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# SPATIAL MAPPING OF CORAL REEF DISTRIBUTION IN KARIMUNJAWA ISLAND USING LYZENGA ALGORITHM

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## ABSTRACT

Coastal areas have high ecosystem productivity and are characterized by abundant fish species and coral reefs. However, these ecosystems are vulnerable to environmental pressures caused by human activities and natural dynamics. Coral reefs, consisting of organisms from the class Anthozoa within the order Scleractinia, which produce calcium carbonate structures, are key indicators of coastal ecosystem health. Coral reefs share biological characteristics with soft corals, hydras, and sea anemones as part of the phylum Cnidaria. Their existence is highly sensitive to environmental changes, whether natural or anthropogenic. In Indonesia, coral reef conditions have experienced significant degradation, with 36.18% in the damaged condition, only 6.56% categorized as very good, and 22.96% as good. The remaining 34.3% fall under the poor category, particularly around Karimunjawa and Kemujan Islands. Accurate data-based monitoring and management are essential for conserving these ecosystems. One method used to map and analyze coral reef distribution is the Lyzenga algorithm, which can distinguish shallow-water characteristics from coral reef habitats using satellite imagery. In this study, the Lyzenga algorithm was applied to SPOT 6 imagery for the Karimunjawa and Kemujan regions, covering an area of 8.46 km². The results showed that live coral reefs cover approximately 46% of the area, while dead coral reefs account for 56%, indicating a level of degradation that requires further attention in conservation and ecosystem recovery strategies. This study highlights the critical state of coral reefs in Indonesia, particularly in the Karimunjawa and Kemujan regions, emphasizing the necessity for conservation efforts driven by precise monitoring techniques such as the Lyzenga algorithm.

Keywords: coral reef cover, remote sensing, Lyzenga algorithm, Karimunjawa

## INTRODUCTION

Ecologically, coral reef habitats, such as those in Indonesia, are found in tropical regions where warm temperatures dominate the waters throughout the year. Throughout the year, the average sea surface temperature in Indonesia is $26^0$ - $30^0$C which is relatively uniform throughout the region. Even during seasonal transitions, the temperature does not change drastically (Aldrian & Dwi Susanto, 2003). The small range of temperature fluctuations is one of the key factors that allows coral reefs to thrive in Indonesian waters, along with the ecosystems they support (Fahrezi et al. 2022). Additionally, Indonesia's coastal waters are generally shallow, with gently sloping seabeds, allowing sunlight to penetrate to depths of approximately 10–25 m, an ideal range in which coral reefs are commonly found (Nayyiroh & Muhsoni, 2023). Gradual depth contours are frequently observed in the underwater morphology of small islands, which help moderate the energy of currents and waves, creating highly favorable conditions for coral reefs to survive physical stress caused by marine forces (Durotunasha et al., 2023)

Coral reef ecosystems are crucial for supporting biotic life inhabiting shallow waters, as well as for their role in protecting coastlines from physical marine forces and sustaining marine tourism that relies on the beauty of underwater attractions. To support sustainable coral reef management, information on the distribution of coral reefs is essential for the effective management of these ecosystems (Durotunasha et al., 2023; Saptarini et al., 2017). Understanding the location and health status of coral reefs can help prioritize areas for protection, restoration, and monitoring (Eddy et al., 2021; Singgalen 2024). This information also supports the implementation of adaptive management approaches that respond to changing environmental conditions and the impacts of human activities.

The approach employed in this study involves utilizing remote sensing technology to monitor the vast areas of Karimunjawa, including clusters of small islands in the area. One of the key advantages of remote sensing is its ability to reduce the costs associated with direct field observations across the entire study area while also improving time efficiency. The Lyzenga algorithm is a remote sensing method well-suited to the characteristics of coral reef habitats in shallow waters (Awak et al., 2016). However, the application of the Lyzenga method for observing coral reef distributions remains limited with respect to satellite imagery. Therefore, this study aimed to monitor the distribution of coral reefs in the Karimunjawa Islands using the Lyzenga method applied to high-resolution satellite imagery (HRSI) from SPOT 6 to obtain accurate results. This information also supports the implementation of adaptive management approaches that respond to changing environmental conditions and the impacts of human activities.

