Remote sensing for coral reef and seagrass cover mapping to support coastal management of small islands

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Abstract Coral reefs and seagrass are critical coastal resources due to their role in the ecosystem benefits for the coastal environment in terms of biodiversity, coastal protection, fisheries, and tourism. It is therefore important to preserve and protect these species. Coral and seagrass percent cover mapping is a simple approach to assess coral and seagrass condition. The application of remote sensing of coral and seagrass percent cover mapping is very challenging with respect to performance and accuracy. This research aims to utilize remote sensing data for coral and seagrass percent cover mapping. Linear and machine learning regressions (RF and SVM) were used to develop a coral and seagrass percent cover model from a Sentinel-2 MSI images. The Sentinel-2 MSI images were transformed into deglint, water column (DII), principal component, and mean texture analysis as input bands for the model. The results showed that coral percent cover mapping accuracy is relatively low (RMSE = ±17%) due to various problems, limitations, and an inaccurate model, whereas the results of the seagrass percent cover map had higher accuracy, with RMSE ±11%. The results obtained indicate that the seagrass percent cover map is suitable for use as basic information to support coastal management. However, the coral percent cover map is not an optimal information source due to its low accuracy.

1. Introduction
Coastal areas contain abundant natural resources and complex ecosystems, including coral reefs and seagrass [1]. In addition, coral reefs and seagrass supply a wide range of important economic and environmental benefits for people and their livelihoods. In recent years, the coral reef and seagrass ecosystem has decreased due to multiple environmental stresses, both anthropogenic (coastal development, exploitation coastal resources) and natural (disaster, global warming, thermal stress) [2]. During the last years, coral reef and seagrass coverage has decreased, especially in Indonesia [3]. If this trend continues, then it will have a negative impact on coastal ecosystems by changing the surrounding marine environment, causing the extinction of species, and affecting fisheries production and people lives [1]. Therefore, monitoring the condition of coral reefs and seagrass is important for their management and conservation, and supports Sustainable Development Goals 14 (SDGs 14) related to marine resources [4]. Mapping is one of the most effective and efficient methods for coral reefs and seagrass monitoring. Coral reefs and seagrass condition can be evaluated by its percent cover [5]. Obtaining such information requires reliable data acquisition that produces synoptic and detailed information. In a mapping and spatial context, this can be achieved by using a remote sensing image as the data source [6]. Remote sensing has been widely used and successful in
mapping coral reef and seagrass habitats, and can obtain accurate information [7]. This research aims to map coral and seagrass percent cover using remote sensing data. Coral and seagrass percent cover mapping is very important as the information can be used for various purposes in coastal management programs [4], especially for monitoring the natural resources, rehabilitation and conservation, tourism, and fisheries [8]. Therefore, this research is expected to be used as a reference in similar studies, especially by government and stakeholders, when applying remote sensing data for coastal monitoring for coastal resources information for management purposes.

2. Method

2.1. Data and Study Area
Sentinel-2 MSI data are used in this research with the acquisition date May 19, 2017, 12-bit radiometric resolution, 10 m spatial resolution (visible and near-infrared bands), 20 m (red edge to SWIR bands), and 60 m (water vapor, cirrus, coastal aerosol bands). This research uses only 10 m bands as this is adequate for coral reef and seagrass mapping [6]. Sentinel-2 MSI data were chosen because it has good performance for coral reef mapping applications, both in the information detail, consistency of the results; in addition, the temporal resolution facilitates researchers to choose the best image quality [4]. The research location is Karimunjawa National Park (Figure 1), Indonesia, which is a coastal ecosystem with high coral reef and seagrass complexity. Coral reefs assume a variety of morphologies at different depths. Coral reefs and seagrass are very important, especially to control the shallow water environment and ecosystem, which has become a major interest for tourism in Karimunjawa National Park.

![Figure 1. Study area](image)

2.2. Image Correction
Sentinel-2 MSI has a Top of Atmosphere Reflectance ($R_{TOA}$) correction level that does not represent surface reflectance; thus, it is necessary to do atmospheric correction using Dark Object Subtraction (DOS) to minimize noise from atmosphere effects on the image and obtain a surface reflectance image. In addition, sunglint correction [9] was also applied to the image to minimize the effect of sunlight reflection from the water’s surface that can affect the results of modeling and image
classification. Water column correction was also applied to minimize the misclassification of benthic habitat due to depth factors. The Lyzenga [10] water column correction method was used because it is simple and accurate.

2.3. Principal Component Analysis (PCA)
PCA is an image transformation technique that reduces noise components and uses dimensional datasets to produce an image that contains information not correlated with each another. The first PC band contains the largest percentage of information and continues to decrease until the last PC band due to very noisy and small data variance [11]. Thus, PCA transformation improves the accuracy of coral reef mapping [12].

