

Spectral Discrimination of Coral Reefs on the Small Islands, Spermonde Archipelago, Indonesia

ABSTRACT

Ecologically, coral reef has a function to protect the others component of marine and coastal ecosystem from pressure of wave and storm. If compared with the other ecosystems, coral reef that are most easily destroyed. Spermonde archipelago consist of more than one hundred small islands, which have the higher potential ecosystem especially of coral reef distribution. It is very influencing and provide higher contributes to the preservation of society, where most livelihoods depend on its shallow water and has high growing human activity. Remote Sensing technologies is an alternative to support the availability of spatial information resources, such as coral reefs in the large area. However, before remote sensing can be viewed as a practical monitoring and diagnostic tool for entire coral communities, there is a need to understand the spectral responses from individual coral. The aim of this study is identifying the spectral reflectance of coral reefs using hyperspectral data, it is expected that they can be used as references in discriminating healthy coral. Spectral reflectance data was collected in Spermonde Archipelago, Indonesia by using a hyperspectral radiometer. Correlation and cluster analysis support that distinct differences in reflectance spectra among categories existed. The analysis result of hyperspectral data shown that live corals, dead corals covered with alga and coral rubble are spectrally separable from each other.

Keyword : Hyperspectral data, spectral reflectance, coral reefs

1. INTRODUCTION

To conserve coral reefs, it is necessary to monitor them. Therefore, spectra of coral reefs is very important information for dynamic coral reefs. Several researchers have attempted to exploit hyperspectral data (from airborne and close range) to study coral groups (e.g., Mumby et al., 1998; Hochberg and Atkinson, 2000; Mishra et al., 2004, 2007; Clark et al., 1997, 2000; Myers et al., 1999; Schalles et al., 2000; Lubin et al., 2001; Joyce and Phinn, 2003; Kutser et al., 2003; and Mishra et al., 2006. Hochberg et al. (2003) provided a comprehensive literature review on *in situ* remote sensing research pertaining to coral reef ecosystem. They classified types of coral communities —healthy coral, dead coral, algae, coral debris and sand but only one of research have attempted in Indonesia by Holden and LeDrew in 1998, 2000 and 2001 to characterize coral groups using field radiometers at close range. Recent studies Hochberg et al. (2006) and; Kutser and Jupp (2006), Stambler and Shashar (2007) and Rundquist et al. (2009) have focused on coral species recognition, and the extent of variability in the reflectance spectra of corals of specific species. Fundamental research regarding the spectral differences between common coral reef features is necessary. Therefore, it is important to determine the spectral characteristics of living coral, dead coral and coral rubble covered with algae.

In this study, we were interested in examining the naturally occurring variations in reflection spectra within a coral rubble, healthy and dead corals covered with algae of a given locality. The objectives of our work were to: (1) document the spectral features of coral rubble, healthy coral and dead corals covered with algae distributed within four study site in the Spermonde archipelago; and (2) develop spectral library to determine whether living and dead corals covered with algae and coral rubble covered with algae are spectrally discriminable and how to achieve discrimination. Whereas, this research is expected as baseline information on optical characters of living and dead coral covered with algae and coral rubble covered with algae that can be used as a basic knowledge in interpretation satellite images. So that they facilitate in identifying existence and differentiating some healthy coral and dead coral covered algae, especially using hyperspectral.

2. MATERIALS AND METHODS

2.1 Spectra collection

Field data collection was carried out in Samatellu Lompo, Samatellu Pedda, Samatellu Borong Island and Gusung in Spermonde archipelago, Indonesia (9479612,68 N, 757922,94 E and 9478861,44 N, 762635,26 E; Figure 1. Spectra were collected on January and February 2010 under generally clear skies. The data collection occurred between 9:00 a.m. and 15.00 p.m. Central Standard Time, using a LOT-2 Spectra Corpspectroradiometer. The samples comprised living and dead coral covered with alga and coral rubble covered with algae. Spot measurement of individual substrate types were made from about 7 cm above the substrate, resulting in a field of view of about 1.5 cm. Each measurement took about half a minute, capturing over one hundred spectra (depending on the integration time)

