**.

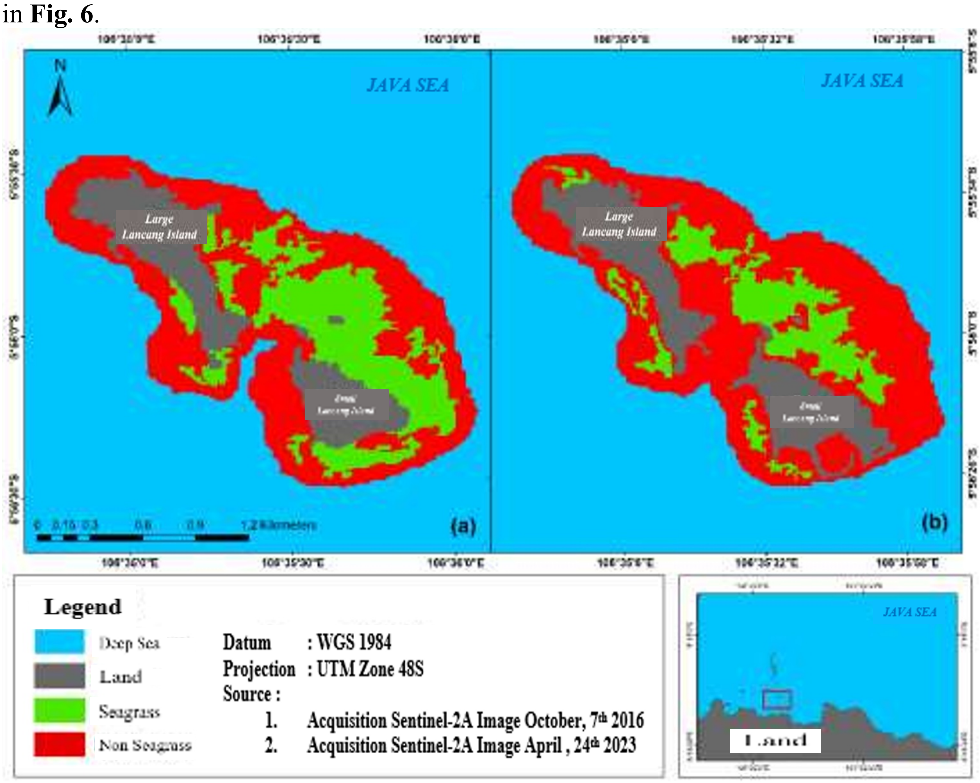


Fig. 6. Level 2 classification of Lancang Island (a) year 2016 (b) 2023 acquisition image.

The shallow water benthic classes generated at level 1 classification were re-segmented at level 2 with segmentation scale optimization, resulting in new seagrass and non-seagrass classes such as sand, coral, rubble, and macroalgae groups, as well as sparse seagrass, which were grouped into non-seagrass classes. Sentinel-2A images with a spatial resolution of 10 × 10 m showed difficulty in detecting sparse seagrass, which could result in misclassification with more dominant substrate objects in one transect or pixel. This increases the possibility of signal mixing between the sparse seagrass and surrounding substrate. [21]

Based on the level 2 classification results, it could be identified that non-seagrass class was the class dominated the benthic shallow waters of Lancang Island in 2016 and 2023. Level 2 classification was used to obtain the seagrass and non-seagrass areas in 2016 and 2023, as shown in **Fig. 7**.

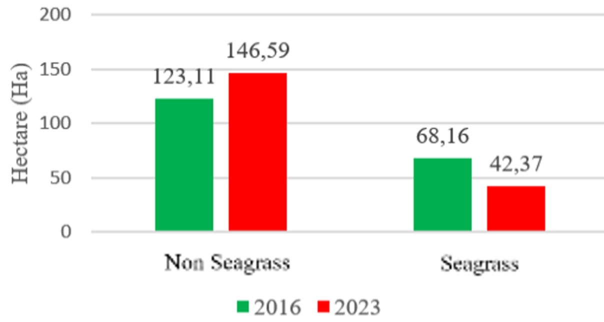


Fig. 7. Histogram of seagrass and non-seagrass area in year 2016 and 2023.

