SATELLITE-BASED BENTHIC HABITAT MAPPING USING LANDSAT 8 IN NUSA LEMBONGAN AND NUSA CENINGAN ISLAND, BALI

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ABSTRACT : The Island of Nusa Lembongan and Nusa Ceningan are two of three islands in Nusa Penida waters, Bali Province, with 296 species of reefs biodiversity at depth less than 30 meters. LANDSAT 8, with 14 days of temporal resolution and spatial resolution of 30 m^2, has becoming an efective and sustainable alternative in satellite-based benthic habitat mapping activies in regional scale. Equipped with the 430-450 nm coastal blue band, the first four channels on LANDSAT 8 now can be used to identify objects in shallow water because of their penetration ability. This study will determine the most effective band combinations used to create RGB composites to calculate the zonation of benthic habitat. Satellite image is geometrically corrected based on the Indonesia Coastal Environment map scale 1:50,000 provided by Geospatial Information Agency (BIG). Atmospheric correction method and water coloumn correction performed using Fast Line-of-sight Atmospheric Analysis of Hypercubes (FLAASH) method and Lyzenga algoritm for reducing the atenuation effect. The combination used to create RGB composite with the best effectiveness is determined by comparing the results of the shallow water habitat map using a combination of clustered into three classes of coral reef, vegetation, and benthic substrate using the unsupervised ISODATA classification method. Analysis of the result conducted by qualitative approach based on the benthic coverage data provided by Marine Research Institute and Observatory (BPOL), as well as several existing web-based GIS of coral reef's databases. The band combination of 123 on LANDSAT 8 stated to be able to provide more effective area information of benthic habitat in the study area consists of 1,618,200 m^2 of coral reefs, 1,684,800 m^2 of vegetation such as seagrass or algae, and 776,600 m^2 of benthic substrate, with total area of 4,080,600 m^2 and ratio between habitat to benthic substrate is 2.1 : 2.2 : 1.

1. INTRODUCTION

Indonesia as a tropical archipelago with 5,800,000 km^2 area of waters and 13,466 islands, is a conducive region for the development of shallow water or benthic ecosystem. This characteristics are shown by the biodiversity of coral reef ecosystems where nearly one-third of the world's coral reef triangle is located in this region. In 2014, a step is being taken by the government in the act of Environmental Protection Plan by publishing Ecoregion map of Indonesia,where the coral reef throughout the coastal areas of Indonesia becoming one of the parameter needed in the making.

Landsat 8 is the newer multispectral satellite developed from Landsat TM and Landsat ETM +, which both have 60% to 64% accuracy rate of identification of benthic object in the clear waters to a depth of 25 meters (Mumby et al., 1998 and Nadaoka et al. 2004). As a newer model, LANDSAT 8 has different channel configurations such as an additional channel with a 0.43 to 0.45 µm wavelength, known as ultra blue, which is useful for cloud and coastal zone idntification. With a temporal resolution of 14 days and satellite imagery that can be downloaded free of charge, LANDSAT 8 has become one of the alternatives in continous regional mapping of shallow water habitats.

This study will generally serve two purposes as listed below:

1. Shallow water habitat mapping using combination of channel 123, 124, 134, and 234 on LANDSAT 8 satellite imagery
2. Determine the most effective combination of channels to perform shallow water habitat mapping using LANDSAT 8 satellite imagery.

2. AREA OF INTEREST AND DATA

Area of interest used in this research are the island of Nusa Lembongan and Nusa Ceningan. These islands are located between 8^o 38' 56.27" S to 8^o 45' 3.69" S and 115^o 24' 58.17 " E to 115^o 34' 52.38" E (Figure 1). This area has a tropical climate with an average annual rainfall of 924 mm and the water temperature ranged between 25^o - 28^o C. The waters around the two islands to Nusa Penida island locally known as Nusa Penida waters. Based on research conducted by Dr. Emre Turak of the Australian Institute of Marine Science (AIMS) in 2010, these waters are surrounded by fringing reefs (fringing reef) with diversity of 296 species of coral. The primary data used in this study were LANDSAT 8 satellite imagery recorded on the date of March 11, 2014 on path number 116 row number 66 with 15% of cloud cover. In addition to primary data, secondary data used is as follows:

1. Indonesia Coastal Environment Map published by Geospatial Information Agency with index number of index 1707-11 on scale 1: 50,000 as base map
2. Distribution data of seagrass and coral reefs of the Marine Research Institute and Observatory (BPOL) in 2010
3. Web-based Geographic Information System of the distribution of the seagrass (in 2005) and coral reefs (in 2010) published by Indonesian Coral Reef Foundation (TERANGI) and the United Nations Environment Programme's World Conservation Monitoring Centre (UNEP-WCMC).

Figure 1. Area of Interest (BIG, 2014)

3. IMAGE PRE-PROCESSING

Shallow water remote sensing complexity occurs because of the electromagnetic waves that emmited to the under water objects will be passing trough two different layers, the atmosphere and the water column (Figure 2). The illustration shows how the total radiance received by the sensor is not solely a solar energy reflected by objects in the form of spectral radiance, but also influenced by other factors. It also shows that the total radiation received by the sensor is the total radiation reflected from the layer of the atmosphere, water surface, and water column, as well as objects that are in seabed. The radiance also influenced by the acquisition angle to the sun, the presence of the atmosphere, as well as the water column with a certain depth which has an influence on the size of the benthic object captured by the sensor. In the above illustration is indicated by the Z variable. Having their own characteristic, the effect of each variable should be reducted before the process of identification and classification of objects benthic through various types of corrections.

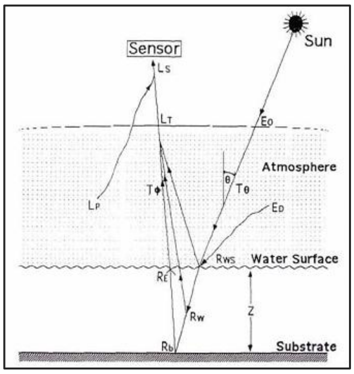


Figure 2. Total Radiation on Remote Sensing of Shallow Water (Bierwirth et al., 1992)

After subsetting the image in accordance with base map, the geometric correction is performed by determining 15 ground control points (GCP) to be matched at the points with position same on satellite imagery as common points using the first degree of the polynomial coordinate transformation. This method was chosen because the area of the research is considered as a relatively small area. The objects selected as GCP are mostly located the tip of the image boundaries, large rivers, and the edge of the island. In addition to the selection of 15 GCP points, 10 independent check points (ICP) are also determined spread on the edge of the island and a big river in the middle of the island. Objects used as ICP are different from the GCP point because it is used to test the quality of the coordinate transformation process by the value of Root Mean Square Error (RMSE). The result of geometric correction shown by RMSE value in this research are 0.471 and 0.387 pixels for GCP and ICP. In general, the quality of the geometric correction is acceptable if it has a RMSE value less than 0.5 pixel.

The reduction of atmospheric effects started by converting digital number to spectral radiance to return the pixel value from the calibrated value to the value of physical elements of a specific object on the satellite image. This conversion utilizes a linear relationship using spectral radiance scaling factor in the satellite image metadata using the equation that was released by the official website of LANDSAT 8. This study use the model approach atmospheric correction known as Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes (FLAASH). This method is able to simulate atmospheric conditions, aerosols, water vapor, and the direction of image capture in tropical atmosphere and maritime aerosol models using MODTRAN4 atmospheric model for reducing atmospheric effects through a physical approach accurately. The results of atmospheric correction is shown by comparing the corrected spectral radiance of, soil and plants to the commonly known spectral characteristics. The comparison of results of atmospheric correction are stated to have good results.

