Multitemporal Analysis of Seagrass Dynamics on Derawan Island (2003–2021) Using Remote Sensing Techniques

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Abstract

The shallow waters around Derawan Island are renowned for their beauty, attracting a significant number of tourists. Since the 2008 National Sports Week (PON) in East Kalimantan, the construction of inns and jetties has enhanced both accommodation and accessibility on the island. However, this development has also impacted the seagrass beds in the surrounding shallow waters. This study examines the changes in the area and density of seagrass beds from 2003 (prior to the PON activities) through to 2011 (a few years post-PON) and in 2021 (the most recent conditions), assessing the effects of lodging and jetty construction on these beds. Data were collected via field surveys using the photo transect method, and the benthic habitat map was created using Landsat 8 OLI Imagery, applying the Lyzenga water column correction algorithm and unsupervised classification method. The Normalized Difference Building Index (NDBI) algorithm and land digitization were utilized to track the development of the inns and jetties, revealing a rapid, widespread increase in construction throughout the island's southern region (R-square = 0.59). The study findings indicate a significant degradation of seagrass meadows between 2003 and 2021, particularly near populated areas on the southern coast, resulting in decreased density levels.

Keywords: *Seagrass, Development, Lyzenga, Unsupervised, Tourism.*

Introduction

Derawan Island, renowned for its stunning underwater landscapes, has become a popular tourist destination for various activities. To support this influx of visitors and foster tourism development, the island is undergoing significant development. However, these developments, particularly in coastal areas, are adversely affecting benthic habitats, notably seagrass beds. Fauzan and Hartono (2017) highlight that coastal developments contribute significantly to seagrass habitat degradation. Land use changes along the coast can lead to issues like eutrophication and increased sedimentation, further impacting these delicate ecosystems.

In shallow marine waters, the seagrass ecosystem exhibits high levels of primary productivity and biodiversity (Miftahudin *et al.*, 2020) and their habitat is close to coral reefs and mangrove forests (Ambo-Rappe *et al.*, 2013). There are 72 species of seagrass in six families and 14 generations worldwide (Short *et al.*, 2016). According to Roem and Laga's (2014) four species of seagrass, including *Syringodium isoetifolium*, *Cymodocea rotundata*, *Halophila ovalis*, and *Halodule uninervis*, can be found on Derawan Island. Several oceanographic factors influence where seagrasses are discovered. Sari and Lubis (2017) found that DO, temperature, and light have the biggest effects on seagrass dispersal. Meanwhile, Rahman *et al.* (2016) stated that salinity, sedimentation, favorable current conditions, and wave speed affect the dispersion of seagrass. The distribution and development of seagrass are influenced by a number of variables, such as light, temperature, turbidity, nutrient availability, depth, currents, waves, substrate, and salt (Sahertian and Wakano, 2017; Sugianti and Mujiyanto, 2020).

As a result of numerous human activities, groundwater (lakes, marshes, rivers, and groundwater) and saltwater quality might diminish, which can be a sign of water pollution (Madyaluha, 2015). The main cause of organic waste is anthropogenic activity, which might worsen the pollution situation (Rahman *et al.*, 2011). If damage and a decline in water quality are allowed to persist, it may affect the life cycles of the creatures that reside there (Adack, 2013). In Indonesia, the amount of

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disruption on the water's surface caused by activities intended to improve the economy causes a decline in the area of seagrass habitats as well as damage to them, therefore pollution is unavoidable (Poedjirahajoe *et al.,* 2013). The quality of waters and their ecosystems can be put at risk by the effects of anthropogenic activities, such as the discharge of organic and inorganic trash. According to Sanchez-Vidal *et al.* (2021), garbage contained in the seagrass ecosystem has a negative impact. Additionally, the disposal of waste through a canal that empties directly into the ocean will result in an excess of nutrients and turbidity, which might hinder the ability of seagrass to reproduce.

One of the technologies used to examine issues on earth is remote sensing technology. The rapid advancements in remote sensing technology, which lower costs and shorten analysis times, make this kind of conservation possible (Mubaraka *et al.*, 2020). Satellite photography is a useful tool for mapping marine ecosystems and shallow-water benthic habitats (Suhendar *et al.*, 2020). In a previous study (Fauzan *et al*., 2021; Pratama *et al.*, 2022), using low to medium resolution images such as Sentinel-2 or Landsat 8 OLI were used to evaluate benthic habitats and map benthic habitats in order to assess the degree of damage to seagrass beds in the coastal area. The goal of this study was to look at changes in seagrass beds before and after development, as well as the most recent conditions, which were in 2003, 2011, and 2021. Then consider the relationship between tourism development and seagrass cover area value.

Materials and Methods

This research was conducted on Derawan Island and its coastal waters. The study area is in the coordinate location of 2° 17' 3" N - 118° 14' 39"S. Derawan Island is one of the islands that are part of the Derawan Archipelago in Berau Regency, East Kalimantan. The scope of the Derawan Archipelago consists of three sub-districts, namely Derawan Island, Maratua, and Biduk-Biduk. The geographical location of the Derawan Islands is on the northern peninsula in the sea of Berau Regency. While the geographical location of Derawan Island is around Panjang Island in the north, Tanjung Batu, Derawan Island District in the west, Maratua Island in the east, and Semama Island in the south.

The underwater photo transect, is used to collect sample points, and that is performed in shallow conditions. The goal of collecting sample points is to conduct out-field validation of the mapped benthic habitat. The technique is to throw rectangular PVC pipes measuring 50 cm x 50 cm or 1 m x 1 m each into shallow water. After the pipe lands on the object, documentation of the shooting is carried out using a portable camera. The 700 sample spots around Derawan Island were obtained based on the data collection findings (Figure 1.), and the photo coordinates and GPS coordinates were thn matched. For a total of 565 sample points, the sample points were also filtered once more. The findings of field validation of data collection on RGB-pixel photographs utilizing the underwater photo transect method are shown Figure 1.

The classification of the benthic habitats in this study refers to The Allean Coral Atlas which is used to classify benthic ecosystems and is divided into six categories: coral reefs, sand, rubble, (rock/reef), seagrass, and microalgae. This classification takes into account the methods used for ecological, geological, and other procedures, as well as the availability of data and mapping capabilities (Kennedy *et al*., 2021).

Data collecting stage

The investigation made use of both primary (Tabel 1.) and secondary data (Table 2.). The primary sources of information used to map seagrass beds and their density percentages are observational surveys of seagrass substrates using the underwater photo transect (UPT) technique. Multispectral images taken by drones are processed to produce high-resolution images. In-depth interviews with local sources were done to learn more about the status of the building of ports and lodging on Derawan Island.

The digitalization of the land cover on Derawan Island in 2003 and 2011 using Landsat 7 ETM Imagery, and subsequently in 2021 using high-resolution photography (UAV Multispectral), serves as the secondary data. Derawan Island's benthic habitat and the density of the built-up area were mapped using Landsat 7 ETM and Landsat 8 OLI Imagery data and the Normalized Difference Building Index (NDBI) method in 2003, 2011, and 2021, respectively. The percentage of seagrass cover and seagrass polygon vector data for the years 2003, 2011, and 2021 were combined with the seagrass density data that was obtained from visible band reflectance data on Landsat 7 ETM and Landsat 8 OLI. This data was regressed with the Yij band corrected by the water column using the Lyzenga algorithm.

