Borneo Journal of Marine Science and Aquaculture
Volume: 05 (02) | Dec 2021, 78-82

Integrating sentinel-2 spectral-imagery and field data of seagrass coverage with species identification in the coastal of Riau Islands, Indonesia

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Abstract

Seagrass plays an important role in marine ecosystem. Plans for sustainable management of marine ecosystem should give due attention to this marine critical habitat. One effort to monitoring the long-term management of seagrass is to use spatial data using remote sensing techniques. Satellite imagery offers an efficient and cost-effective means of estimating water conditions in shallow environments. This study aims to map the coverage of the seagrass meadows using satellite images spatially, determine the species composition of the seagrass meadows, and examine the accuracy level from the results obtained by the Sentinel-2 images. Investigations reported here were conducted in the Riau Islands (4 Stations at Lingga Island and 2 Stations at Singkep Island) in Indonesia from 3 - 7 October 2020. The satellite image data used Sentinel-2 at the acquisition year of 2019 based on the method of Depth Invariant Index (DII) with Support Vector Machine (SVM) classification. The *in situ* observations were made from 6 October 2020, same with the validation date, to verify the data obtained through satellite imagery. This was needed for calculating the accuracy of results based on seagrass images and identifying the species using the Seagrass-Watch (Transect Quadrant). The result showed that the seagrass in the Riau Islands can be detected with the DII method with seagrass coverage area of 175 km^2 from the satellite in Lingga and Singkep Island. Percentage of Seagrass coverage for all transects was estimated to be about 78%. The seagrasses species identified were: *Halophila ovalis*, *Halophila minor*, *Thalassia hemprichii,* and the dominant species was *Enhalus acoroides.*

Keywords: Depth invariant index, Remote sensing, Riau islands, Seagrass, Sentinel-2

Introduction

Seagrasses are flowering plants that live and grow immersed in marine environment. Seagrasses are found in shallow marine and brackish waters in many parts of the world but mainly in the tropics although some species have been reported from colder regions. The seagrass meadows function as a primary producer, carbon absorber, sediment catchers, and nutrient recyclers. They provide spawning and feeding grounds for many marine species. Seagrass is also important as a food for several endangered species such as dugongs and sea turtles.

Seagrass meadows are dynamic, or volatile, in several ways (Hemminga and Duarte, 2000). Indonesia has at least 30.000 km^2 seagrasses meadows throughout the Indonesian Archipelago and the diversity of seagrasses in Indonesia is higher compared to several other countries in the region (Kuriandewa, 2005). They undergo changes in biomass, species composition, growth and productivity (McKenzie, 2004). Based on the important role of seagrasses there is a need to fill the knowledge gaps for their informed management. In this context, spatial data using remote sensing techniques assumes importance.

Seagrass meadows can be mapped using a wide range of approaches from *in situ* observations to remote sensing. The choice of technique is scale- and site-dependent. However, the use of remote sensing technology in mapping has many advantages compared to other conventional methods. Satellite imagery offers a means of estimating water conditions in shallow areas and in remote locations (Congalton and Green, 2009). Seagrass mapping using a variety of satellite sensors has been done, to determine the ability of a satellite sensor to produce a more accurate map. There are algorithms that can produce more accurate seagrass maps.

Image processing using depth invariant index (DII) is a developed by Lyzenga (1981). It involves calculating the value of the ratio of band DII resulting from sampling on the same substrate having different depths. Corrections in data are conducted to reduce or eliminate the influence of the water column towards the bottom to map the objects based on satellite images (Mannuputy, 2016).

Some studies on seagrass mapping using different satellite sensors with the DII method have been done but revealed different levels of accuracy. For example, Manuputy (2016) analyzed the Quickbird-2 Satellite for seagrass mapping in Karang, Bongkok and Kotok Island, Indonesia used DII image enhancement with 75% accuracy. Another study was carried out a seagrass ecosystem mapping in the Philippines by WorldView-2 satellite images by using the DII with Maximum likelihood classification and that showed 75.54% accuracy (Tamondong et al., 2013). Seagrass mapping using DII method with SVM classification is still new and limited. This study was undertaken to map the seagrass meadows with the DII Method and integrate findings with seagrass field data coverage and species.