4. WATER COLOUMN CORRECTION

According to Nadaoka (2004), the water column above the reef surface will absorb energy with wavelengths more than 650 nm. Referring to the wavelength range of the electromagnetic spectrum based, this study will only use the 1^{st} to 4^{th} band in the LANDSAT 8. Same objects will be indicated by the same spectral radiance. In the water column, the energy of penetrated sunlight will be absorbed and scattered by the water molecul or particles, decreasing it's intensity by the increasing of the depth (Bierwirth et al., 2010). The effect known as attenuation. Therefore, we need a correction to the water column to the same object at different depths have the same spectral radiance value.

Lyzenga (1981) stated that the extraction of information from benthic object using LANDSAT MSS is based on linear relationship of the spectral radiance and the reflectance of objects on the bottom of the shallow waters, and experiencing the exponential attenuation. Water column correction using imagery approach would be done using Lyzenga algorithms that are widely used in the basic cover mapping shallow waters in some areas of the world and has been developed previously by Lyzenga (Lyzenga, 1978) :

$$\mathrm{Yij} = \ln(\mathrm{bi}) + \frac{\mathrm{Ki}}{\mathrm{Kj}}\ln(\mathrm{bj}) \tag{1}$$

$$\frac{\mathrm{Ki}}{\mathrm{Kj}} = \mathrm{a} + \sqrt{(\mathrm{a}^2 + 1)} \tag{2}$$

$$\mathrm{a} = \frac{\sigma^2{}_{\mathrm{bi}} - \sigma^2{}_{\mathrm{bj}}}{2\,\sigma_{(\mathrm{bi.bj})}} \tag{3}$$

where Yij is the result of information extraction channel bottom, Bi is Reflectance on channel i, Bj is Reflectance on channel j, $\frac{\mathrm{Ki}}{\mathrm{Kj}}$ is the attenuation coefficient between channel i and channel j, a is the variance covariance variable, σ^2 is the variance of the canal, and σ is the covariance between bands

To obtain the attenuation coefficient between the two bands, 10 sample pixels selected calculate variance value of each band and the covariance to the other bands. Sample points were selected based on three observation areas of coral reefs conducted by the BPOL (Figure 3) indicated by a red point. While the yellow point is 10 points reef samples according to the spectral characteristics shown by [Maedar et al., 2002] shown by Figure 4.

Figure 3. Coral Reefs Observation and Sampling Points

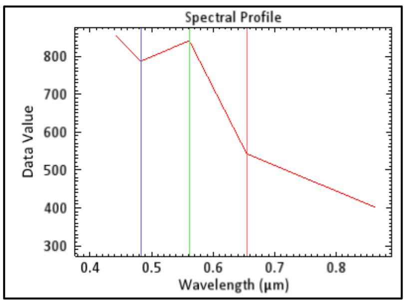


Figure 4. Example of Spectral Characteristic of Coral Reefs on the Sampling Point

In th... were use... ables. The selection of sample points is acceptable if the object between the two channels have good correlation and produces a linear relationship between the ln (band 1) against ln (band 2), indicated by the value of the correlation coefficient (r^2) is getting closer to 1. This is certainly due to the relationship which reflects the linear attenuation process, only obtained from the same object but different depths. The attenuation coefficient were calculated using the linear relationship between bands and the correlation values obtained (Table 1). Correlation between objects is considered for correlating each other if the r^2 indicates a value above 0.8. On several combination of bands, such as l-4 and 2-4, the value of r^2 is still acceptable due to the actual attenuation on each channel, which is not homogeneously exponential, especially on channel 4 with high radiance attenuation effect, although within the same object.

Table 1. Correlation and Atenuation Coefficient of Band Combination

Band Combination	**Correlation Coefficient (r^2)**	**Ki/Kj**
1 and 2	0,9786	0,8513602
1 and 3	0,8657	0,6770958
1 and 4	0,6789	0,9257200
2 and 3	0,9103	0,8115093
2 and 4	0,7165	1,1285978
3 and 4	0,854	1,3741030

The use Lyzenga algorithm will form a new band from the other relations between the two bands. The use of four bands in this study was able to produce six new bands in accordance with the relationship between the type of channel in Table 1 above. To be able to determine the ratio between the combination band on LANDSAT 8, 4 new composite images were made using combination of band 123 (12-13-23), 124 (12-14-24), 134 (13-14-34), and 234 (23-24-34).