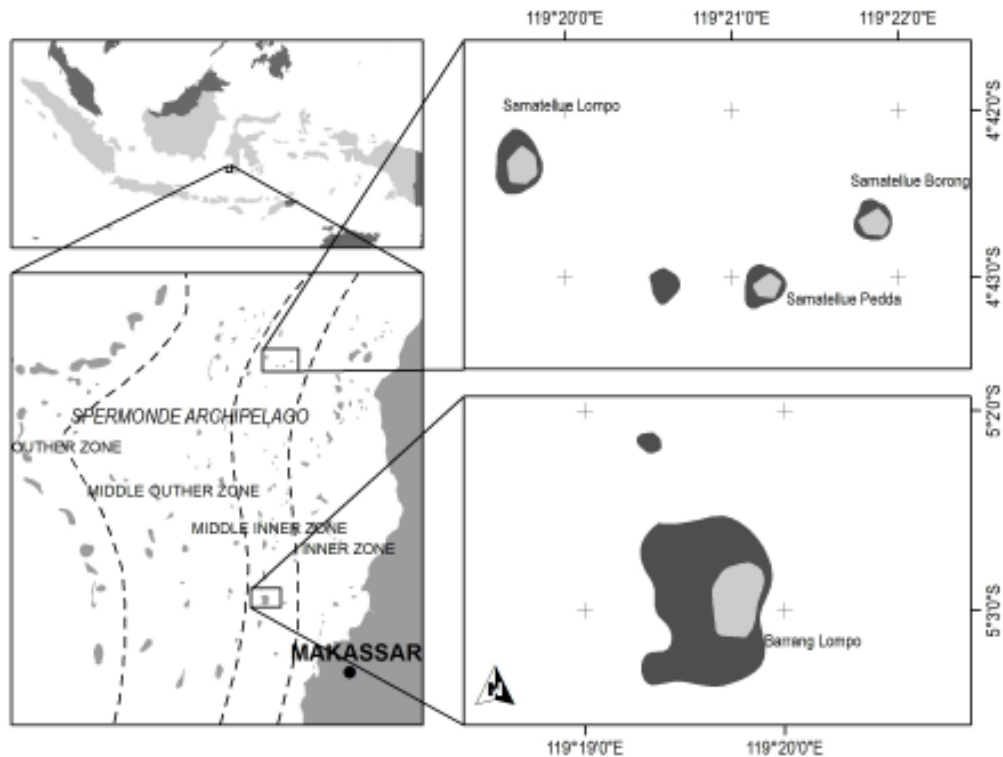


Fig1. Study are are Samatellu Lompo, Samatellu Borong, and Samatellu Pedda island in Spermonde Archipelago, South Sulawesi, Indonesia.

We studied the optical properties of the *in situ* measured living and dead coral covered with algae and decided to divide the substrates into the following classes: live corals (*Acropora formosa*, *Seriatopora stellata*, *Acropora macrostoma*, *Acropora sarmentosa*, *Porites columnaris*, *Porites mayeri*), dead corals covered with algae (dead *Porites* and dead *Acropora*), coral rubble (<3 months and >3 months). In the present study the coral rubble were divided into recently (less than 3 month) and long time (considerably greater than 3 months) coral rubble. Dead coral was greater than 3 months. Recently coral rubble began covered with turf algae and coralline white is visible clearly. Long time coral rubble are mainly covered with turf algae that growing rapidly and significantly darker than recently coral rubble and therefore more easily separable.

A total of 90 representative samples of living coral and 26 of dead coral covered with algae and 106 of coral rubble were selected randomly. The reflectance spectra were taken over each sample between 1 and 3 m in depth, and each spectrum was the result of averaging of individual scans compiled over approximately 30 seconds total. The spectral range of the instrument is 300 - 1100 nm. Spectra are sampled with 3 nm intervals. The total number of substrates for which reflectance spectra were collected was 222.