Data processing

Primary data were collected by sampling the benthic habitat substrate using an underwater photo transect and high-resolution aerial photography. In-depth interviews with several informants were conducted to learn more about the process of building accommodations and wharf facilities. Secondary data were obtained by using Landsat 7 and Landsat 8 satellites to collect image data on the development of lodging facilities on Derawan Island and map its benthic habitat in the last 18 years, namely 2003, 2011, and 2021. The Lyzenga algorithm was used to correct water column and built-up area detection in the mapping of benthic habitats. Meanwhile, multispectral image data and Google Earth images will be processed to create a land cover map. The percentage of seagrass beds on Derawan Island will then be determined. Meanwhile, spatial and temporal image data on the development of lodging facilities on Derawan Island will be compared and analyzed. A study will also be conducted to determine the impact of the construction of lodging facilities on Derawan Island on the percentage of seagrass area.

Processing Data using ArcGIS software, photo data was transformed into high-resolution image data for this investigation. A map of Derawan Island's benthic ecosystem was created using Satellite Imagery from google earth after analysis of the seagrass data. The procedure consists of three steps: pre-processing, which employs the Lyzenga method to correct the water column, processing, which begins with the creation of a composite image, and classification, which makes use of unsupervised classification. According to Manessa (2016), who cited Lyzenga (1978), the following equation was used to derive the Lyzenga algorithm:

$$Xi = \log\,(\rho i - \rho\infty i) \tag{1}$$

$$Transformed\ \frac{Reflectance}{Radiance}$$

= log (shallow water reflectance radiance-deep water reflectance radiance)

then proceed with calculating the attenuation coefficient with the following formula,

$$Y_{ij} \ = \ X_i - \frac{k_i}{k_j}\, X_j \tag{2}$$

Yij is the depth invariant index where Xi and Xj represent the radians transformation in the i and j bands, respectively. The attenuation coefficient ratio (ki/kj) applies when the pixels of the same object at different depths are distributed linearly in the relationship between the two bands (Lyzenga, 1978; Manessa *et al.*, 2016).

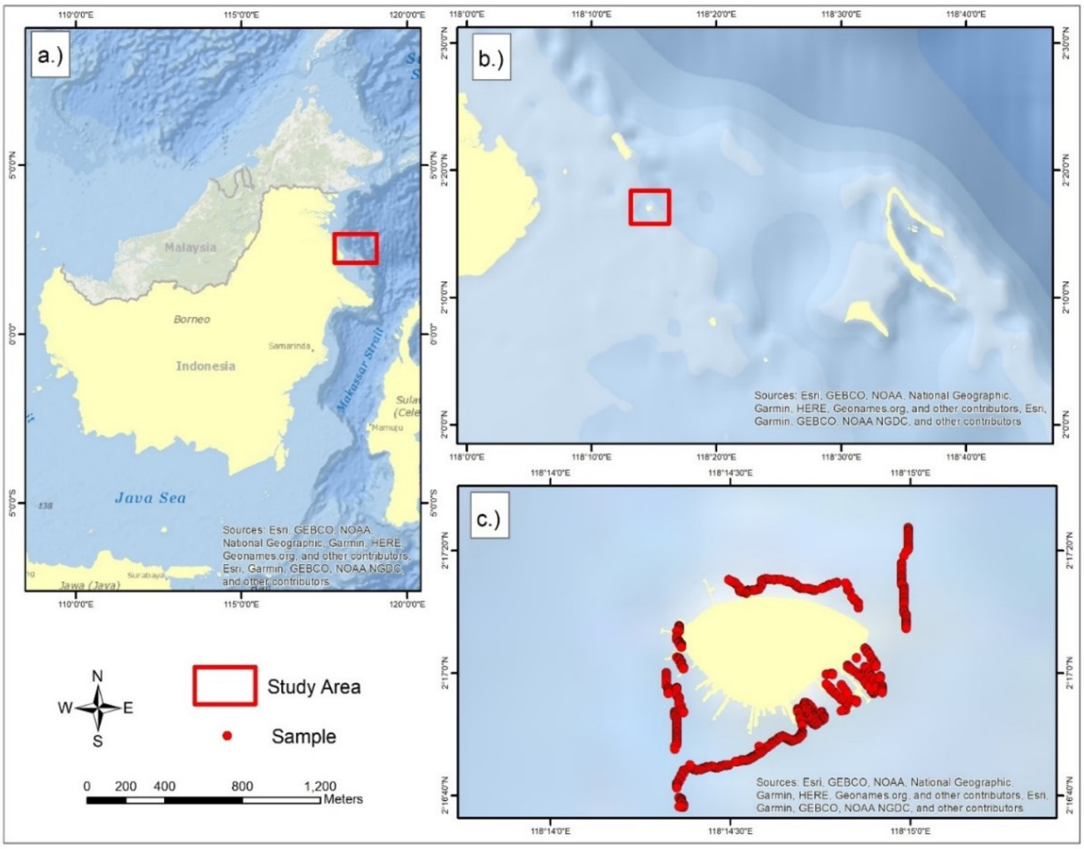


Figure 1. Study area: a.) Map of Kalimantan Island; b.) Derawan Archipelago c.) Distribution of UPT sample points in the shallow waters of Derawan Island