5. BENTHIC HABITAT CLASSIFICATION

This study used one of the unsupervised classification method that is commonly used, known as Iterative Self-Organizing Data Analysis Technique (ISODATA). ISODATA algorithm begins by randomly selecting a class center and perform calculations repeatedly to separate objects into classes (clustering) to the expected parameters has been reached, or a change in the class of the pixels in the image in a very low percentage. This study use the minimum and maximum number of classes of 10 and 25, 71 times of iterations, value of 50 pixels as the minimum number of pixels in a class, a maximum of 1 standard deviation of digital number, and minimum distances between classes by 5 digital number.

Multispectral satellite has the ability to distinguish three types of objects waters of the coral reefs, vegetation (seagrass and algae), as well as the bottom substrate (Mumby, 1999, Arce, 2004, Mishra, 2006). The results of the initial classification of the entire channel combinations to produce 10 classes, where class 4 is thought to be the third part of the object based on the position relative to the coastal areas and depth of data held. Reduction into 3 classes is based on a visual analogy to the secondary data. The area of the classification that has been reduced can be calculated by number of pixels and are represented using thematic map of benthic habitat using band combination of 123, 134, 124, and 234. The classification result are listed on Table 2 below.

Table 2. Area of Benthic Habitat Classification Result

Variable	**Band Combination**			
	123	**124**	**134**	**234**
Coral Reefs (m^2)	1.618.200	1.662.300	1.277.900	1.115.100
Vegetation (m^2)	1.684.800	1.433.700	1.890.900	1.340.100
Substrate (m^2)	777.600	621.000	995.400	1.388.500
Total (m^2)	4.080.600	3.717.00	4.164.200	3.843.700
Habitat Ratio to Substrate	2,1 : 2,2 : 1	2.7 : 2.3 : 1	1,3 : 1,9 : 1	0.8: 0,96: 1

6. ANALYSIS

In determining the effective channel combinations in identification of shallow water habitat, qualitative analysis were performed related to image processing method, spectral characteristics of the object to the classification result, as well as qualitative analysis using secondary data. From the results of this classification, although the combination of base channel 134 is able to identify 83,600 m2 are of shallow waters wider than the 123 channel combinations, but in some parts of the island, the combination of channel 123 is able to identify coral reefs more significant compared with the composite image shown by the black circle in Figure 6.

In this study, it is unknown whether the habitat of hard corals and soft corals can be combined into a coral reef habitats. The same thing happens with the bottom substrate, both due to the limitations of the existing literature related to the spectral characteristics. The ratio comparison in Lembongan Point area shows that the ratio between reef habitat to the bottom substrate which were hard coral and sand, it will get a value of 34: 7. If the habitat coral reef habitat is assumed as combination of hard coral and soft coral with the bottom substrate assumed to be a combination of rocks and sand, the obtained ratio is 67: 33 or about 2: 1, however, it can be concluded that the two ratios are generally illustrates the dominance of coral reefs to the bottom substrate. Based on the classification results in this area, only composite of 124 and 123 has the closest to the data, with the dominance of coral reefs are quite high.

Horizontal transects conducted on the northern island of Nusa Lembongan to obtain the complex spectral profile of each image. The red color on the graph shows the combination of the second and third band, the green shows combination of the first and third, while blue shows combination of the first and second channel on each composite (Figure 5). Object indicated by the peak values, where the combination of channel 123 has a tighter pattern and dynamic, indicated by a significant slope and peak values, so that the dense spectral pattern of band combination of 123 is considered better in distinguishing benthic objects.