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90 2.2 Data Analysis

91 Correlation analysis and cluster analysis were applied to data analysis. Cluster analysis was used to
92 determine spectral similarity in and among coral species based on spectral responses at observed
93 wavelengths. Similarity scale used was euclidean distance. Distance scale determined spectral
94 similarity and dissimilarity in which object with shorter distance would be more similar each other
95 compared to object with longer distance.

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97 3. RESULTS AND DISCUSSION

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99 3.1 Spectral Analysis

100 Our efforts focused primarily on measurements of living corals, dead corals covered with algae, and
101 coral rubble. Reflectance spectra (Avg± Std, range 0-1) from 10 categories are shown in Fig.2. The
102 coral rubble were divided into recently (less than 3 month) and long time (considerably greater than 3
103 month) coral rubble. Recently coral rubble began covered with turf algae and coralline white is visible
104 clearly. Long time coral rubble is mainly covered with turf algae that growing rapidly and significantly
105 darker than recently coral rubble and therefore more easily separable. The live corals, dead coral and
106 coral rubble had a similar reflectance. This indicated that living corals couldn't be easily separated
107 from dead corals and coral rubble.

108 Dead *Porites* appeared similar in spectral magnitude and shape to dead *Acropora* (Fig.3B). They
109 have a peak reflectance at 605nm and reflectance minima at 674nm. Coral rubble display measured
110 spectra with reflectance minima at 674nm. All of the measured parts of the live corals showed
111 distinctive spectral features (Fig. 3C), such as a peak reflectance at 579nm, and drop at 674nm, and
112 a steep rise around 700nm. Furthermore, with few exception, *Seriatopora stellata* and recently coral
113 rubble spectra displayed highest reflectance (9%). The average maximum reflectance values were
114 between 4% and 9% for all categories. There were certain spectral features common to most living
115 corals, dead coral covered with algae and rubble covered with algae. Curva of mean apparent
116 reflectance spectra showed that there are more spectral variations in the shape of the curves of living
117 coral measurements than dead coral covered with algae measurements (Fig.3A,B), but there do not
118 appear to be any significant differences in spectral reflectance within dead coral covered with algae
119 category (Fig.3D). Reflectance was generally lower in the shorter wavelength region (400-500nm)
120 and in most cases there were not distinctive features between substrates in this region.

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123 3.2 Correlation analysis

124 To examine the similarities between the categories, Pearson correlation coefficients were calculated
125 as summarized in Table 1. The Pearson correlation coefficient considers the profile, or spectral, shape
126 (Wilkinson et al., 1996), so the coefficients represent the similarities of the entire spectrum as a whole.
127 The average spectra for each 10 categories that comprise living and dead coral covered with algae
128 and coral rubble were included in the correlation analysis. When the entire average spectrum is
129 considered, the correlations between categories are high suggesting a high degree of similarity
130 overall.