2.4. Texture Analysis
Texture analysis is a filtering function that distinguishes spatial variation in pixel intensity in a moving window. This analysis refers to variations in image brightness level (radiometric) where the difference in brightness levels is regarded as a textural pattern difference. Heterogeneous pixel values will result in a more varied texture compared with homogeneous objects. The use of texture analysis improves mapping accuracy [13]. The texture analysis applied in this study is “mean texture.”

2.5. Benthic Habitat Mapping
Benthic habitat mapping was done according to four major classes—coral reef, seagrass, macroalgae, and bare substrate—in accordance with SNI 7716: 2011. Benthic habitat mapping is processed using multispectral classification with a machine learning algorithm, i.e., Random Forest (RF) or Support Vector Machine (SVM). Machine learning algorithms have become an alternative method in digital image classification and improve mapping accuracy [14]. From the benthic habitat maps, the best accuracy and spatial distribution of coral reefs and seagrass was used as masking to focus the unit analysis of percent cover map. The input bands in benthic habitat classification are quite varied and include SR, deglint, and DII bands as well as the results of PCA and mean texture analysis transformation.

2.6. Percentage of Coral and Seagrass Cover Mapping
Coral and seagrass percent cover mapping was done by empirical modeling using linear regression and machine learning regression, i.e., Random Forest Regression (RFR) or Support Vector Regression (SVR). This approach uses a simple linear regression mixed with machine learning methods; thus, the automated empirical modeling of big data is not a problem. This method has been successfully applied to benthic habitat and seagrass mapping and provides high accuracy [15]. The input bands in coral and seagrass percent cover modeling process are similar to those in benthic habitat mapping.

3. Result
3.1. Benthic Habitat Mapping
The benthic habitat classification results showed an overall accuracy of 56–73%. Table 1 compares accuracy between the two machine learning algorithms. The highest benthic habitat overall accuracy is 71.18% and 73.14%, obtained from the RF and SVM algorithm, respectively, using the surface reflectance (SR) band.
Table 1. Summary of benthic habitat map overall accuracy assessment (*depicts the highest benthic habitat classification accuracy)

| Machine Learning Classification Algorithm | Band Deglinit | SR | PCA | Texture | DII | PCA | Texture |
|------------------------------------------|---------------|----|-----|---------|-----|-----|---------|
| RF Accuracy (%)                          | 71.18         | 67.06 | 70.20 | 69.02 | 68.24 | 63.92 | 59.22 | 66.86 | 56.27 |
| Kappa                                    | 56.28         | 51.15 | 54.95 | 54.22 | 53.09 | 46.69 | 40.52 | 51.01 | 36.17 |
| SVM Accuracy (%)                         | 73.14*        | 71.57 | 67.84 | 68.63 | 70.78 | 68.04 | 65.49 | 64.71 | 64.90 |
| Kappa                                    | 58.97*        | 56.66 | 51.67 | 53.23 | 55.44 | 50.75 | 48.75 | 48.35 | 46.54 |

Although their accuracy values differ, the results of the RF and SVM classification algorithms showed a similar spatial distribution pattern as the benthic habitat map (Figure 2). However, there are slight differences, especially in terms of misclassification. The benthic habitat results obtained from RF misclassified macroalgae as coral reefs and seagrass beds and vice versa, at a minor level. Meanwhile, benthic habitats from SVM misclassified macroalgae as bare substrate, coral reefs, seagrasses and vice versa. The misclassifications are quite massive for bare substrate and seagrass objects. This is due to the similarity of pixel values between macroalgae and seagrass, coral reefs, and also the carbonate sand substrate. Particularly in a low-density condition, the background of carbonate sand will be more exposed and contribute to the total reflectance value [12]. Overall, although the SVM results are statistically more accurate, the RF results have a more appropriate and ideal spatial distribution with the field condition (shown in the red box in Figure 2). The back reef, reef crest, and fore reef were classified as coral reefs, reef flat classified as bare substrate, macroalgae and seagrass, especially parallel and near the coastline. The lagoon classified as bare substrate and coral reef; thus, the coral reef and seagrass classification result used as masking in the percent cover analysis are the benthic habitat result from RF.