## MATERIALS AND METHODS

### Time and Location of Research

This research was conducted in June 2023 for remote sensing data processing and validation of in situ sample data from Karimunjawa Islands. Administratively, the study area includes the southern part of Karimunjawa District and the southern part of Kemujan District. 41 field data points were used to assess the accuracy of the image classification analysis with coordinate boundary: (Longitude : 110º24'-110º30'E Latitude 5º46'-5º54'S)

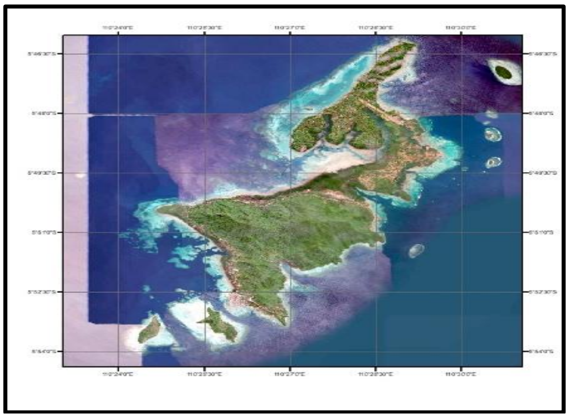


Figure 1. Map of the research area

### Data Preparation

SPOT 6 provides high-resolution satellite imagery with a panchromatic resolution of 1.5 m and multispectral resolution of 6 m. Subsequently, sunglint correction was applied to improve the image quality by eliminating the interference caused by sunlight, which is perpendicular to the sea surface (Anggoro et al., 2016). In this study, the bands used for sunglint correction were band 1 (blue), band 2 (green), band 3 (red), and band 4 (near-infrared (Near)). This process is intended to minimize errors in the energy values in images due to uneven light reflection on the surface of the water caused by the physical influence of ocean dynamics, such as wave currents and tides. The Sunglint correction formula is expressed as follows:

$$Ri^{"} = Ri - Bi\ (RNIR - MinNIR)$$

Where;
$Ri^{"}$ denotes the sunglint correction value and represents a transformation of the reflectance values in each band (blue, green, and red band sunglint).
$Bi$ is denoted as the slope regression value of the statistical results (blue - infrared, green - infrared, and red - infrared),
$RNIR$ as the reflectance value in the near infrared band, and
$MinNIR$ shows the calculation results of the minimum reflectance value of the near-infrared band from all selected samples.

In situ field data collection for monitoring underwater objects was conducted using the stop-and-go method to validate the remote-sensing data while also gathering ecological information. This was based on the variability of the classes obtained from the satellite image classification results. Observations were carried out using a snorkeling approach to obtain a direct visual representation of coral reef ecological features, utilizing an underwater camera and a Global Positioning System (GPS) to record the exact positions of the monitoring points.

### Remote Sensing Data Processing

The water column at a specific depth affects the spectral calculations between bands from satellite imagery. Its influence can reduce the attenuation effect on the water column, thereby increasing the accuracy of coral reef ecosystem classification (Nguyen et al., 2021; Zoffoli et al., 2014). To reduce this effect, this study used the Lyzenga algorithm with a depth-invariant index approach based on the results of bands a and b calculations, which were then combined into a new band, expressed as follows:

$$Index_{ij} = Ln(Bi) + \frac{Ki}{Kj} Ln\ (Bj)$$

Where;
$Index_{ij}$ : Water depth invariant bottom index
Bi : Value of band i
Bj : Value of band j
$Ki/Kj$ : Ratio of the water column attenuation coefficients between band i and band j

Meanwhile, the value $\frac{Ki}{Kj}$ is expressed as follows:

$$Ki/Kj = a + \sqrt{(a^2 + 1)}$$

Where;
A= variance and covariance variables

$$a = \frac{(Var\ B1 + Var\ B2)}{(2\ x\ Cor\ B1\ B2)}$$

Where: $Var$ is the variance value of the digital number, and $Cor$ is the coefficient of variation of the digital number.