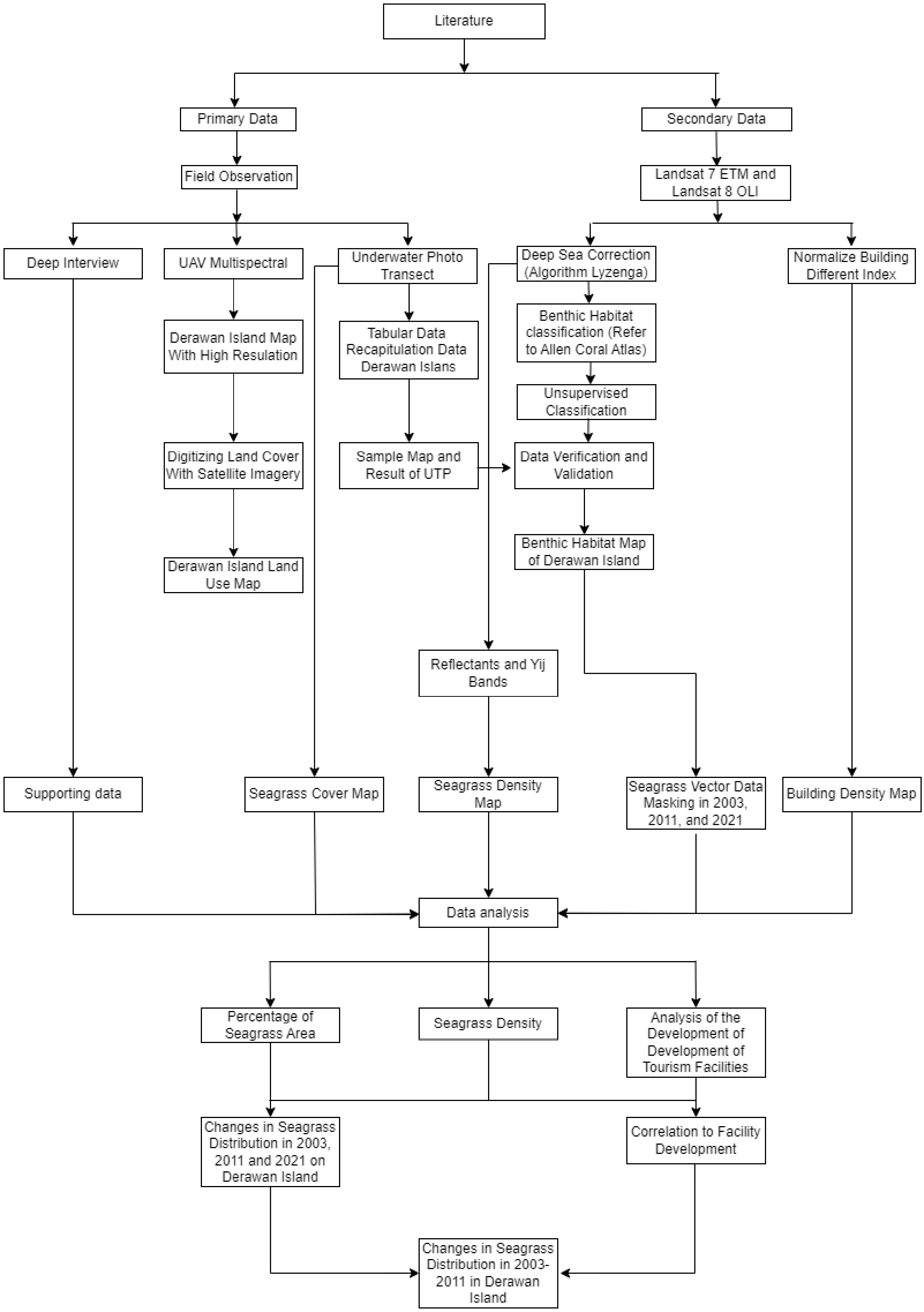


Figure 2. Data Processing Method

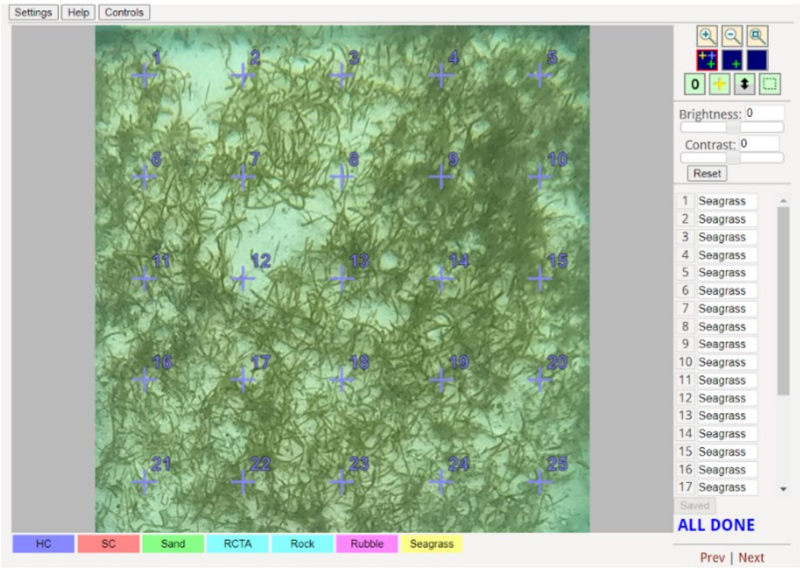


Figure 3. Seagrass cover interpretation process

Table 1. Primary data

Data	Method	Data Source	Scale and Resolution
Benthic Habitat Data Sampling	UPT 50cm x 50cm	Field Survey	-
Important Informant Interview	Deep Interview	Online Interview	-
Multispectral High Resolution Image of 2021	Drone Data Capture	Drone	Resolution 5m x 5m
Percentage of Seagrass Cover	UPT	GOPRO Photos	-

Table 2. Secondary data

Data	Method	Data Source	Scale and Resolution
Research Area: Derawan Island	Digitizing	Landsat 8 OLI	1:10,000 Scale Map Resolution 30m x 30 m
Land Cover Year 2003, 2011, 2021	Digitizing	Landsat 8 OLI (2003 and 2011) and Drone Multispectral Imagery (2021)	1:10,000 Scale Map Resolution 30m x 30 m
Build Area Density in 2003, 2011, 2021	NDBI	Landsat 7 ETM and Landsat 8 OLI	Resolution 30m x 30m
Benthic Habitat Map 2003, 2011, 2021.	Unsupervised Classification, Water Column Correction	Landsat 7 ETM and Landsat 8 OLI	Resolution 30m x 30m
Seagrass Density 2003, 2011, 2021	Raster Calculator, Masking	Reflectance and Yij Band, Seagrass Cover Percentage, Seagrass Polygon Vector Data Year 2003, 2011, 2021	1:10,000 Scale Map

After that, to obtain Yij data is to perform composite bands on the calculation results of the relationship between the two bands. To obtain data on the density of seagrass meadows, it is carried out in several stages. The first is to interpretation UPT data (Figure 2.). This interpretation process uses a digital application from the site https://coralnet.ucsd.edu/.

Then, by computing the percentage of seagrass cover, calculating with a linear regression technique, processing combined bands in ArcGIS Pro, and masking with seagrass polygon data, the seagrass density map was processed. Using the Normalized Differenced Built-up Index algorithm and watching the periods of development from 2003, 2011, and 2021, it is possible to determine the development of tourism amenities on Derawan Island. The index will focus on built-up land or green open land. Therefore, this algorithm can be used to help map urban areas. NDBI has the following formula:

$$NDBI = (SWIR - NIR) / (SWIR + NIR) \quad (3)$$

The selected images in data processing are Landsat 7 ETM+ and Landsat 8 Operational Land

Imager (OLI). Spectral values on NBDI have a range of -1 to +1. The range of values -1 to 0 is the detection of undeveloped land areas, whereas the value range of 0 to 1 is the detection of built-up areas. Additionally, digitizing land cover in 2003, 2011 and 2021 will help us better understand how it has changed over time.

Data analysis

The descriptive method is used in this study to map the spatial-temporal distribution of seagrasses in shallow waters near Derawan Island, as well as changes in seagrass beds and the growth of tourism infrastructure between 2003, 2011, and 2021. And they were descriptively analyzed in terms of the relationship between seagrass density and building density, as well as the effect of nutrient distribution on seagrass density. While the confusion matrix method and the R-square method were used in the statistical analysis to test the accuracy of benthic habitats,

Result and Discussion

Benthic habitat distribution and percentage

The distribution of seagrass beds on Derawan Island is known by mapping the shallow water benthic habitat. The images used in this study are Landsat 7 ETM for 2003 and 2011, and Landsat 8 OLI for 2021. The classification method uses unsupervised classification, which is to categorize pixel groups by relying on software without the help of training samples (Hafizt *et al.*, 2017) as seen on each map (Figure 4.), there has been a decline in seagrass beds during the past 18 years. The distribution of seagrass beds on Derawan Island has altered between 2003, 2011, and 2021. On the north and east of the island, the majority of the distribution changes took place. Compared to the eastern part of the island, the distribution of seagrass in the northern portion has decreased, but not significantly. Physical variables like the influence of nutrient distribution in shallow waters and anthropogenic causes, such as development activities in coastal areas, are some of the factors that affect changes in the spread of seagrass (Geevarghese *et al.*, 2018).

