Original Research Article

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

ABSTRACT

Coral reefs play important ecological services such as providing foods, biodiversity, nutrient recycling etc. for human society. On the other hand, they are threatened by human impacts such as illegal fishing and environmental changes such as a rise of sea water temperature and sea level due to global warming. Thus it is very important to monitor dynamic spatial distributions of coral reefs and related habitats such as coral rubber, dead coral, bleached corals, seagrass, etc. Hyperspectral data, in particular, offer high potential for characterizing and mapping coral reefs because of their capability to identify individual reef components based on their detailed spectral response. We studied the optical properties by measuring *in situ* spectra of living corals, dead coral and coral rubber covered with algae. The study site was selectedin Spermonde archipelago, South Sulawesi,Indonesia becausethis area is included in the highest diversity of corals in the world named as Coral Triangle, which is recognized as the global centre of marine biodiversity and a global priority for conservation. Spectra were collected under generally clear skies, 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 rubber covered with algae.A total of 90representative samples of living coral and 26 of dead coral covered with algae and 106 of coral rubber were selected randomly. Correlation analysis and Cluster analysis support that distinct differences in reflectance spectra amongcategories existed. Common spectral characteristic of living corals, dead corals and coral rubber covered with algae was a reflectance minimum at 674 nm.Healthy corals, dead coral covered with algae and coral rubber covered with algae showed high similarity of spectral reflectance. It is estimated that this is due to photsynthetic pigments.

Keyword : Hyperspectral data,spectral reflectance, coral rubber, livingcorals, dead corals

1. INTRODUCTION

Coral reefs are very important ecosystem in tropical waters. 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, 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. Recents 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 differencesbetween common coral reef features is necessary. Therefore, it is important to determine the spectral characteristics of living coral, dead coral and coral rubber covered with algae.

In this study, we were interested in examining the naturally occurring variations in reflection spectra within a coral rubber, 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 rubber, healthy coral and dead corals covered with algaeas distributed within four study site in theSpermonde archipelago; and (2) develop spectral library to determine whether living and dead corals covered with algae and coral rubber 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 rubber covered with algae that can be used as a basic knowledge ininterpretating satellite images so that they facilitate in identifying existence and differentiating some healthy coral and dead coral covered algae, especially usinghyperspectral.

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 Januaryand Pebruary 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 rubber 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)

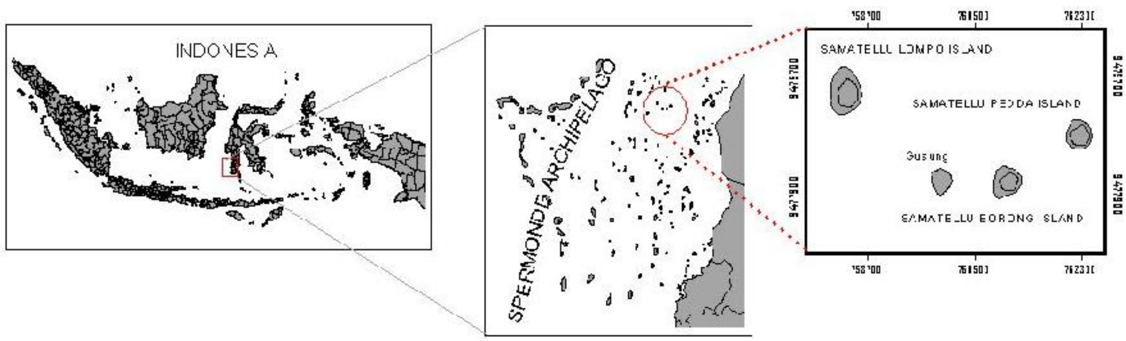

Fig1. Location of the Samatellu Lompo, Samatellu Borong, and Samatellu Pedda island study sites in Spermonde Archipelago, South Sulawesi, Indonesia.

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

A total of 90representative samples of living coral and 26 of dead coral covered with algae and 106 of coral rubber 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 individualscans 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.