Materials and Methods

The study was conducted in Lingga and Singkep Islands (Figure 1). Sentinel-2 satellite data obtained from Copernicus, ESA, was processed and integrated with the field data. The *in situ* seagrass observation was carried out at six stations (Stations A-F) Stations A, B, C are located at Singkep Island and stations E and F are located at Lingga Island.

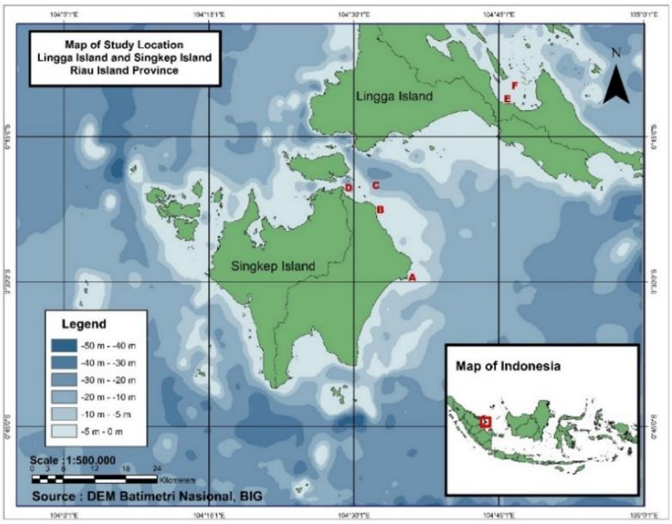

Figure 1. Stations A, B, C, D at Singkep Island and E, F at Lingga Island.

This study was divided into two parts: the satellite image processing tools and *in situ* observations. The satellite image processing was carried out with ENVI 5.1, Er Mapper 7.1, and ArcGIS 10.2. The *in situ* seagrass observations were done by using Global Positioning System (GPS) for coordinates measurements, seagrass-watch materials such as quadrant transects, roll meter, stationary, seagrass identification list (Seagrass Watch), underwater cameras and snorkels.

Image Processing Data

Sentinel-2 image processing was performed in several steps such as geometric correction, radiometric conversion, and atmospheric correction, image segmentation, and image enhancement. Geometric correction is the process of adjusting the position of a satellite image according to the position of the earth's surface. The Sentinel-2 geometric corrections were performed using the rational polynomial coefficient (RPC) model. Atmospheric correction was conducted to reduce the atmosphere effects to get the surface spectral reflectance from an image. Radiometric correction was applied to remove atmospheric effect, while image enhancement was used to improve the gray level of the satellite image.

The image enhancement process was conducted by correcting the water column data using the DII (Lyzenga, 1981). DII equation is shown in the equation 1.

$$\text{Depth-invariant index}_{ij} = \ln(L_i) - \left[\left(\frac{Ki}{Kj}\right)\ln(L_{ij})\right] \text{.................} 1$$

$$\frac{K_i}{K_j} = a + \sqrt{(a^2+1)}\ dan\ a = \frac{\sigma_{ii} - \sigma_{jj}}{2\sigma_{ij}}$$

Where, Li and Lj = reflectance value of the band-I and band-j. Ki/Kj = ratio coefficient attenuation of the band-I, and j. σii = Variance of the band i, σjj = Variance of the band j and σij ij = Covariance of the band. The area of the spread of the fields can be calculated spatially for each island using ArcGIS raster calculator

In Situ Seagrass Observation (Ground Truth)

Monitoring involved observing an ecosystem to examine changes for protecting and managing the resources in coastal areas (McKenzie, 2004). Monitoring of seagrass meadows is repeated in benthic ecosystems in a certain area for observing the status and condition of the seagrass meadows with Coremap_CTI LIPI Seagrass Category table (Table), and to know whether it is stable, increasing, or decreasing. Seagrass monitoring could be done by using various methods such as Seagrass-Watch.