As shown in **Fig. 7**, the seagrass area decreased from 68.16 hectare in 2016 to 42.37 hectare in 2023, while the non-seagrass area increased from 123.11 hectare to 146.59 hectare. This reduction is influenced by human activities, such as fisheries, aquaculture, development, marine traffic, and sand dredging, which could damage seagrass habitats. Seaweed cultivation also has the potential to displace seagrasses because of competition for growing space. [22] In addition, abiotic factors, such as currents and wind, also contribute by moving seeds or shedding seagrass leaves. [23] This condition was consistent with the situation observed at Lancang Island, which was experiencing the construction of a jetty and an increase in seaweed cultivation.

3.4.3 Level 3 classification

Level 3 classification results are the result of reclassifying the seagrass classes obtained in the level 2 classification. The Level 3 classification process was almost the same as the classification process carried out at Level 2; the difference lies only in the input of the classification data. In the level 3 classification process, only data points related to seagrass cover conditions were used as classification points. The purpose of this level 3 classification was to determine the density of the seagrass cover classes on Lancang Island. Seagrass density classes were determined using OBIA, in which seagrass objects were grouped and classified based on the texture and color of relatively homogeneous areas. [24] Two new classes were formed based on the percentage of seagrass cover, namely dense seagrass and moderate seagrass. The classification method used in Level 3 is the SVM algorithm. The map of seagrass classification results in 2016 and 2023 in Lancang Island shows the distribution of seagrass classification areas spatially presented in **Fig. 8** and the histogram of seagrass density area shown in **Fig. 9**.

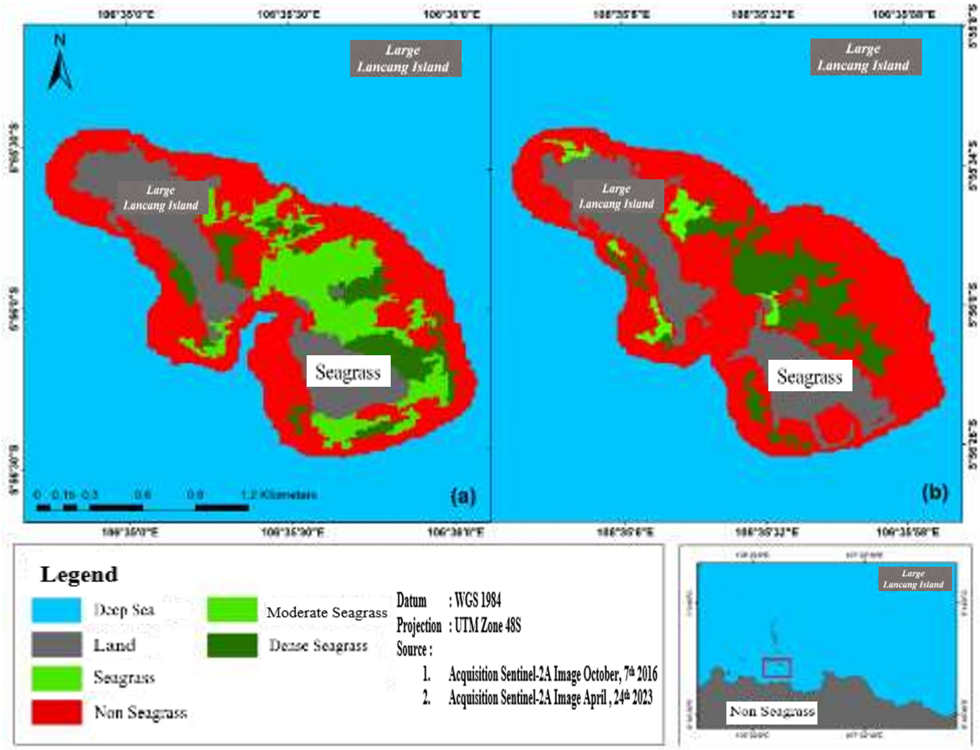


Fig. 8. Level 3 classification of Lancang Island (a) year 2016 (b) 2023 acquisition image.