2.2 Data Analysis

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

3. RESULTS AND DISCUSSION

3.1 Spectral Analysis

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

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

3.2 Correlation analysis

To examine the similarities between the categories, Paerson correlation coefficients were calculated as summerized in Table 1. The Pearson correlation coefisient considers the profile, or spectral, shape (Wilkinson et al., 1996), so the coefficients represent the similarities of the entire spectrum as a whole. The average spectrafor each 10 categories that comprise living and dead coral covered with algae and coral rubber were included in the correlation analysis. When the entire average spectrum is considered, the correlations between categories are high suggesting a high degree of similarity overall.

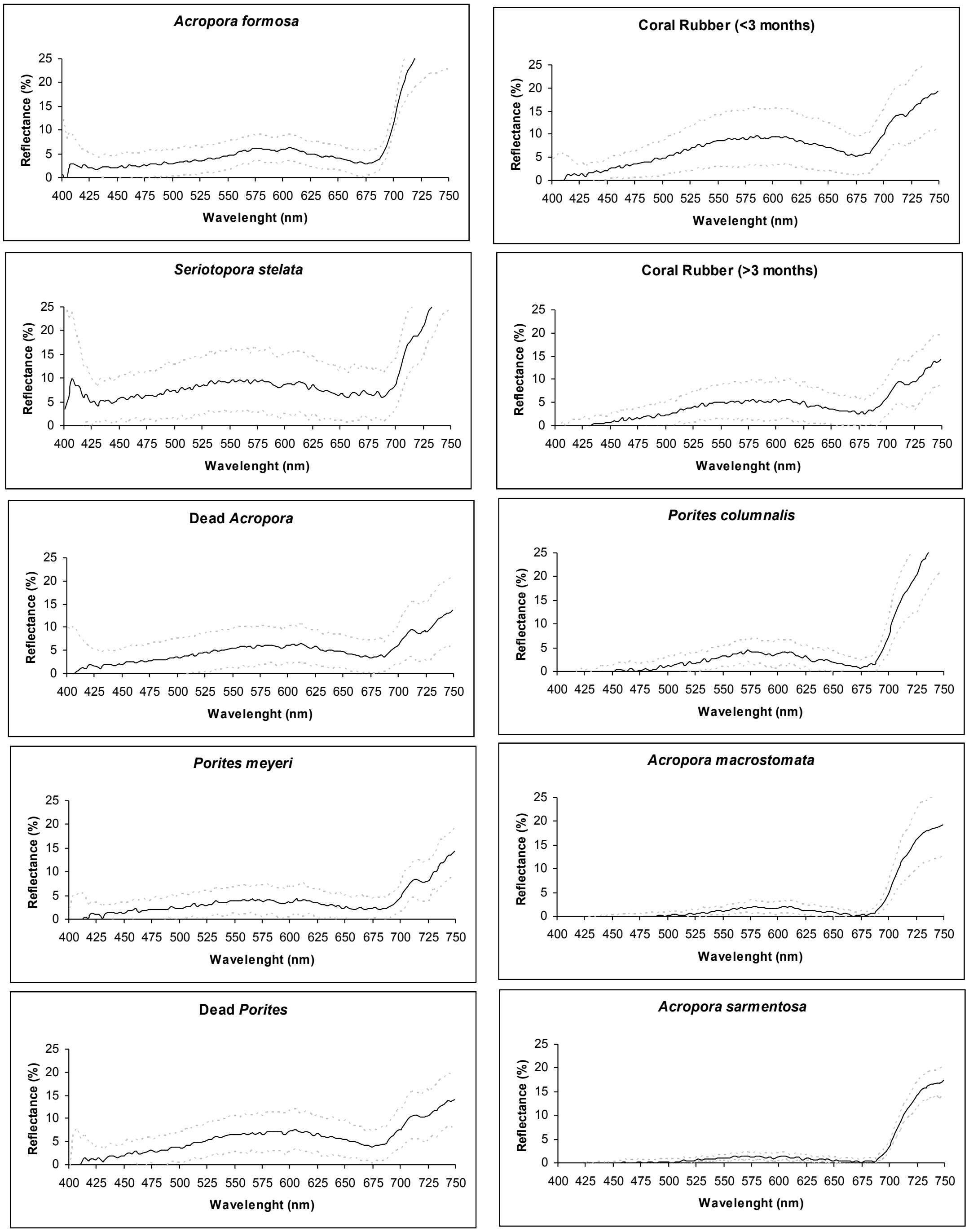

Fig.2 Reflectance spectra (Avg± Std, range 0-1) from 10categories

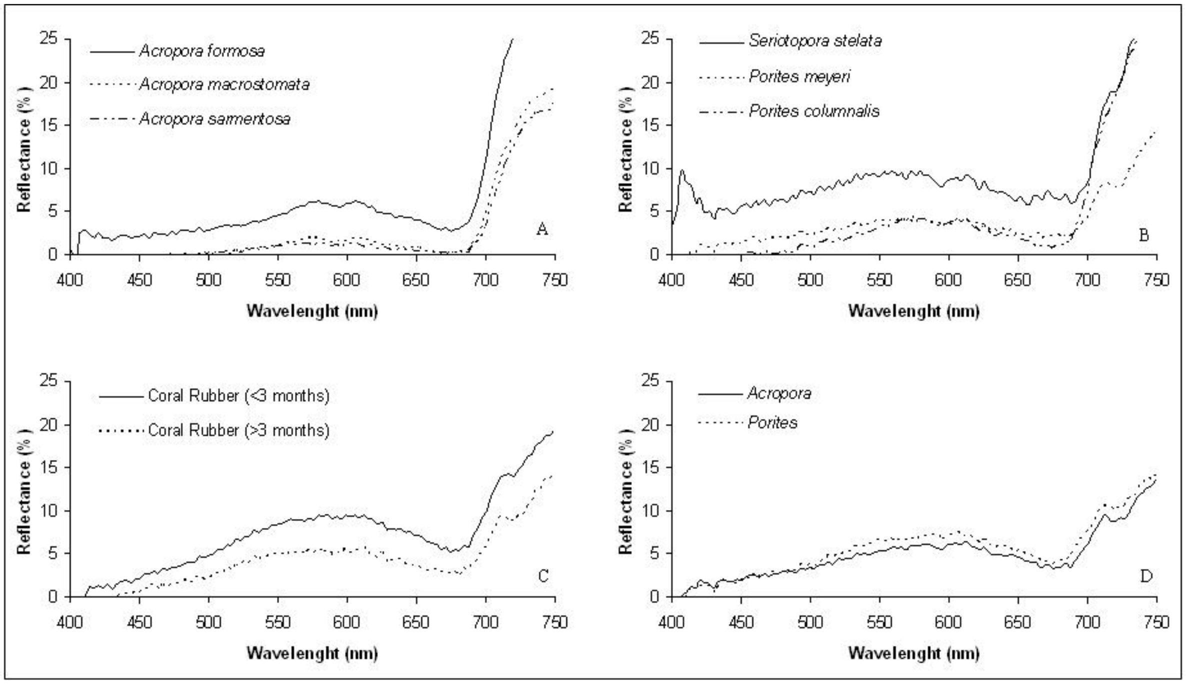