Table 1. Coremap-CTI LIPI Seagrass Category

Coverage percentage	Category
0-25	Very Bad
26-50	Bad
51-75	Good
76-80	Quite Good
81-100	Very Good

Data such as seagrass coverage and species identification were collected along the three transects of a length of 100 m each and the distance between one transect line and the other was 50 m. In addition, seagrass cover area was to calculate from the transect quadrant with ten transect quadrant per transect line. Seagrass species were also identified in each transect station. The *in situ* seagrass observation was carried out from 1- 7 October 2020, during the monsoon transition period from East Monsoon to the West Monsoon in Indonesia.

Accuracy Test

One of the most important steps to integrate seagrass observations with remote sensing is the accuracy test. Accuracy test was carried out to compare satellite data with field data by calculating an Error Matrix (Matrix Confusion or Contingency) (Green, et al., 2000). The accuracy test envisaged determining the values of User Accuracy (UA), Producer Accuracy (PA), and Overall Accuracy (OA) (Komatsu, et al., 2008).

The error was calculated by comparing the *in situ* observation data with the corresponding satellite image. Each column of the Matrix Confusion represents a class of *in situ* observations and the values in the column correspond to the classification of the satellite data processing pixels.

Result and Discussion

The image in February 2019 was chosen to represent the west monsoon because it provided the cleanest cloud cover about 12%, compared to other months with about 47-67% cloud cover (Figure 2). The DII method and SVM classification were applied to the satellite image. The SVM classification in the DII method also identified other benthic classes besides seagrass, such as coral, sand, sediment, cloud, and mangrove.

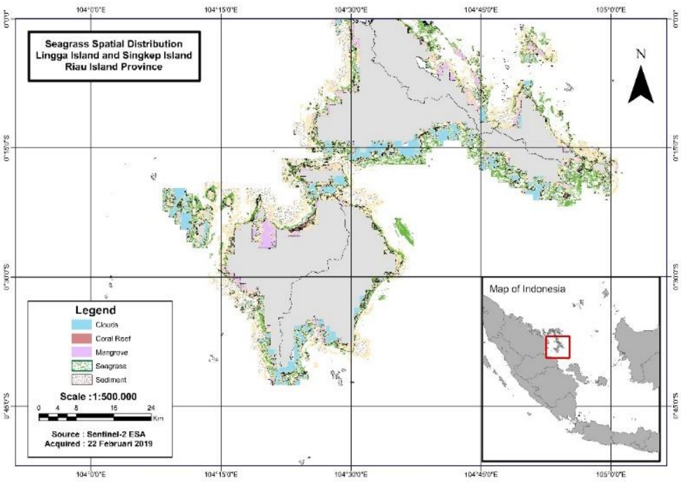

Figure 2. Benthic ecosystem map, consisting of seagrass, coral, mangrove, sediment, and clouds in February 2019.

The seagrass spatial distribution area was estimated as 173 km^2 based on the distribution presented in Figure 2. The seagrass distribution on the Singkep Island was extended towards the northeast and southwest of the Island (Figure 3). Meanwhile, the distribution of seagrass in Lingga Island was in the northeast and south of the Island.

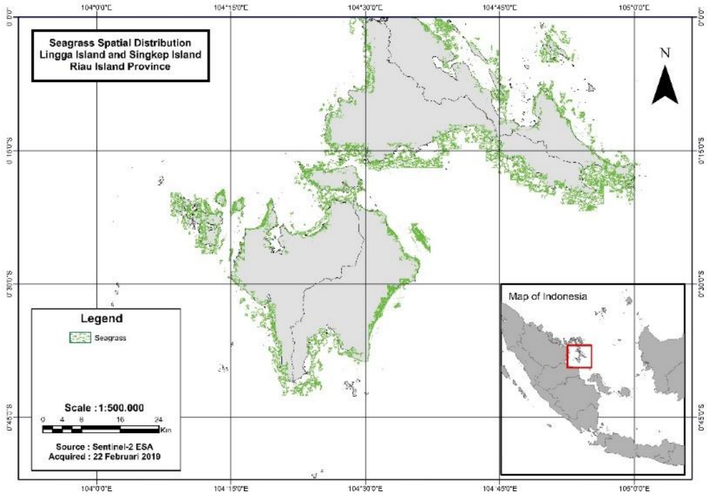

Figure 3. Benthic ecosystem map showing the spatial distribution in February 2019.