## RESULTS AND DISCUSSION

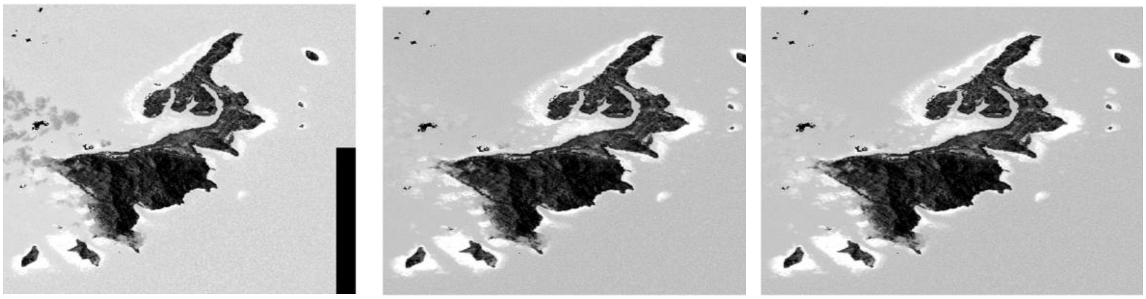
### Sunglint Correction

Sunglint correction is a crucial process in satellite image processing that enhances the accuracy of aquatic data interpretation. Sunglint effects occur because of the specular reflection of sunlight on the sea surface, especially when light hits waves at specific angles, causing optical distortion that reduces underwater feature visibility. This phenomenon can hinder the use of satellite image analysis in coastal environment mapping, including coral reef detection, sedimentation, and ocean current patterns (Hochberg, 2003).

To address this issue, various sunglint correction methods have been developed, including regression-based approaches and spectral transformation techniques. In the SPOT 6 imagery, correction was performed using spectral bands 1, 2, 3, and 4 (NIR), where the NIR band is often used as a reference because of its relatively low reflectance from water surfaces (Table 1 and Figure 2). The correction method based on spectral differences between bands allows for the reduction of the sunglint influence, resulting in imagery with a more homogeneous radiometric distribution and improved readability of subsurface features (Hedley et al. 2005).

Table 1. Sunglint correction result

| No | Band | Formula | R Value |
|---|---|---|---|
| 1 | B1 and B4 | b1-(0.992959*(b4-115)) | 0.986 |
| 2 | B2 and B4 | b2-(0.970749*(b4-115)) | 0.942 |
| 3 | B3 and B4 | b3-(0.934712*(b4-115)) | 0.874 |



(a) (b) (c)

Figure 2. Sunglint correction: (a) band pairs 1 and 4, (b) band pairs 2 and 4, and (c) band pairs 3 and 4.

The results of applying the sunglint correction showed significant improvements in image quality, both visually and quantitatively. Visually, the image after correction appeared smoother with reduced noise owing to ocean waves and excessive sunlight reflection, making coral reef features clearer and easier to identify (Fig. 2). Quantitatively, the correction values for each band pair showed a decrease in unwanted radiance values, which contributed to the improved classification accuracy of the living and dead coral reefs. Thus, sunglint correction not only improves the appearance of the image but also increases the reliability of the data used in spatial analysis and decision-making related to coral reef ecosystem management. This process is a crucial step in processing shallow-ocean satellite imagery, particularly in tropical regions such as Kemujan Island and Karimunjawa, which have complex water conditions and are susceptible to sunglint disturbances.

### Lyzenga Algorithm

The results of the classification of Spot 6 satellite images using the Lyzenga algorithm successfully distinguished live and dead coral reefs on the Kemujan and Karimunjawa Islands. This algorithm utilizes spectral differences in several image bands to identify the unique characteristics of live coral reefs, which usually have higher reflectance than dead coral reefs or other substrates, such as sand and mud (Lubis et al., 2020). From the classification results, the area of live coral reefs detected was approximately 46% of the total study area, while dead coral reefs accounted for approximately 54%

(Table. 2). The spatial distribution shows that live coral reefs are more concentrated in shallow-water areas with relatively good water quality, whereas dead coral reefs are spread over a wider area and tend to be in deeper waters or exposed to environmental pressures such as sedimentation and human activities.