![Figure 2. Benthic habitat maps: a) RF with OA 71.18%, b) SVM with OA 73.14%](image-url)
3.2. Coral Percent Cover Mapping

Coral and seagrass percent cover mapping has a slight modification to the sample design, especially the selection of data and the involvement of other objects in the modeling process. This is related to the similarity of the pixel value of coral reefs despite having a different percent of live coral cover. Therefore, the model becomes saturated due to low pixel variation. In this case, there is little involvement of sand objects that have a live coral cover composition to fix saturation of the model. This is a main problem faced in coral percent cover modeling [16]. The results of the coral percent cover mapping using linear regression, RF, and SVM algorithms can be seen in Figure 3. The Root Mean Square Error (RMSE) values obtained from the overall results of empirical modeling range from 17 to 21% (Table 2).

Table 2. RMSE and $R^2$ of coral percent cover map result (*depicts the best result of coral percent cover map)

| BAND | LINEAR | RF | SVM |
|------|--------|----|-----|
|      | $R^2$  | RMSE (%) | $R^2$ | RMSE (%) | RMSE (%) |
| SR   | 0.33*  | 17.90* | 0.30 | 19.47 | 19.84 |
| PCA  | 0.33   | 18.02  | 0.22 | 19.52 | 19.86 |
| Texture | 0.31 | 17.39  | 0.13 | 18.01 | 20.50 |
| Deglint | 0.31 | 17.85  | 0.30 | 19.49 | 20.44 |
| PCA  | 0.31   | 18.00  | 0.20 | 20.24 | 20.37 |
| Texture | 0.30 | 17.47  | 0.15 | 19.28 | 20.59 |
| DII  | 0.07   | 20.77  | 0.13 | 20.19 | 21.42 |
| PCA  | 0.28   | 19.02  | 0.22 | 18.82 | 20.10 |
| Texture | 0.01 | 21.26  | 0.08 | 19.65 | 20.98 |

RMSE is used to determine how much error results from the model. The smaller RMSE the value the better the map produced and vice versa. Based on the overall results, linear regression obtained the smallest RMSE of ± 17% of the input SR band followed by RF and SVM with 19.47% and 19.84%, respectively. Spatial distribution of coral percent cover maps dominated, with more than 50% live coral cover. This is due to the similarity of pixels between coral reefs with different percent cover. The different depths also affected the value of the coral reef pixels. The deeper the coral reef, the lower the pixel reflectance and identified as a high coral live cover, and vice versa.

Figure 3. Coral percent cover maps: a) Linear SR (RMSE = 17.90), b) RF SR (RMSE = 19.75%), c) SVM SR (RMSE = 19.84%)
3.3. Seagrass Percent Cover Mapping

The results of seagrass percent cover modeling have an RMSE of 11–15%. Linear regression produces a seagrass percent cover map with the smallest RMSE value of ±11% obtained from the deglint bands. This result shows that the seagrass percent cover map is quite accurate. Based on the $R^2$ value of $> 0.45$, the model result has a moderate relationship between remote sensing data with ground truth data. Table 3 shows $R^2$ and RMSE values of seagrass percent cover using different methods.

Table 3. RMSE and $R^2$ of seagrass percent cover map result (*depicts the best result of seagrass percent cover map)

| BAND     | LINEAR | RF  | SVM  |
|----------|--------|-----|------|
|          | $\text{R}^2$ | RMSE (%) | $\text{R}^2$ | RMSE (%) | RMSE (%) |
| SR       | 0.57   | 11.67 | 0.52 | 14.10 | 13.87 |
| PCA      | 0.50   | 11.21 | 0.55 | 13.15 | 13.58 |
| Texture  | 0.60   | 12.12 | 0.52 | 14.81 | 14.55 |
| Deglint  | 0.58*  | 11.53*| 0.51 | 14.42 | 13.19 |
| PCA      | 0.56   | 11.54 | 0.40 | 14.05 | 13.15 |
| Texture  | 0.51   | 12.10 | 0.48 | 14.46 | 14.48 |
| DII      | 0.06   | 14.38 | 0.48 | 14.01 | 15.55 |
| PCA      | 0.02   | 14.21 | 0.57 | 13.46 | 12.84 |
| Texture  | 0.25   | 15.21 | 0.44 | 15.68 | 14.47 |

Seagrass cover in the study area has a spread pattern, especially in the north and northeast of Kemujan, a small peninsula on the east and west sides of Karimunjawa, and in Menjangan Besar and Menjangan Kecil Island. The pattern of distribution is also influenced by characteristics of the local shallow water environment, especially the factors of depth, substrate, water clarity, solar radiation, and the chemical quality of the water. The seagrass percent cover result from linear regression, RF, and SVM methods has a similar spatial distribution with insignificant differences (Figure 4).