The area of spread of the fields calculated spatially for each island using ArcGIS raster calculator provided useful estimates: seagrass area in Singkep Island was estimated to be 68 km^2 and Lingga Island about 81 km^2; the small islands such as Rusukbuaja Island, Posik Island, Bandahara Island and Selajar Island measured 24 km^2. Most of the seagrass cover was in Lingga Island (Table 2).

Table 2. Spatial area distribution of seagrass beds in Singkep and Lingga Islands.

	Seagrass Spatial Distribution of 2019			
	Singkep Island	Lingga Island	Surrounding Islands	Total Area (km^2)
Spatial Area	68	81	24	173

Seagrass meadows were observed through *in situ* efforts in Singkep Island at stations A, B, C, and D. Maximum seagrass coverage of 88.4% was found at station C, which was located in Kote village, and was in good condition according to Coremap-CTI LIPI classification, while the minimum seagrass coverage area 45.7% was found at station A which was located near the Dabo Airport, also in good health (Table 1). The seagrass beds distributed on the Lingga Island (stations E and F), were healthy and dense, with a coverage area of 98.4%, as shown on Table 3.

Table 3. Seagrass coverage and condition in Singkep Island and Lingga Island.

Station	Location	Coordinates	Coverage (%)	Condition (Coremap CTI-LIPI)
A	Dabo (Singkep Island)	0°29'28.50"S - 104°35'39.25"E	45.7	Quite Good
B	Kote (Singkep Island)	0°24'17.30"S - 104°32'58.54"E	88.0	Very Good
C	Kote (Singkep Island)	0°23'4.42"S - 104°33'3.07"E	88.4	Very Good
D	Kote (Singkep Island)	0°21'58.62"S - 104°32'4.21"E	52.5	Quite Good
E	Daek (Lingga Island)	0°11'57.48"S - 104°48'18.41"E	98.4	Very Good
F	Daek (Lingga Island)	0°11'23.13"S - 104°48'9.94"E	95.4	Very Good
	Average coverage of seagrass in all the stations		78.0	

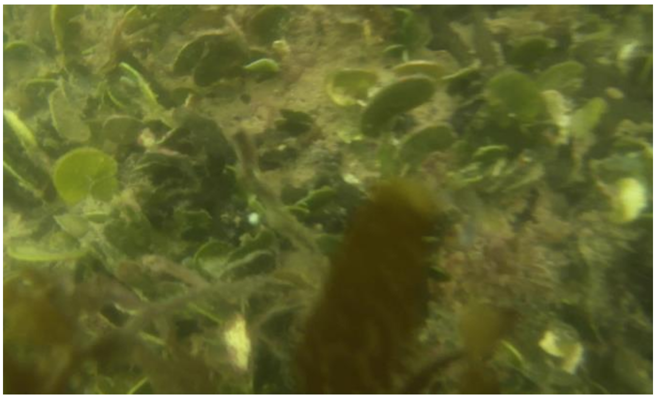

Figure 4a. Seagrass (*Halophila ovalis*) at station A.

Figure 4b. Seagrass (*Halophila minor*) station A.

In situ observations identified four seagrass species in Singkep Island, *Thalassia hemprichii* (Figure 5a), *Enhalus acoroides*, *Halophila minor* (Figure 4a), and *Halophila ovalis* (Figure 4b). Only *Enhalus Acoroides* (Figure 5b) was found in Lingga Island (Table 3). The differences in distribution and species of seagrass in the waters of Singkep Island and Lingga Island are caused by their ability to adapt with the changing environmental conditions.