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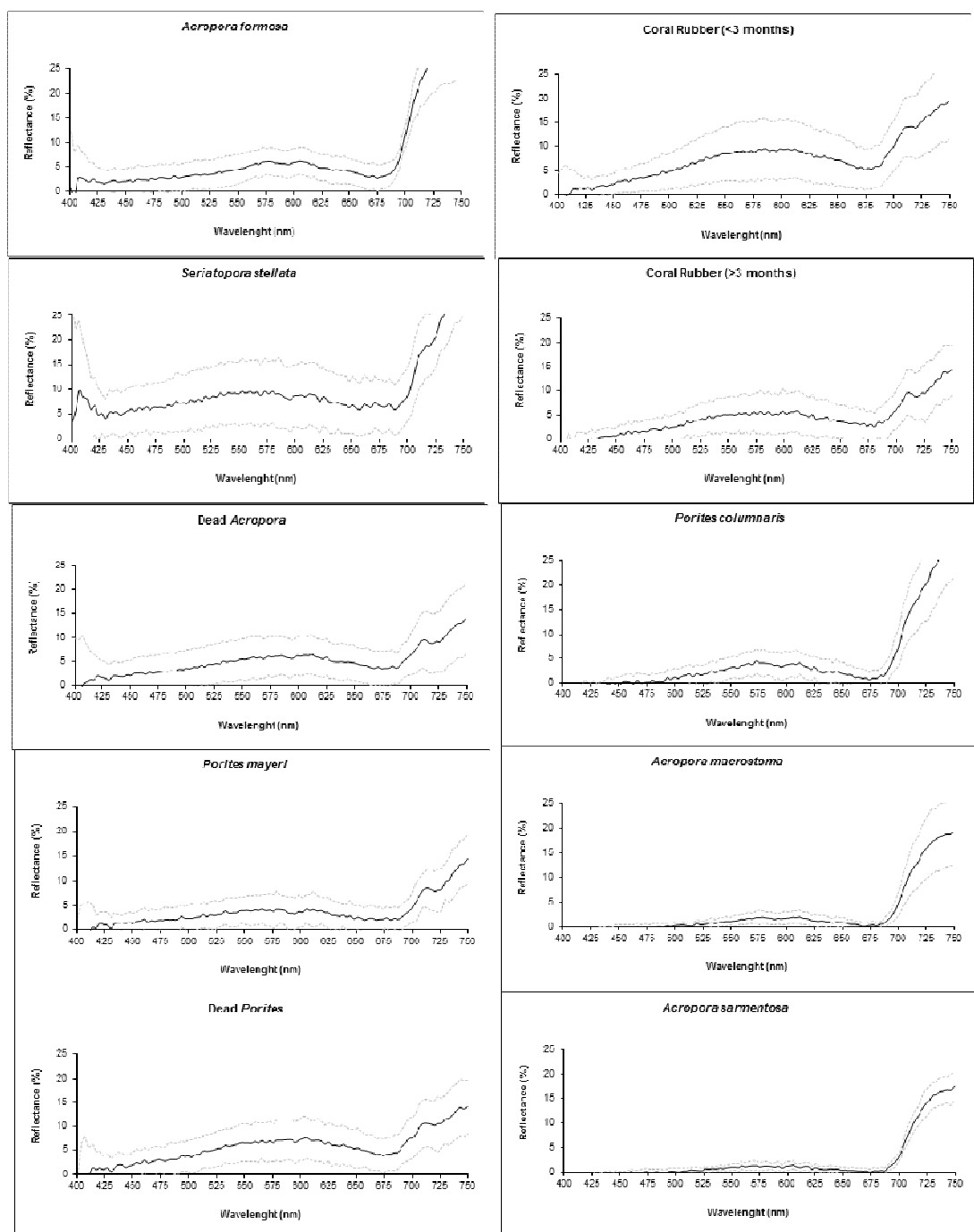


Fig.2 Reflectance spectra (Avg \pm Std, range 0-1) of live corals (*Acropora formosa*, *Seriatopora stellata*, *Acropora macrostoma*, *Acropora sarmentosa*, *Porites columnaris*, and *Porites mayeri*), Dead coral covered with algae (Dead *Porites* and Dead *Acropora*), and coral rubble (<3 months and >3 months)