Table 2. Area coverage of the coral reef class

| No | Class | Area coverage | Percentage % |
|---|---|---|---|
| 1 | Living Coral Reefs | 4,0488 | 46% |
| 2 | Dead Coral Reefs | 4,4096 | 54% |
| Total | | 8,4584 | |

The Lyzenga method is advantageous in the context of remote sensing for shallow marine ecosystem studies because it can correct for water column effects and enhance the contrast between different underwater objects, thereby producing more accurate and reliable classifications (Lubis et al., 2018; Manessa et al., 2016; Pratomo et al., 2024). This method is also relatively efficient in multispectral data processing and can address common challenges in marine satellite imagery, such as distortions caused by sunlight reflection and variations in water depth. Therefore, the Lyzenga algorithm is a suitable choice for mapping coral reef distribution in tropical regions, such as Kemujan and Karimunjawa Islands, where dynamic and heterogeneous aquatic conditions require a sensitive and precise analytical approach (Satya et al. 2023; Wardhani et al. 2025). The results of this classification serve as a critical foundation for further analysis of coral reef ecosystem conditions and support conservation efforts based on valid, updated spatial data.

The coral reef classification results validated in this study used a confusion matrix based on field data as the primary reference. This confusion matrix presents a comparison between the class of satellite image classification results and the actual conditions observed in the field, allowing for a comprehensive evaluation of the classification accuracy. The validation results showed a fairly high overall accuracy value was obtained, indicating that the classification method using the Lyzenga algorithm can distinguish between live and dead coral reefs with an adequate level of reliability (Table. 3). In addition to accuracy, other evaluation metrics, such as precision and recall, were calculated for each class, providing a more detailed picture of the model's ability to accurately identify positive and negative classes.

Table 3. Confusion matrix of coral reef in Karimunjawa and Kemujan island

| Classification Results | Living Coral Reefs | Dead Coral Reefs | Total | Producer accuracy (%) |
|---|---|---|---|---|
| Living Coral Reefs | 17 | | 21 | 85% |
| Dead Coral Reefs | | 20 | 20 | 100% |
| Total | 17 | 20 | 41 | 37 |
| Overall accuracy (85%) | | | | |

The interpretation of these accurate test results is critical in the context of the reliability of satellite imagery data for marine ecosystem studies, particularly coral reef management and conservation. High classification accuracy allows researchers and marine resource managers to use these data as a basis for informed decision-making. For example, areas identified as living coral reefs can be prioritized for conservation and monitoring efforts, whereas areas with dead coral reefs can be further analyzed to identify the causal factors for degradation. Thus, robust validation ensures that the resulting data are not only spatially representative (Figure 3) but also reliable for supporting sustainable management strategies in the Kemujan and Karimunjawa Islands.