Fig. 3 Mean apparent reflectance spectra (%) of live coral acropora (A), live coral non acropora (B), rubber covered with algae (C), dead coral covered with algae (D).Dead coral covered with algae are represented by a reflectance spectrum of *Porites* and *Acropora*, live corals by *Acroporaformosa, Seriotoporastelata, Acroporamacrostomata, Acroporasarmentosa, Poritescolumnaris,* and*Poritesmeyeri* spectrum

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

	Acroporaformosa	*Acroporamacrostomata*	*Acroporasarmentosa*	*Seriotoporastelata*	*Poritesmeyeri*	*Poritescolumnalis*	Coral Rubber (<3 months)	Coral Rubber (>3 months)	Dead *Acropora*	Dead *Porites*
Acroporaformosa	1									
Acroporamacrostomata	*0.97*	1								
Acroporasarmentosa	0.97	0.99	1							
Seriotoporastelata	0.96	0.93	0.94	1						
Poritesmeyeri	0.89	0.96	0.95	0.90	1					
Poritescolumnalis	0.96	0.99	0.99	0.95	0.98	1				
Coral Rubber (<3 months)	0.86	0.91	0.89	0.84	0.95	0.93	1			
Coral Rubber (>3 months)	0.77	0.88	0.86	0.76	0.96	0.90	0.96	1		
Dead *Acropora*	0.85	0.92	0.90	0.85	0.98	0.94	0.99	0.98	1	
Dead *Porites*	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 caregories 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 rubber, it can be observed that there is a similar spectral among categories.