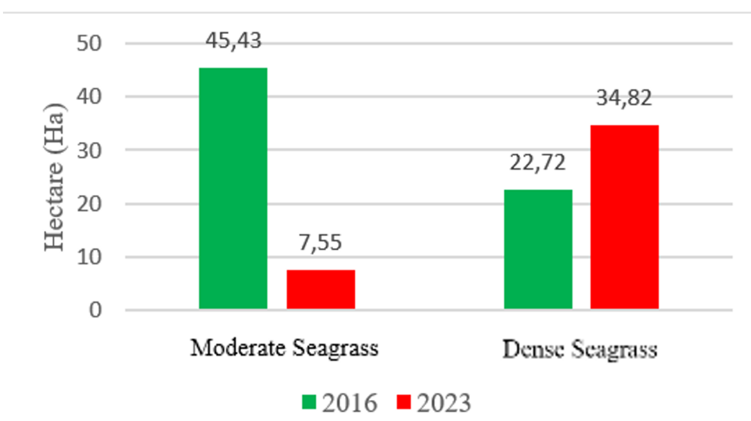


Fig. 9. Level 3 histogram of Lancang Island (a) year 2016 (b) 2023 acquisition image.

Based on the data in **Fig. 9**, the area of dense seagrass in year 2016 about 22.72 hectare increase about 12.1 hectare in year 2023. The moderate seagrass area in 2016 (45.43 hectare decreased about 37.88 hectare in 2023 yield 7.55 hectare. Based on the Level 3 classification results, it was found that the medium seagrass class dominated the seagrass cover of Lancang Island in 2016. The dense seagrass class was more abundant on Small Lancang Island because human activities on Small Lancang Island were less than those on Large Lancang Island, whereas Large Lancang Island was found to be a residential settlement for humans.

The accuracy test of seagrass mapping with Sentinel-2A images in year 2023 and field data employing the confusion matrix method yielded the Overall Accuracy (OA), Producer

Accuracy (PA), User Accuracy (UA), and kappa coefficient values. The accuracy value of the seagrass classification accuracy for the year 2023 is shown in **Table 2**.

Table 2. Confusion matrix of Seagrass Classification result year 2023.

		Field Data			
		DS	MS	NS	Total
Image Classification	DS	19	2	4	25
	MS	2	8	8	18
	NS	5	3	29	37
	Total	26	13	41	80
Producer Accuracy (%)		73.08	61.54	70.73	
User Accuracy (%)		76	44.44	78.38	
Overall accuracy (%)		70			
Kappa Coefficient				0.65	

Descriptions: NS (Non-Seagrass), MS (Moderate Seagrass), DS (Dense Seagrass).

The classification results need to be examined for accuracy to ensure eligibility based on established standards. The accuracy test using 30% field data points yielded a producer accuracy between 61.54 - 73.08%, the highest in the dense seagrass (DS) class and the lowest in the medium seagrass (MS) class. User accuracy ranged from 44.44 - 78.38%, with the highest value for non-seagrass (NS). An overall accuracy value of 70% indicated that the image classification was good and acceptable. Based on Green et al., an ideal standard of >60% accuracy was accepted for shallow marine habitat mapping [25].

3.4.4 Detection of changes in seagrass meadow area

Images from two different years of classification were compared using an overlay technique to identify alterations in the seagrass area of Lancang Island between 2016 and 2023. The overlay resulted in four classes of change: dominating non-seagrass (red), dominating seagrass (green), increasing seagrass (soft green), and decreasing seagrass (yellow) (**Fig. 10**).