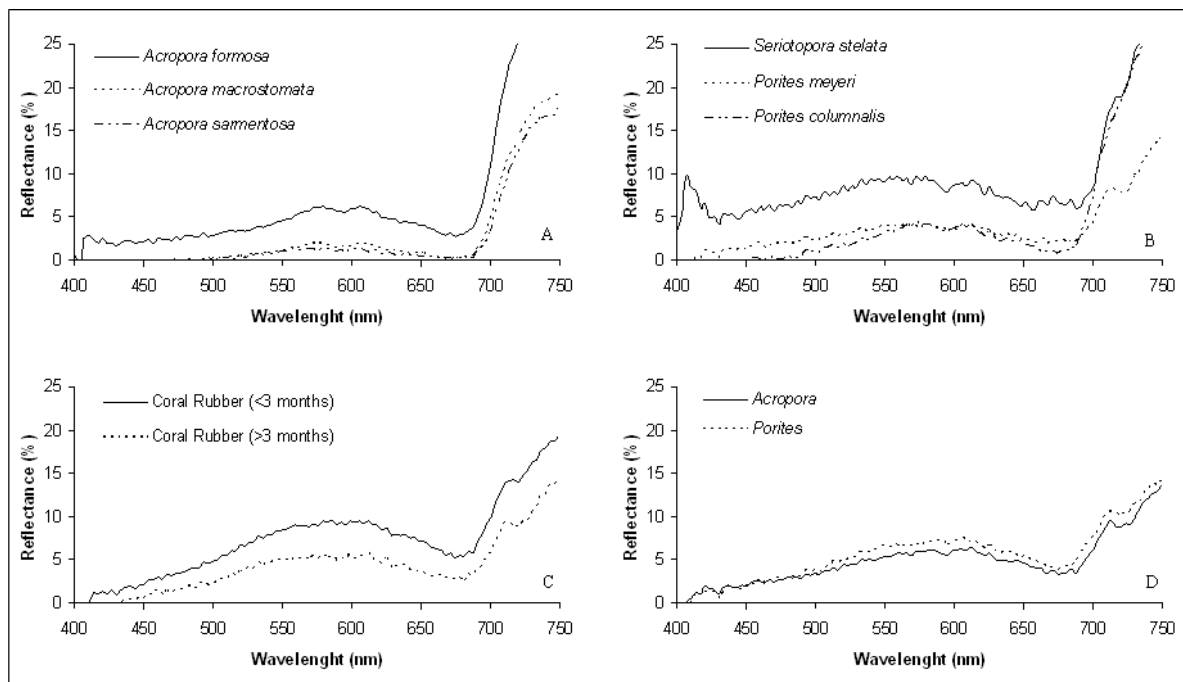


Fig. 3 Mean apparent reflectance spectra (%) of live coral acropora (A), live coral non acropora (B), rubble covered with algae (C), dead coral covered with algae (D). Dead coral covered with algae are represented by a reflectance spectrum of *Porites* and *Acropora*, live corals by *Acropora formosa*, *Seriatopora stellata*, *Acropora macrostoma*, *Acropora sarmentosa*, *Porites columnaris*, and *Porites mayeri*

Table 1. Correlation coefisien for 10 categories of live corals, dead corals covered with algae, coral rubble covered with algae

	<i>Acropora formosa</i>	<i>Acropora macrostoma</i>	<i>Acropora sarmentosa</i>	<i>Seriatopora stellata</i>	<i>Porites mayeri</i>	<i>Porites columnalis</i>	Coral Rubble (<3 months)	Coral Rubble (>3 months)	Dead <i>Acropora</i>	Dead <i>Porites</i>
<i>Acropora formosa</i>	1									
<i>Acropora macrostoma</i>	0.97	1								
<i>Acropora sarmentosa</i>	0.97	0.99	1							
<i>Seriatopora stellata</i>	0.96	0.93	0.94	1						
<i>Porites mayeri</i>	0.89	0.96	0.95	0.90	1					
<i>Porites columnalis</i>	0.96	0.99	0.99	0.95	0.98	1				
Coral Rubble (<3 months)	0.86	0.91	0.89	0.84	0.95	0.93	1			
Coral Rubble (>3 months)	0.77	0.88	0.86	0.76	0.96	0.90	0.96	1		
Dead <i>Acropora</i>	0.85	0.92	0.90	0.85	0.98	0.94	0.99	0.98	1	
Dead <i>Porites</i>	0.81	0.89	0.87	0.80	0.95	0.91	0.99	0.98	0.99	1

3.3 Spectral clustering

Cluster analysis is the generic name for a multivariate procedure of clumping similar objects into categories enabling identification of (1) outliers, and (2) the basic structure of the dataset. No satisfactory general method has been developed for deciding how many clusters exist in data set of unknown structure (Wilkinson et al., 1996). Therefore, the number of cluster is a subjective decision based on knowledge of the dataset characteristics. The objective of cluster analysis is to determine which objects are similar and dissimilar and categorize them accordingly (Holden and LeDrew., 1998).