Verification of data on the distribution of benthic habitats on Derawan Island Using the photo transect method, also known as the Underwater Photo Transect, which was carried out in shallow waters. The purpose of taking sample points is to carry out field validation of the benthic habitat mapping that has been done (Table 3.).

According to the classification of seagrass beds, the research area in 2003 was approximately 76.047 ha, making up for 51% of the overall benthic class. However, from 2011, the area of seagrass beds had decreased in size to 56.18 ha, accounting for 37% of the overall benthic class. In 2021, the area of seagrass beds slightly decreased, to 52.5681 ha, making up for 35% of the total benthic class.

The results of the accuracy test using the confusion matrix show that the level of accuracy in the seagrass class is very high when compared to the sand – rubble and coral reef class levels. Seagrass class accuracy level on producer's accuracy is 86% and user's accuracy is 75%. The accuracy level for the sand-rubble class on the producer's accuracy is 58% and the user's accuracy is 78%. Finally, the level of accuracy for the coral reef class on the producer's accuracy is 55% and the user's accuracy is 47%. Furthermore, overall accuracy in mapping benthic habitats has a percentage of 71%. Referring to SNI 7716:2011 concerning "Mapping of shallow marine habitats - Part 1: Mapping of coral reefs and seagrass beds", the minimum level of accuracy required is 60%. Thus, the accuracy of mapping benthic habitats using Landsat 8 imagery is quite good.

Seagrass density and nutrient distribution

A map of the density of seagrass beds was produced using the results of processing seagrass density data from 2003, 2011, and 2021, as shown in Figure 5. The fading of the greenish pixel hue over the past 18 years has shown a change in density. The density level is decreasing when it is close to the coastline, notably in the south of the island, starting in 2003, 2011, and 2021.

Given that at the green color on the pixels, something happens that suggests that the color of the pixels near the boundary between shallow waters and deep-seaWater looks more concentrated when compared to shallow waters. See Figure 5. The results of this modeling are not necessarily very accurate. The seagrass beds are less dense the closer you go to the shallow waters. Errors in interpretation or image sensor reception of substrate information on the bottom of the waters are things that can point to an erroneous occurrence in the percentage of seagrass density.

Figure 6 depicts the relationship between estimated pixel density and percentage of seagrass cover. The density prediction in the image is affected by the percent of seagrass cover under actual conditions by 59.83%, according to the line equation produced by the linear regression graph, $Y = 0,5983x + 28,591$. However, the percentage number has not been able to provide any beneficial results due to a 40.17% miscalculation in percentage. The percentage of seagrass cover and its predicted density in the image are incorrect due to this inaccuracy.

Table 3. UPT Survey Data Verification on Derawan Island

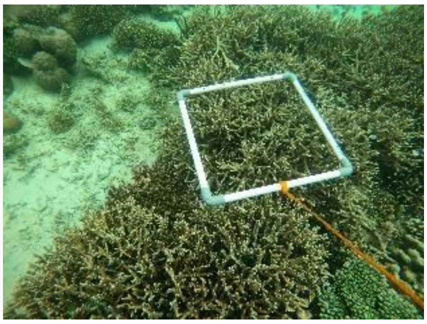
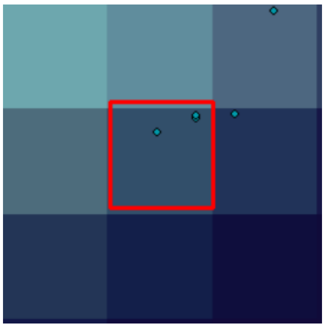
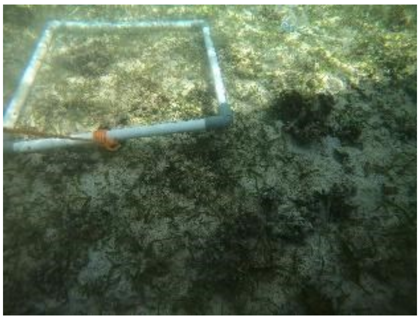
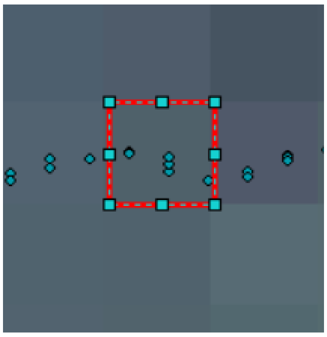
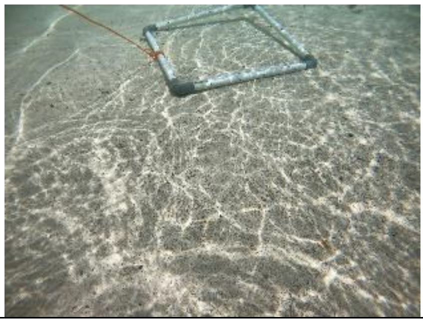
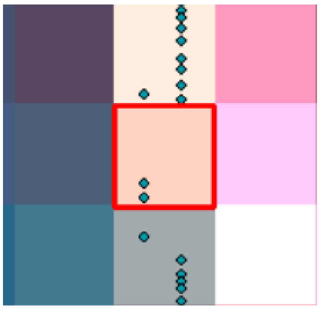
Result UPT	Pixel RGB	Object
		Coral Reef
		Seagrass
		Sand and Rubble

Table 4. Percentage of benthic habitat area on Derawan Island for 18 years

Percentage of Benthic Habitat Area on Derawan Island for 18 Years (ha)						
Class	Area in 2003	Percentage in 2003	Area in 2011	Percentage in 2011	Area in 2021	Percentage in 2021
Sand-Rubble	59,67	40%	84,78	56%	86.82	57%
Seagrass Bed	76,04	51%	56,18	37%	52,56	35%
Coral Reef	14,31	10%	10,88	7%	12,67	8%
Total	150,033	100%	151,85	100%	152,072	100%

Table 5. Accuracy test of Benthic Habitat Mapping with Landsat 8 Using Confusion Matrix.