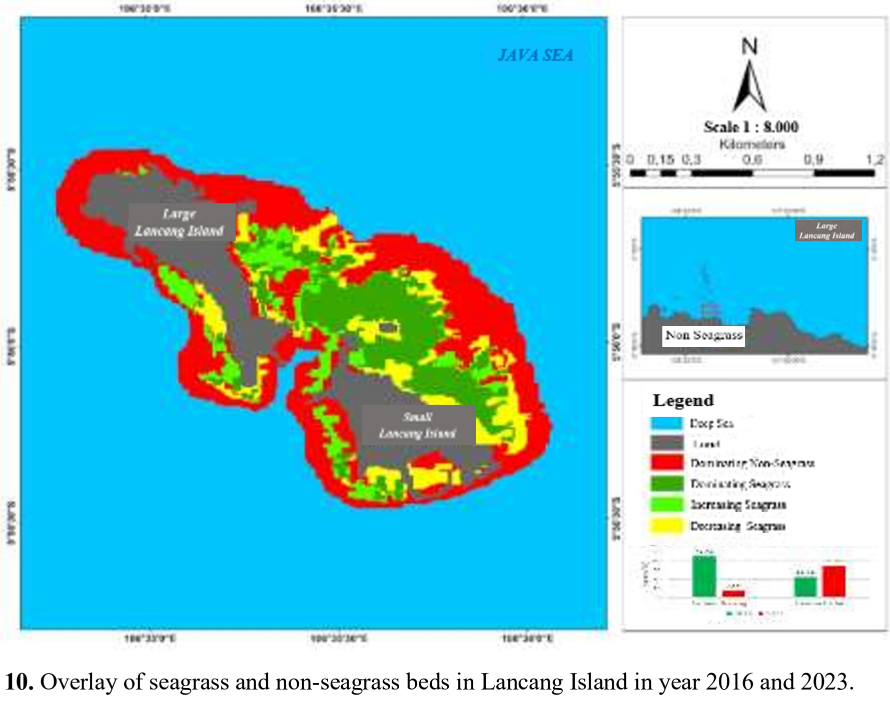


Fig. 10. Overlay of seagrass and non-seagrass beds in Lancang Island in year 2016 and 2023.

By overlaying seagrass and non-seagrass classes, yield in four classes, such as dominating non-seagrass (red color), dominating seagrass (dark green color), increasing seagrass (light green color), and decreasing seagrass (yellow color). These classes are distributed across the shallow waters of Lancang Island, with reduced seagrass found mostly around the shore and near the shelf. Alterations in the areas of each class (**Fig. 11**).

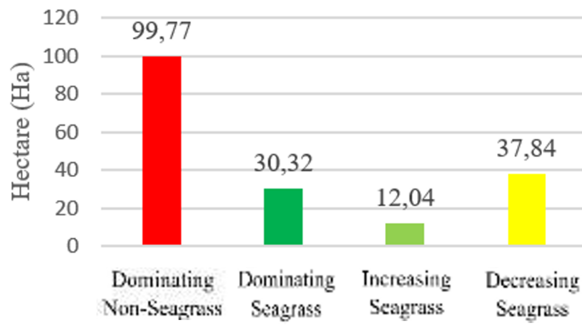


Fig. 11. Histogram seagrass and non-seagrass area changes in Lancang Island, year 2016 to 2023.

Based on **Fig. 11**, it can be seen from 2016 to 2023 that the non-seagrass class did not changed by about 99.77 hectare while seagrass that did not change (Seagrass remains) was around 30,32 hectares, non-seagrass that changed into seagrass area (seagrass increases) was about 12,04 hectare, and seagrass area that changed to non-seagrass (seagrass decreased) was about 37,84 hectares. However, the largest area change occurred in the non-seagrass class, whereas the seagrass class experienced the least area change.

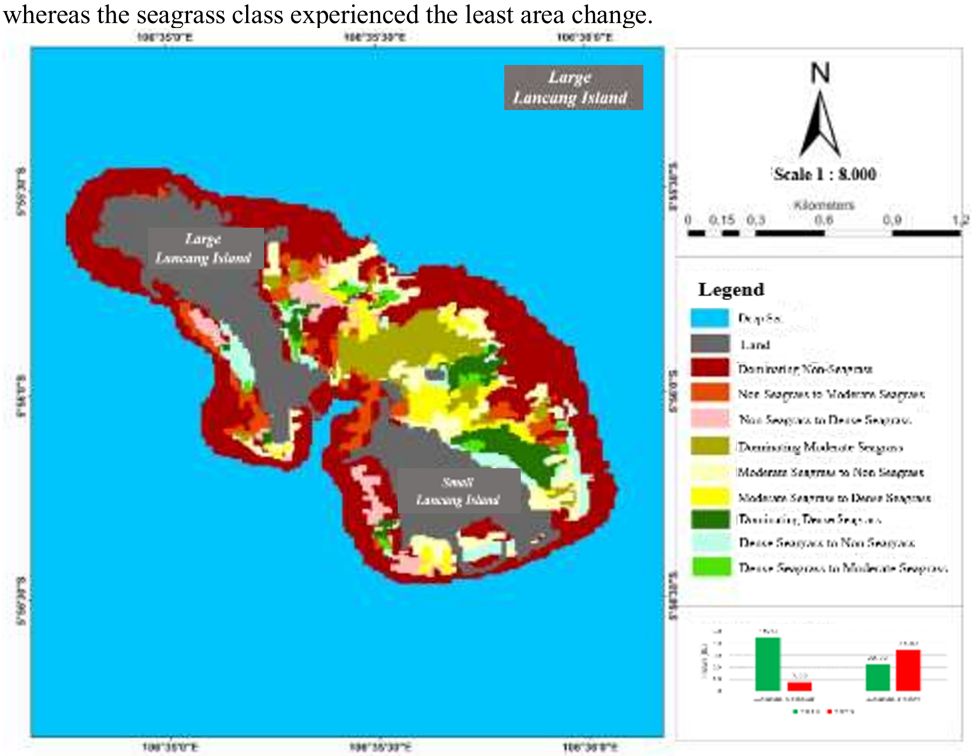


Fig. 12. Map of seagrass cover change in Lancang Island in year 2016 and 2023.