Figure 4. Seagrass percent cover maps: a) **Linear** Deglint (RMSE = 11.53%), b) **RF** SR PCA (RMSE = 13.15%), c) **SVM** DII PCA (RMSE = 12.84%)

The spatial distribution of seagrass percent cover has a class variation different from the coral percent cover, which is dominated by a certain percent cover class. This variation is due to the fact that each location has a different species composition. *Thalasia hemprichi, Cymodocea rotundata,*
and *Enhalus acroides* tend to have a high percent cover. *Cymodocea serrulata* and *Syringodium isoetifolium* have moderate percent cover. Species of the genera *Halophila* and *Halodule* tend to have a low percent cover because they have a small size and are clustered with low density. In addition, seagrass percent cover has different spectral characteristics than those from coral reefs. The seagrass pixel characteristics tend to be strongly influenced by the bare substrate background. When it has a low percent cover, the pixel value will be high because it is dominated by the bare substrate response. Meanwhile, when having a high percent cover, the pixel value will be darker or low because the source of the spectral response on a pixel is only represented by seagrass objects. This causes seagrass percent cover variation to be represented through images with acceptable quality and model accuracy.

4. Discussion

This research analyzed remote sensing data for benthic habitat, coral reef, and seagrass percent cover mapping for information that can be used to support coastal management. The possibility of using Sentinel-2 MSI data came to the researchers’ attention due to its consistent performance, ease of access and flexible quality selection with high temporal resolution [4]. The results of benthic habitat classification using Sentinel-2 MSI imagery have an accuracy of 56–73%, which is similar to the benthic habitat map accuracy of [12] using four major classes. The accuracy value has exceeded the minimum standards for major classes (60%) used by the Geospatial Information Agency (BIG) in Indonesia. Therefore, benthic habitat information can be used as input information in coastal management. The use of RF and SVM algorithms did not make a significant difference in the accuracy of results. However, RF provided more consistent performance in terms of spatial distribution and its similarity to the field condition compared with SVM [14].

Based on the overall results of coral and seagrass percent cover maps, DII bands have the highest error value and a very low model correlation. Regarding deglint bands, the result does not differ significantly from the SR. The application of image transformations such as PCA and texture analysis also does not improve the map’s accuracy significantly. The coral and seagrass percent cover mapping concept emphasizes the variation aspects of pixel values on each object so the model can run optimally. Thus, when the pixel variation is very low, the model will saturate and cause a large error. In the DII band, the image pixel shows the object index value. Each object, for example, coral reefs, have similar DII values to another coral live cover (low variation). Thus, when the model is applied, saturation occurs, which produces high error in the maps. In addition, variations of coral and seagrass percent cover tend to be represented by the spectral response on the SR bands (visible) [15]. The use of Sentinel-2 MSI images in very good clarity conditions, there is no need for additional correction or transformation treatments such as DII because it can worsen the pixel value of the image and decrease the accuracy [4].

The coral percent cover mapping results have accuracy and other problems that are comparable to those found in some studies [16]. Until now, coral percent cover mapping has rarely been attempted due to the low accuracy of the results; however, the information obtained is still quite representative and useful for coastal management. Seagrass percent cover map results have higher accuracy than those reported in [15]. This is because the image used in [15] is created by PlanetScope, which has low radiometric quality and a low signal-to-noise ratio. In this study, however, the Sentinel-2 MSI was used with more consistent radiometric quality [4]. Although the results obtained from the Sentinel-2 MSI are more accurate, the level of precision is lower due to differences in spatial resolution. Thus, the performance of PlanetScope and Sentinel-2 MSI cannot be compared directly. Future technology developments should be implemented to obtain more accurate information of coastal resources, especially coral reefs and seagrass [7]. This is important because coastal resources information is needed in order to support an effective coastal management plan. In Indonesia in particular, this information is developing the Zoning Plans of Coastal Areas and Small Islands (RZWP3K), particularly to support and control the utilization and preservation of coastal resources through conservation and legal aspects.
5. Conclusion
Remote sensing for benthic habitats and seagrass percent cover mapping, especially using Sentinel-2 MSI, can provide good performance and high accuracy of 73.14% and RMSE ± 11%, respectively. This study found the application of machine learning algorithms in the mapping process to be very effective as it improved the performance of remote sensing imagery to produce maps. Currently, the results for coral live cover mapping are not optimal although the RMSE ±17%. These results indicate that the benthic habitat and seagrass percent cover information obtained from remote sensing data is quite accurate and can be used as a reference or basis information in coastal management. However, for the results of coral percent cover maps, the information obtained cannot be relied on as reference information in coastal management due to its low accuracy. Although the accuracy is low, this result can still be useful in comparison to field results. This would be a logical next step in exploring ways to support the coastal resources information needs for effective coastal management.

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