Benthic Object	Sand-Rubble	Coral	Seagrass	Total	*User's Accuracy*
Sand – *rubble*	120	10	24	154	78%
Coral	45	52	13	110	47%
Seagras	42	32	227	301	75%
Total	207	94	264	565	
Producer's Accuracy	58%	55%	86%		
Overall Accuracy					71%

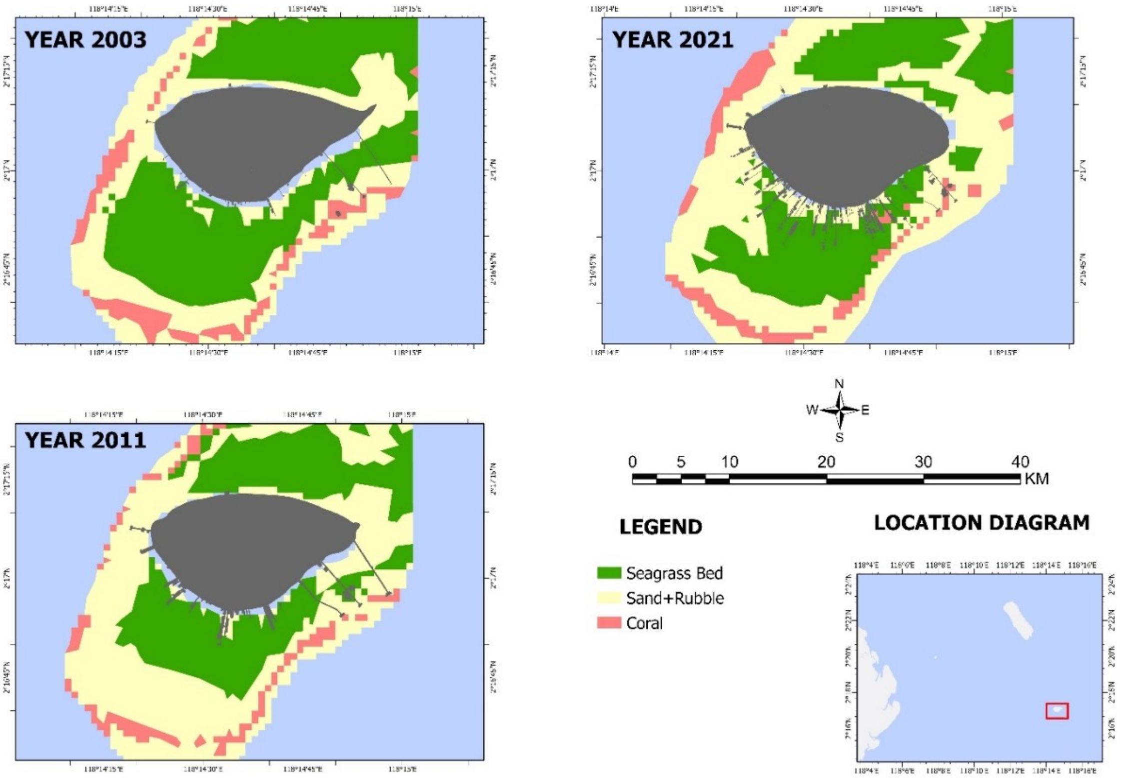


Figure 4. Comparison of benthic habitat classification in Derawan Island, year 2003, 2011, and 2021

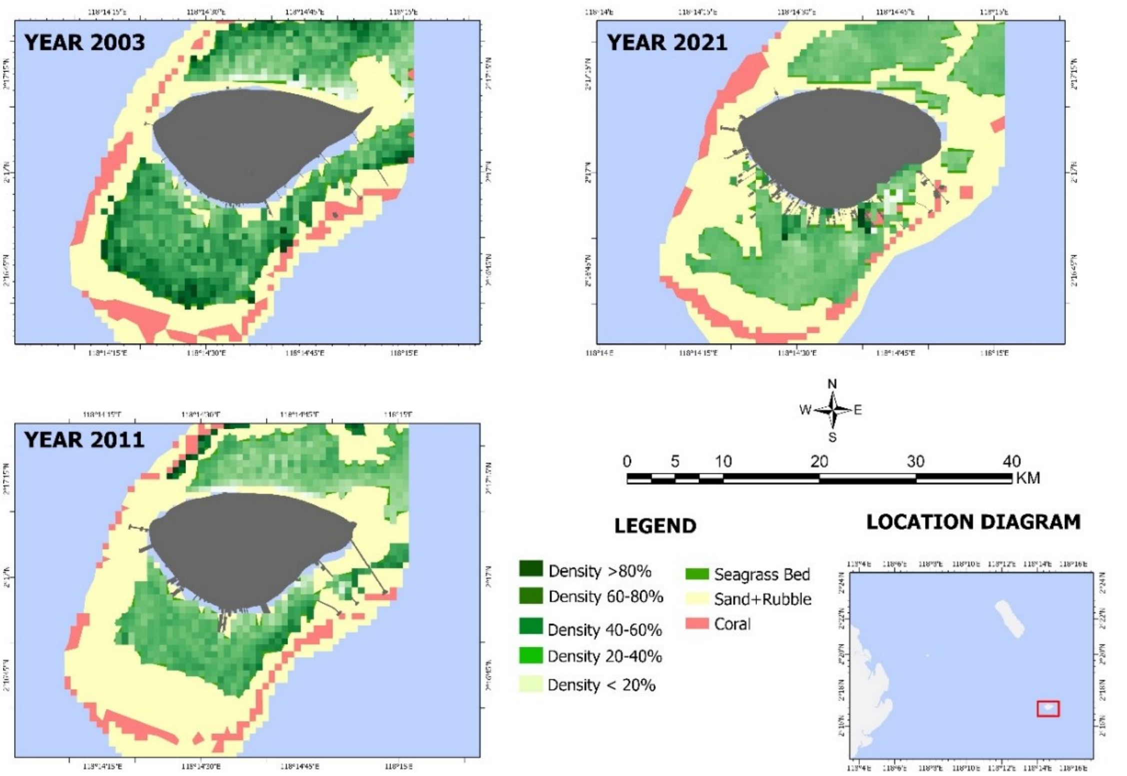


Figure 5. Comparison of the development of seagrass density in Derawan Island, year 2003, 2011, 2021.

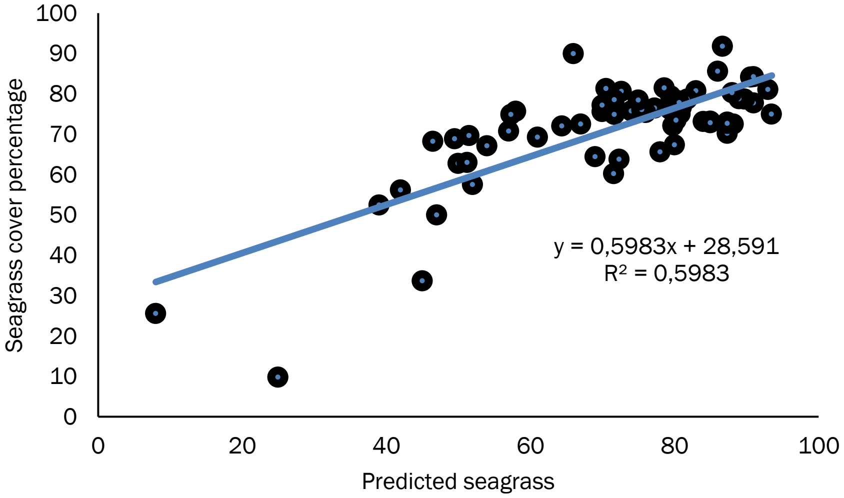


Figure 6. Correlation prediction of seagrass density

The fact that other elements, such as substrate, depth, water temperature, and salinity were have an impact on the density prediction in the image in addition to the proportion of seagrass density is an indication of the error's root cause. The accuracy data seagrass density in R-square = 0.59 and have standart error 11,68%

Through the flow of water currents, the distribution of nitrate and phosphate for seagrass in the waters of Derawan Island may be shown. In general, wind movements that tend to push the water's surface, such as the wind's direction, have an impact on sea surface currents (Azis, 2006). A wind gust produces waves and currents on the surface. The movement of seawater currents, however, is not synchronized with the direction of the wind and is instead twisted due to the Coriolis Effect (Azis, 2006). Windrose can be used to determine the speed and direction of the wind. The graph (Figure 7.) depicts the distribution of wind speed and direction over time at a specific point. Two-season wind data from 2011 and 2021 were combined to examine the wind direction and speed. The west monsoon blows from the west to the east from October to March. The east monsoon, which occurs between April and October, blows from east to west.