Results of visualization at curve of reflectance curve were tested with cluster analysis applied to all of those coral species. In cluster analysis, it was found groups based on the spectral responses of each sample to eight wavelength groups and based on scale of similarity distance among these samples in which an object with shorter distance among samples would be more similar one to others compared to the objects having longer distance. Display of group division at overall wavelengths was presented in dendrogram graph as shown at Figure 4.

Based on Figure 3, there are many clusters as spectra, while on the right there is only one cluster. Therefore, moving from left to right denotes an encreasing degree of difference between spectra where a small Euclidean distance suggests that the spectra are most similar. Based on the reflectance values and formation of spectral curve pattern at the six live corals, two dead coral covered with algae, and 2 coral rubble, it can be observed that there is a similar spectral among categories.

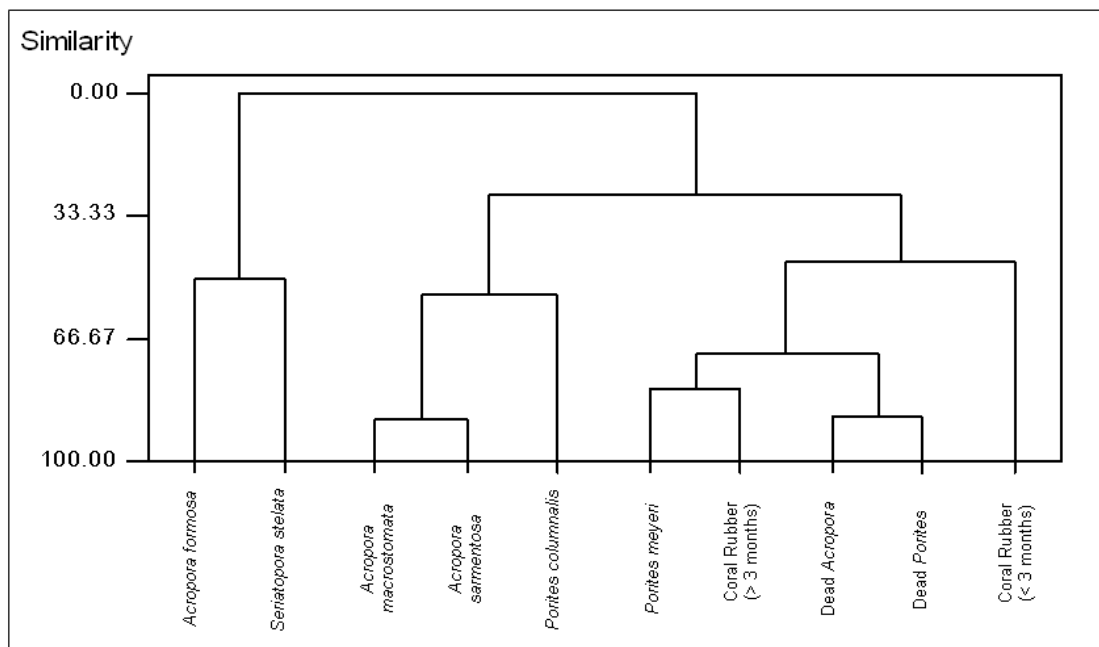


Fig.4. Dendrogram Graph of ten categories divided into six live corals (*Acropora formosa*, *Acropora macrostoma*, *Acropora sarmentosa*, *Seriatopora stellata*, *Porites meyeri*, and *Porites columnaris*), two dead coral covered with algae (Dead *Acropora*, and Dead *Porites*) and two coral rubble (<3 months, and >3 months)