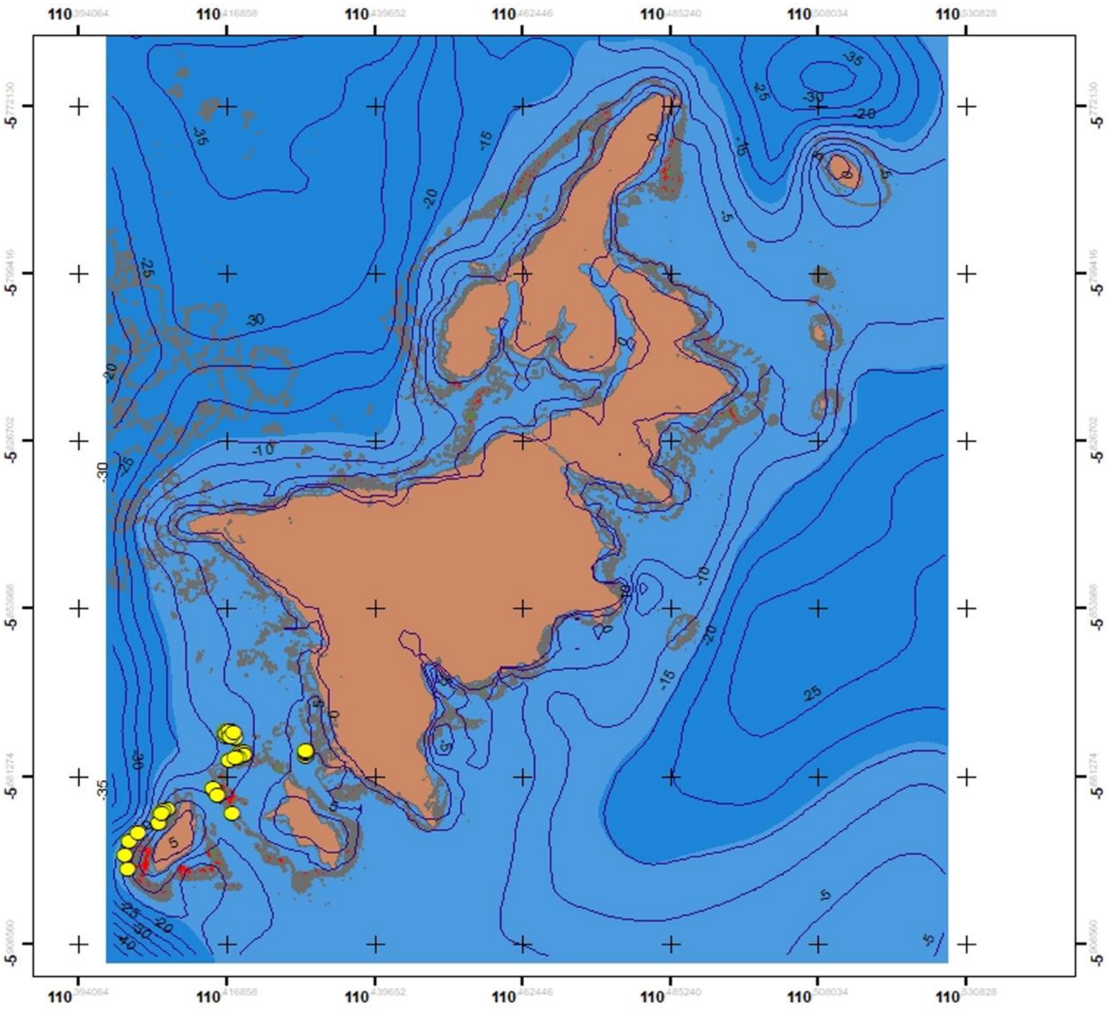


Figure 3. Coral reef distribution map with validation points (yellow dots), living coral reefs (grey), and dead coral reefs (red).

## CONCLUSION

This study shows that the Lyzenga algorithm method applied to SPOT 6 satellite imagery successfully detected and identified the distribution of coral reefs in the waters of Karimunjawa and Kemujan Islands in Indonesia. The total area of the identified coral reefs was 8.4584 km², where dead coral reefs dominated with an area of approximately 4.4096 km² (56%), whereas live coral reefs covered approximately 4.0488 km² (46%). These results provide a clear picture of the condition of the coral reef ecosystem in the region, which is very important for the conservation and management of marine resources. In addition, this study also emphasizes.

It is important to use high-resolution satellite imagery and sunlight correction to obtain accurate data, although there are constraints, such as cloud cover, that can affect the results of image processing. Thus, this study not only provides spatial details regarding the distribution of live and dead coral reefs but also serves as a basis for communities and policymakers to design strategies for preserving and managing coral reefs on Karimunjawa and Kemujan Islands. The success of using the Lyzenga algorithm in this study also opens up opportunities for the application of similar methods in other coastal areas with shallow water characteristics, so that they can support efforts to monitor and conserve marine ecosystems more widely and efficiently.

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