The results of the analysis show that the distribution of nutrients around the shallow waters of Derawan Island is mostly north and south due to stronger currents (Figure 8.) based on windrose compared to the East and West sides. The wind strongly influences the direction and strength of the currents on the sea surface (Adalya and Mutaqin, 2022). the nutrients movement is assumed that influenced by the movement of shallow water currents. Presence of currents are affected by waves due to friction of wind speed gusts This is consistent with the distribution of benthic habitat on Derawan Island, where seagrass beds are found in the south to southwest and north to northeast.

Derawan Island's land cover in 2003, 2011, and 2021

Derawan Island is one of the Derawan archipelago's marine tourism attractions, owing to the beauty of its shallow waters. Have seen this ability, the tourism development on Derawan Island continues, with the goal of making tourism successful and improving the people's economy. The government has promoted tourism in a variety of ways, including social media. The promotion was designed to entice tourists to visit Derawan Island. On the other hand, the community and entrepreneurs are constructing lodging facilities on Derawan Island in order to accommodate more tourists. The following is the result of digitizing land cover using Landsat 7 ETM imagery in 2003, Landsat 7 ETM in 2011, UAV Multispectral in 2021, and deep interview to determine the progress of the lodging facility construction.

Below are the results of digitizing land cover in 2003 using Landsat 7 UTM imagery. According to the digitization results, the red tint, which also represents developed land, predominates from the west to the south of the island. Derawan Island's resort is purple, and also its pier is brown. The jetties is still nearly invisible, and vegetation dominates the area. Furthermore, according to three informants, Derawan Island was not an objective for natural and marine tourism prior to the PON being held in 2008. The majority of the individuals on Derawan Island used to be fishers. It is a little bit of the world's finest. What had previously been a vegetated region began to become undeveloped land.

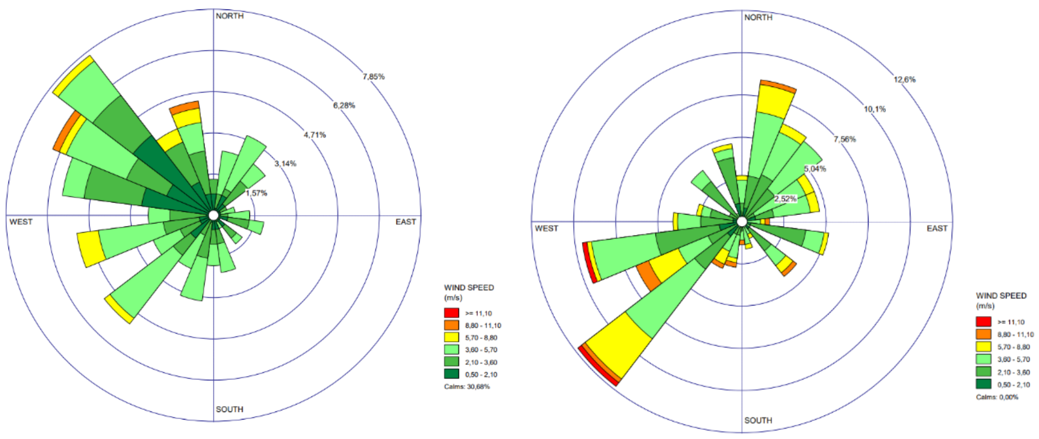


Figure 7. Windrose of Derawan Island Area in year 2011 (A) and year 2021 (B).

According to the findings of informant interviews, the development of lodging facilities on Derawan Island has taken place since the hosting of PON XVII in 2008 in East Kalimantan as one of the primary supporting elements for success in tourism. Meanwhile, the Derawan community owns unoccupied land that is spread across a variety of vegetation types. The findings for 2021 show that the island's southern region has more hotel options and jetties facilities. Gray denotes the conversion of land into a burial site that occurs in the vegetation area. The enhancement of tourist amenities on Derawan Island has an impact on the social circumstances of the island population.

Land cover interpretation

The built-up land identification model shown below was created using the Normalized Difference Building Index (NDBI) technique for Derawan Island in 2003, 2011, and 2021. The difference between vegetated land and built-up land is suppressed by this algorithm using the NIR and SWIR bands as shown on Figure 10.

The built-up area of the island, which stretches from its northern to southernmost points, is depicted in red. Inns and piers have significantly expanded during the past 18 years in the southwest, south, and southeast. The amount of land built in the area is also demonstrated by the NDBI value, which began in 2003 with a value of NDBI is 0.21 and has since increased to 0.30 in 2011 and 0.36 in 2021.

The relationship between the area of seagrass fields and the development of lodging and pier facilities

It is impossible to tell whether the seagrass beds in Derawan Island's northern region degraded based on Figure 11. The nutrient content of seagrass in the northern portion of the island is thought to be comparable to that in the southern region, which could be the reason for seagrass degradation in the northern waters. The addition of nutrients to the process of promoting the growth and distribution of seagrass beds is a result of human actions such as the removal of hotel garbage. Due to the fact that the trash includes nutrients and that there are fewer buildings in the northern part of the island than there are in the southern part. Environment-related indicators that influence seagrass growth include salinity, turbidity, length of sunlight, and turtle overgrazing (Fauzan and Hartono 2017). In the meantime, construction of jetties and hotels in coastal areas with shallow waters is thought to be the cause of the degradation in the area and reduced density of seagrass in the southern region of Derawan Island. These structures prevent sunlight from penetrating the water and obstruct photosynthesis by seagrass (Figure 12.).

Nitrate and phosphate are nutrients that seagrass needs in order to grow and thrive (Rayyis *et al.,* 2021). It is crucial to preserve the primary productivity of seagrass since its presence in the water helps to simplify the system's nutrient cycle (Handayani *et al.*, 2016). However, excessive nitrogen levels in water might cause seagrass productivity to be disrupted. Eutrophication, sometimes referred to as an increase in nutrient concentration in the water column, is a process that promotes the growth of phytoplankton, algae, and seagrass (Susi, 2011). Growing algae casts a shadow, which lessens the sunlight that reaches the water column. This disrupts photosynthesis of the seagrass, which results in a slowing of its development rate. Because seagrass productivity is declining, less oxygen is present in the sand, and more hazardous nutrients, including sulfides, are present (Larkum *et al.*, 2006). Sulfur dioxide in high proportions disturbs seagrass roots and kills seagrass plants.