The results of the advanced classification of seagrass cover in 2016 and 2023 can be overlaid to produce a map of seagrass cover change, which identifies several new classes. These classes were the result of the transformation of the seagrass classification from 2016 to 2023 on Lancang Island. This overlay map displays the distribution changes that occurred on Lancang Island (**Fig. 12**). Based on the figure, the distribution of seagrass cover changes based on its density can be identified. The overlay results of the 2016 and 2023 seagrass cover classification maps in the shallow waters of Lancang Island show the existence of 9 (nine) new classes, each of which is spread throughout the shallow marine waters on Lancang Island. These classes included those that experienced changes in seagrass density, as well as those that experienced no change. The extent of change in the seagrass classification of each class was calculated in detail, as shown in **Table 3**.

Based on **Table 3**, the medium seagrass class decreased by area about 37.88 hectare from 2016 to 2023. In contrast, the dense seagrass and non-seagrass classes increased about 12.1 hectare and 23.48 hectare respectively. The details were medium seagrass remained 1.98 hectare, dense seagrass 19.14 hectare, and non-seagrass 21.23 hectare. Dense seagrass remained 8.56 hectare, changed to medium seagrass 0.34 hectare, and to non-seagrass 13.13 hectare. Non-seagrass remained 99.77 hectare, changed to medium seagrass 4.65 hectare, and to dense seagrass 6.81 hectare. Each class showed fluctuations in area over the study period.

Table 3. Statistics on changes in seagrass classification area in 2016 and 2023.

Area Classification (Ha)		MS	DS	SS/NS
2016	MS	1.98	19.14	21.33
	DS	0.34	8.56	13.13
	SS/NS	4.65	6.81	99.77
Total area in 2016		45.43	22.72	123.11
Total area in 2023		7.55	34.82	146.59
Total changes		-37.88	12.1	23.48

Descriptions: sparse Seagrass/Non Seagrass), MS (Moderate Seagrass), DS (Dense Seagrass).

The overall seagrass area in 2016 experienced a decrease in 2023, especially in the medium seagrass class. This decrease in area was likely influenced by various factors, including coastal environmental influences and human activities. Coastal environmental influences, such as degradation of water quality and the influence of coastal waves, sea tides, and sea currents, could affect the life of seagrasses. Uncontrolled human activities, such as dumping garbage or waste directly into the sea, fishing activities, and recreational activities in the coastal zone, could disrupt the ecosystem function of seagrass ecological systems. [1] In contrast, there were factors that probably influenced the increase in seagrass cover area in the dense seagrass classification, namely the existence of linkages with other ecosystems such as mangroves that could affect seagrass growth, where mangroves could provide habitat for seagrass and reduce the impact of pollution, thereby reducing damage to seagrass and allowing better seagrass growth [26].

4 Conclusions

In this study, it was concluded that the waters of Lancang Island possess a variety of benthic habitats such as seagrass meadows, which play an important role in coastal ecosystems. Mapping alteration in the distribution and condition of seagrass beds observed on Lancang Island based on Sentinel-2A imagery and employing the OBIA method showed a decrease in seagrass area from 68.16 hectare in 2016 to 42.37 hectare in 2023. Between 2016 and 2023, approximately 37.84 hectare of seagrass changed to a non-seagrass area, while the non-seagrass area that changed to seagrass was 12.04 hectare. The classification of moderate seagrass classes decreased, whereas that of non-seagrass and dense seagrass classes increased from 2016 to 2023. The moderate seagrass class decreased by approximately 37.88 hectare from the initial area. The non-seagrass and dense seagrass classes increased about 23.48 hectare and 12.1 hectare respectively from the initial area. The accuracy test of Sentinel-2A image classification using the OBIA method yielded an overall accuracy value of approximately 70%. These results show that Sentinel-2A imagery can be used for the analysis of seagrass cover mapping in coastal areas.

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