There were six main groups at similarity distance of 70,87% i.e. *Acropora macrostoma* and *Acropora sarmentosa* having spectral similarity, categorized in one group. *Porites meyeri* having spectral similarity with old coral rubble, dead *Acropora* and dead *Porites*, categorized in one group. However, *Acropora formosa*, *Seriatopora stellata*, *Porites columnaris*, recently coral rubble have formed groups with himself. They have not shown a spectra similarity with another categories.

At similarity distance of 87,81%, it was show eight groups i.e. *Acroporamacrostomata* and *Acroporasarmentosa* categorized in one group. Dead *Acropora* and dead *Porites* having spectral similarity categorized in one group. *Acroporaformosa*, *Seriatopora* *stellata*, *Poritescolumnaris*, *Poritesmayeri* recently coral rubble, and old coral rubble have not shown a spectra similarity with another categories. They have formed groups with himself.

3.4 Discussion

The Pearson correlation analysis revealed that when the entire spectral curve is considered, there is a strong correlation between and within the living corals, dead coral covered with algae and coral rubble covered with algae. Coral rubble is covered with epiphytic algae after bleaching by blast fishing activities. As time goes on, epiphytic algae become thicker. Reflectance of coral rubble is changed with period after bleaching. Epiphytic algae become visible size by three months after bleaching. By virtue of change in algae cover over time, it was possible to discriminate between coral rubble bleached less than 3 months, and more than 3 months.

Therefore coral rubble showed the similar shape but have a different of spectral magnitude and peak position between two groups of coral rubble. These differences could be used as precise indicators and predictors for identifying coral rubble conditions reflecting the chlorophyll concentration. It contributed significantly to the increase in value of reflectance. All photosynthetic organisms (living corals, dead corals covered with algae, and coral rubble covered with algae) displayed a reflectance minimum at approximately 674nm, a feature related to the presence of chlorophyll.

In generally, living corals, dead corals covered with algae and coral rubble spectra display a reflectance minimum at 674nm. Additionally, all of the live coral and coral rubble spectra have a peak in reflectance at 579nm. However, dead coral have a peak reflectance at 605nm. The object will tend to reflect the same colour as its colour and to absorb the other colours so that the intended object will have higher reflectance values at similar wavelength colour to the original colour. Similarly perceived colors may be the outcome of different spectra. Therefore, it is beneficial, if often difficult, to examine spectra rather than colors when attempting to classify corals (Clark et al., 1997; Holasek et al., 1998; Holden and LeDrew, 1999; Hochberg and Atkinson, 2000; Hochberg et al., 2003; Mazel et al. 2003; Mazel and Fuchs, 2003).

Reflectance spectra of their study are similar in shape and magnitude to those of the our study. The highest reflectance value of live corals was achieved at wavelengths of 579nm. Dead coral was achieved a highest reflectance at 605nm. This is in agreement with a study by Kutser *et al* (2003) that hard coral had high mean reflectance value at wavelength 550-700nm. Similar trend was found by Nurdin and Rani (2008) which take measurement in the laboratory that reflectance peak for hard corals was at wavelength 550-620nm. Low value at blue and green wavelengths are largely the result of absorption by photosynthetic and photoprotective (Salih et al., 2000). Similarly, higher values at red wavelength indicate lack of absorption or presence of active fluorescence (Mazel, 1995).

Chlorophyll in the zooxanthellae is an efficient absorber of light at the wavelength transmitted by seawater, but its fluorescence emission at 685nm and longer wavelengths is strongly absorbed by seawater (Mazel and Fuchs, 2003). Our results are in general agreement with other studies, which measured light signals returned from corals. High spectral resolution measurements provide opportunities for more refined assessments, primary because of pigment specific absorbance bands and the great impact of pigments on intercepting light in the coral (Holden and LeDrew 1998).