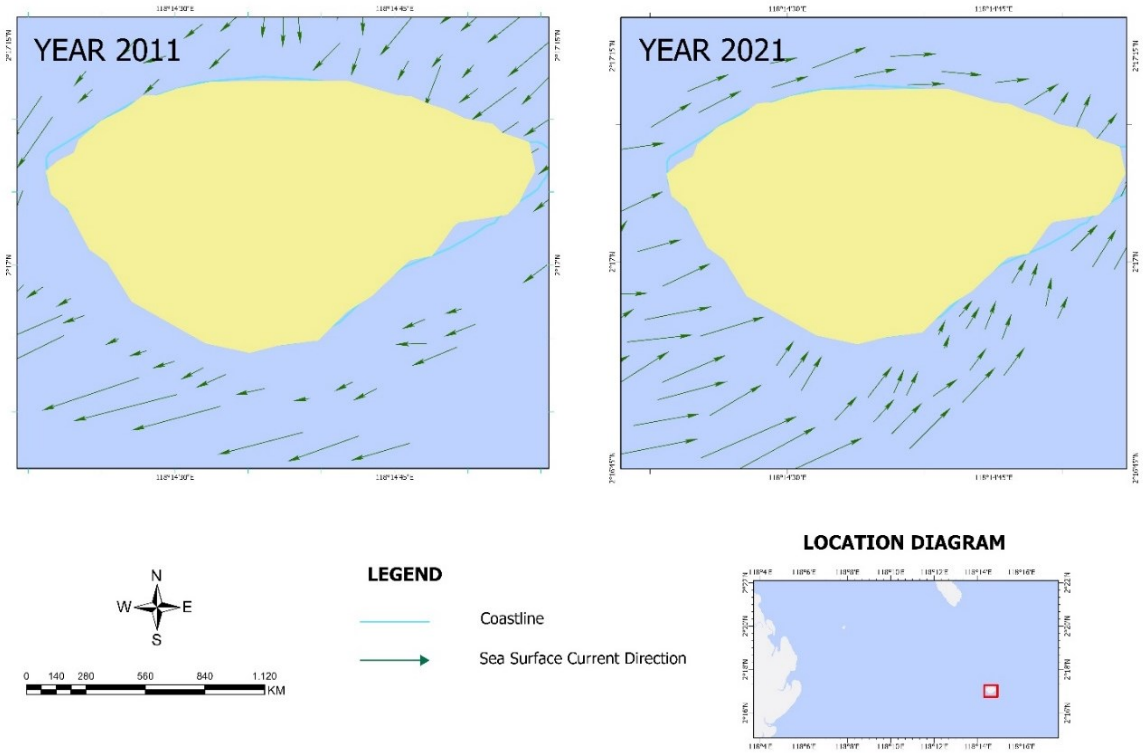


Figure 8. Direction of surface current movement on Derawan Island in year 2011 and 2021.

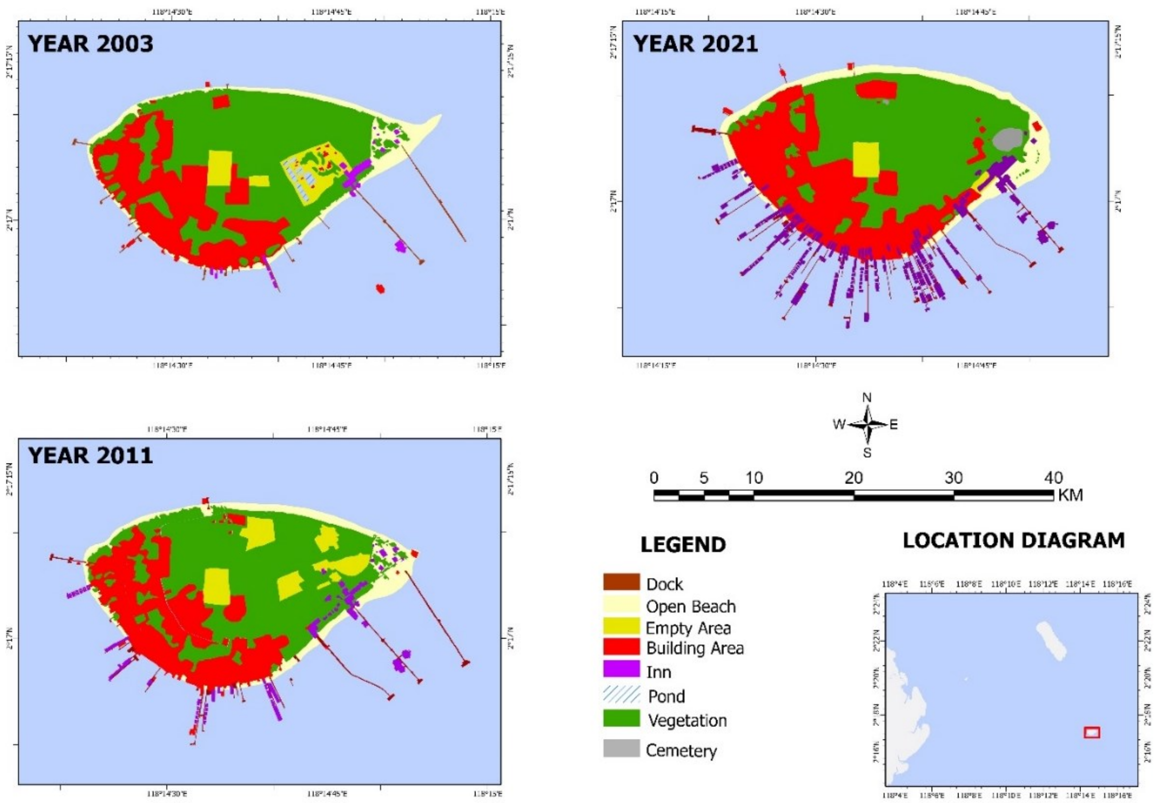


Figure 9. Derawan Island land cover comparison in year 2003, 2011, and 2021.