Other secondary data used are the coral reef and seagrassdatabase from a web-based geographic information system owned by TERANGI, UNEP-WCMC and ReefBase (Figure 10). This data is used to see the distribution of coral reefs and seagrasses in general, that the seagrass habitat concentrate in the north and east of the island of Nusa Lembongan, while the edge of the coral reef ecosystems in both the data around the entire coast of the island of Nusa Lembongan and Nusa Ceningan. In this database, ReefBase was using LANDSAT ETM+ image in 2010, while TERANGI is also using satellite imagery with unknown sensor. Both were made in the same year. In general, the classification results of the three composites in this study shows the composition of coral reefs and seagrass same on a small scale. On a larger scale, field validation is needed to ensure the quantitative accuracy of this research. From the seagrass habitat database in 5 locations belongs to BPOL, very high seagrass dominance were found in the second through fifth location while a density of 160 individuals / m2 where seagrass remains on the first location. From the results of image classification, only the combination of channel 123 was able to identify zones of seagrass habitat, although only a few pixels only as shown in Figure 6 with a red circle.

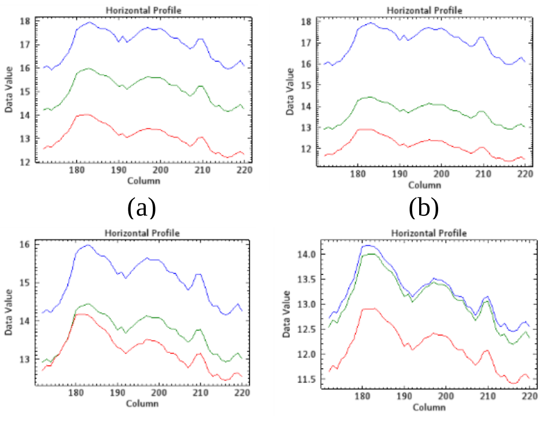


Figure 5. Spectral Profile of Horizontal Transect Using Band Combination of 234 (a), 134 (b), 124 (c), and 123 (d)

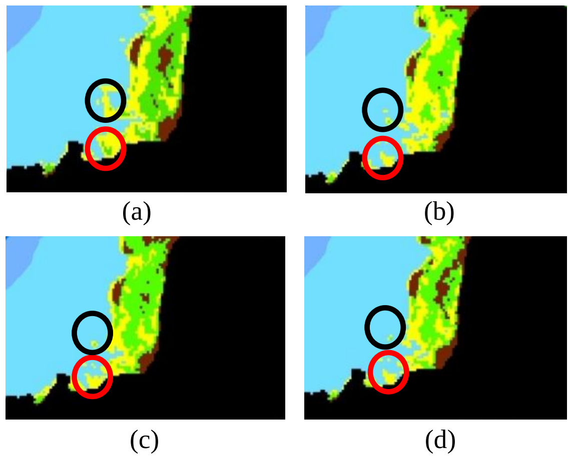
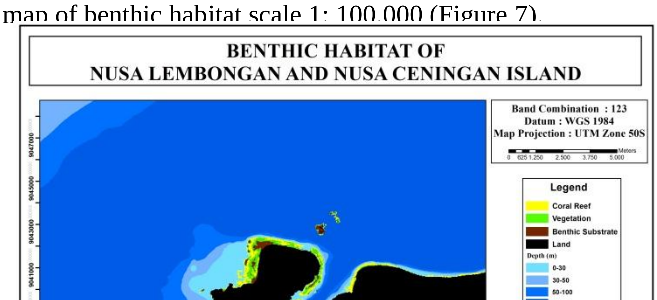


Figure 6. Comparison of Classification Result Using Band Combination of 123 (a), 124 (b), 134 (c), and 234 (d)

7. CONCLUSION

Based on the analyzes above, it was concluded that the combination of channel 123 is the most effective combination to perform satellite-based shallow water habitat mapping using LANDSAT 8 in this study area because of its ability to distinguish benthic objects according to the secondary data. From the classification result, the calculated area for shallow water is 4,080,600 m2 which consist of 1.618.200 m2 of reefs, 1.684.800 m2 of vegetation such as seagrasses and algae, as well as 776.600 m2 of bottom substrate of sand, stone, or dead coral reefs. The overall calculated ratio of objects to the substrate bottom habitat, is 2.1: 2.2: 1. The result of this study also presented by thematic map of benthic habitat scale 1: 100.000 (Figure 7).



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