The results of cluster analysis are encouraging with respect to the separability of live corals, dead coral covered with algae and coral rubble reflectance. Similarity level among groups formed was high or on the other word spectral reflectance variability among ten categories was low. *Porites meyeri* was in the same group with dead coral covered with algae and old coral rubble had a similar reflectance. This indicated that *Porites meyeri* couldn't be easily separated from dead corals and old coral rubble. All photosynthetic organisms (living and dead corals covered with algae, coral rubble covered with algae) displayed a reflectance minimum at approximately 595 nm and 674nm, a feature related to the presence of chlorophyll. The living coral and coral rubble reflectance spectra showed the most variation in shape and magnitude in comparison with the other groups. Within dead coral had the least variation in spectral shape. The results of study by Holden and LeDrew (1998) showing that the healthy cluster include two bleached spectra and two macroalgae spectra. Thus, there is a certain degree confusion between healthy coral, bleached coral and algae. Since the macro algae contain

photosynthetic pigments, the confusion with healthy coral containing zooxanthellae is understandable. The overall results of this cluster analysis suggest good separability based on measured reflectance.

Similarity level among groups of live corals, dead coral covered with algae and coral rubble showed high similarity level or low variability of signal reflectance. Reflectance of coral is readily distinguishable from that of other reef bottom types (Hochberg et al. 2003). This indicates significant spectral differences between corals and other bottom types that are independent of coral grouping (e.g., taxa), which further implies that variability in reflectance of coral must not be random (Hochberg et al. 2004). In this respect, corals share a high degree of similarity in reflectance. At the same time, it is possible that live corals and dead coral covered with algae groups themselves are distinguishable from each other. Discrimination between corals and other types may rely on spectral features that are independent of those features that might discriminate between coral groups (Hochberg et al. 2004). This was caused by difference in composition structure of coral corallite and corallite size (big or small). We have documented that a differences in the magnitude and shapes of spectral curves from different categories and a strong absorption of them at 674nm region (Fig. 3). However, the interpretation of the peaks and shoulders of our spectra as areas of lower pigment activity and absorbance is probably fluorescence features associated with the coral polyp host tissue (Mazel, 1995).

Our results described 9-38 spectral pattern within one category. For example, *Porites meyeri* (non acropora) has 30 spectral pattern and *dead Porites* has 12 spectral pattern. At these categories demonstrated that within and between live coral, dead coral and old coral rubble can present such a range of colors, making spectral discrimination between them difficult. According to a research by Karpouzli and Malthus (2003), spectral reflectance among coral species showed high variability. This was caused by difference in pigment content of each substrates. Different pigments would reflect and absorb light at different wavelengths, so that affecting their reflectance values. Longer wavelength than 600nm will be absorbed by chlorophyll-a, whereas the shorter wavelengths will be absorbed by accessory pigments (Hochberg and Atkinson, 2004). Thus it is not surprising that reflectance of living and dead corals and coral rubble also shows variability at these study.

Basically, every material has different structure or particle composition and this difference influences its electromagnetic response pattern. Trace amounts of macroalgae were visible on the surface of dead coral. The stage of dead coral is temporary and the affected corals will either recover to their normal pigmentation and be colonized by macroalgae (Holden and LeDrew, 2001). However, dead corals and coral rubble are rapidly colonised by algae whose pigmentation may be similar to that of the coral's zooxanthellae, making the distinction between live corals, dead corals and coral rubble more complicated. We developed spectral library to determine whether live coral, dead coral covered with algae and coral rubble covered with algae are spectrally discriminable and how to achieve discrimination. However, it was difficult to find a completely dead coral without colonization by algae. More investigation is required to statistically determine the degrees to which various categories groupings are spectrally discriminable. We have shown that basic live corals, dead corals and coral rubble have characteristic reflectance, that within them, and that they are spectrally separable from each other.

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