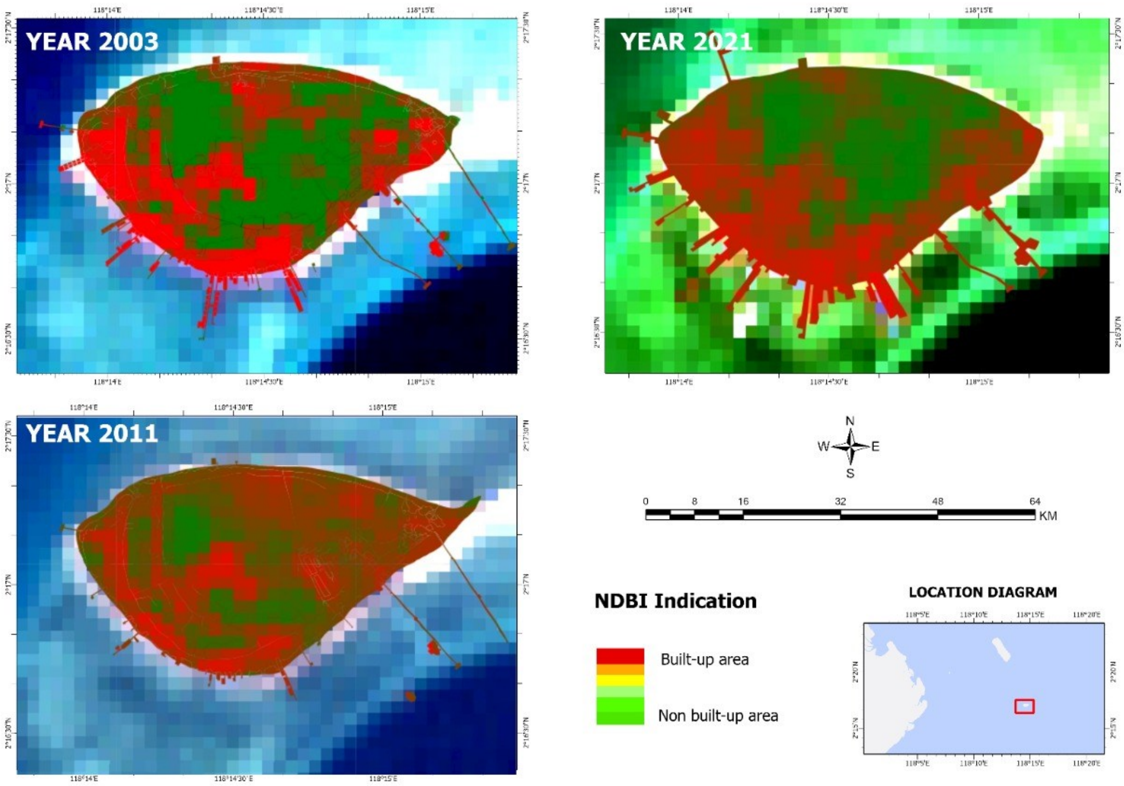


Figure 10. NDBI algorithm in Derawan Island in 2003, 2011, and 2021.

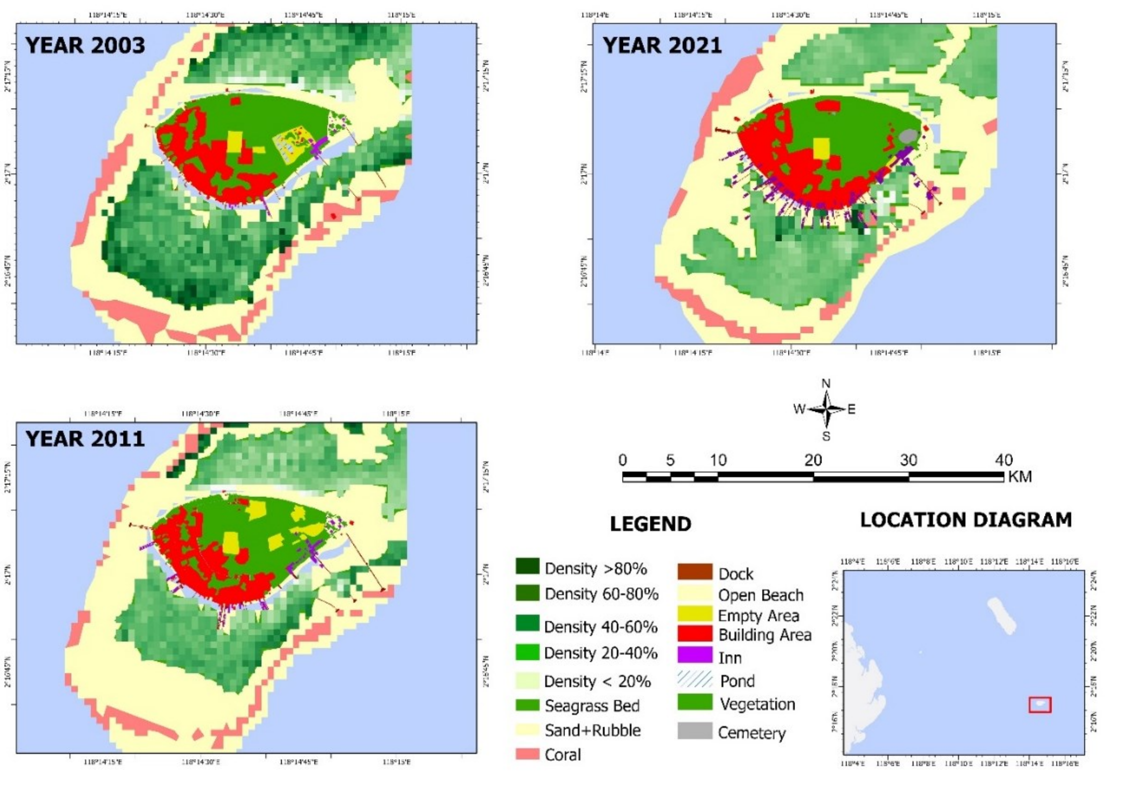


Figure 11. Comparison of benthic habitat classification and land cover in Derawan Island Year 2003, 2011, 2021

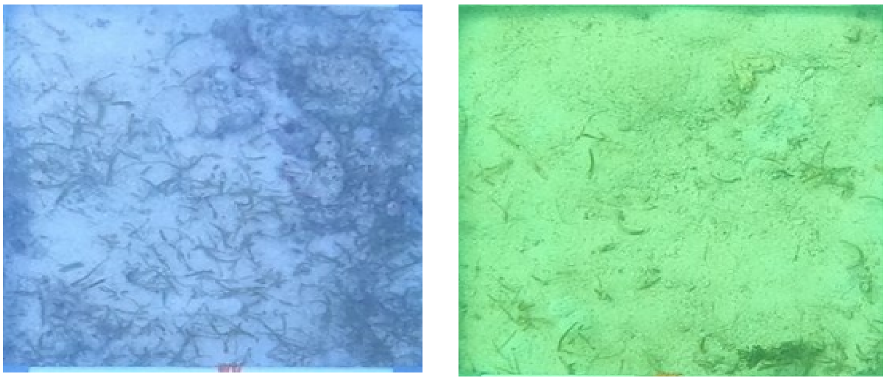


Figure 12. Seagrass beds affected by eutrophication

Conclusion

The distribution of seagrass beds on Derawan Island has changed over the last 18 years. This study is demonstrated by a 23.47 ha decrease in the area of seagrass beds in shallow marine waters. The analysis results show that the rise in human activity in the form of tourism facility construction activities, that is lodging and jetties on Derawan Island, has an impact on changes in the distribution of seagrass beds and seagrass density, as indicated by the fading of the green color in the pixels that represent the density of the field from 2003 to 2021. An indication of the cause of seagrass degradation is the obstruction of sunlight entering the body of water due to the activity of building accommodation and jetties, so that seagrass photosynthesis is disturbed. Other activities such as the disposal of waste from lodging can also cause nutrient overload resulting in a eutrophication effect. This effect raises a lot of algae on the leaves of the seagrass so that it blocks sunlight from being absorbed by the seagrass which causes disruption in the photosynthesis process as well.

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