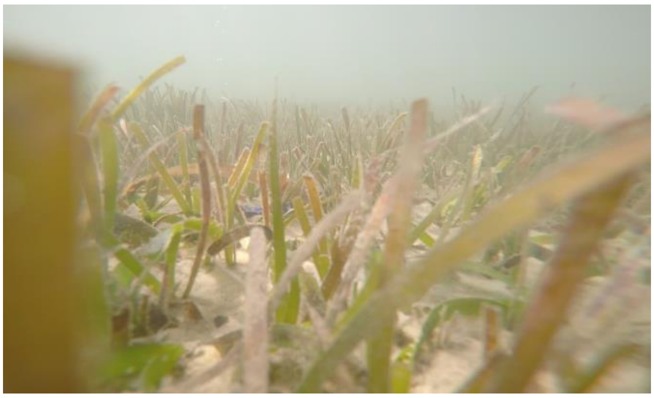

Figure 5a. Seagrass (*Thalassia hemprichii*) at Station B

Figure 5b. Seagrass *(Enhalus acroides*) at station F

Enhalus acoroides was distributed in both the locations. It is a widely distributed and a common seagrass species in Indonesia (Kuriandewa, 2005) together with *Thalassia hemprichii* (Table 4). However, the seagrasses appear to be sustaining their growth under the condition on Lingga and Singkep islands, while mostly occurring in muddy areas, medium and coarse sand, debris to dead coral.

Table 4. Species identification

Locations	Species			
	Thalassia hemprichii	*Enhalus acoroides*	*Halophila minor*	*Halophila ovalis*
Station A. Dabo (Singkep Island)	-	-	+	+
Station B. Kote (Singkep Island)	+	-	-	-
Station C. Kote (Singkep Island)	+	+	-	-
Station D. Kote (Singkep Island)	+	+	-	-
Station E. Daik (Lingga Island)	-	+	-	-
Station E. Daik (Lingga Island	-	+	-	-
Description: + Found, - Unfound				

Seagrasses around the Singkep and Lingga Islands were found in the tidal zone at a depth range of 1-10 meters. These are important feeding and nursery grounds of many marine animals, and contribute to rich biodiversity in the area. Green Turtles (*Chelonia mydas*), Hawksbill Turtles (*Eretmochelys imbricata*), and Dugongs (*Dugong dugon*) have also been seen foraging in these seagrass habitats (Hemminga and Duarte, 2000).

The accuracy test of the benthic habitat classification with a confusion matrix on Singkep Island and Lingga Island suggested a value of more than 65% which means a high level of accuracy (Congalton and Green, 2009) (Table 5).

Table 5. Accuracy test for comparing the satellite data and *in situ* observations.

Satellite Data	Ground Truth Data			
	Seagrass	Other Class	Row Total	UA (%)
Seagrass	62	1	63	62/63 (98.4)
Other Class	33	4	37	33/37 (89.1)
Coloumn Total	95	5	100	
PA (%)	62/95 (65.2)	4/5 (80)		
OA (%)			68/100 (68)	

The classification of seagrass in Lingga and Singkep Island used the DII method and yielded a Producer Accuracy (PA) value of 65.2%, User Accuracy (UA) value of 98.4% and Overall Accuracy (OA) value of 68%. The Overall Accuracy (OA) value of 65-70% can be considered suitable for the results of the accuracy test of benthic habitat mapping using remote sensing (Congalton and Green, 2009)

Conclusion

The seagrass meadows in Singkep Island and Lingga Island are in a healthy condition. These ecologically important habitats can be detected by the DII method with an accuracy of 68%, using the Matrix Confusion accuracy test. The seagrass area in Singkep and Lingga islands is estimated to cover 68 km^2 and 81 km^2, respectively. Given the important role of this vast habitat, it is important to generate more scientific information and apply knowledge-based measures for sustainable management of this resource that is so vital for marine biodiversity.

Acknowledgments

This work is part of a master's thesis supported by scholarship from the Joint Supervision Korea-Indonesia Marine Technology Cooperation Research Center (MTCRC).

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