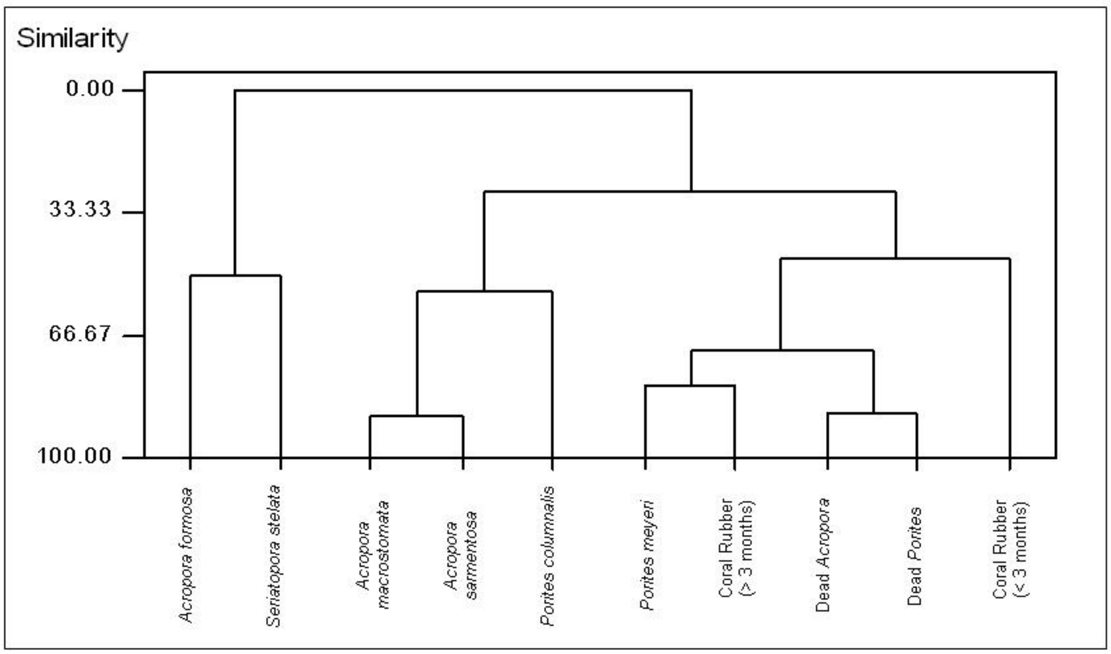

Fig.4. Dendogram Graph of ten categories divided into six live corals(*Acroporaformosa*, *Acroporamacrostomata*, *Acroporasarmentosa*, *Seriotoporastelata*, *Poritesmeyeri*, and *Poritescolumnaris)*, 2 dead coral covered with algae (*Acropora, and Porites)* and 2 coral rubber (<3 months, and >3 months)

There were six main groups at similarity distance of 70,87% i.e. *Acroporamacrostomata* and *Acroporasarmentosa*having spectral similirity, categorized in one group.*Poritesmeyeri* having spectral similirity with old coral rubber, dead *Acropora* and dead *Porites*, categorized in one group. However, *Acroporaformosa, Seriotoporastelata, PoritesColumnaris,* recently coral rubberhave formed groups with himself. They have not shown a spectra similarity with another categories.
At similirity 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 similirity categorized in one group. *Acroporaformosa, Seriotoporastelata, PoritesColumnaris, Poritesmeyeri* recently coral rubber, and old coral rubber 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 rubber 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 rubber 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 alga, and coral rubber 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 rubber spectra display a reflectance minimum at 674nm. Additionally, all of the live coral and coral rubber 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 ad 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 aggreement 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 wavelenghts are largely the result of absorption by photosynthetic and photoprotective (Salih et al., 2000). Similarly, higher values at red wavelenght indicate lack of absorption or presence of active fluorescence (Mazel, 1995).

Chlorophyll in the zooxanthellae is an efficient absorber of light at the wavelenght transmitted by seawater, but its fluorescence emission at 685nm and longer wavelenghts 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 oppurtunities 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 algaeand coral rubber 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 rubber had a similiar reflectance. This indicated that *Porites meyeri* couldn`t be easily separated from dead corals and old coral rubber.All photosynthetic organisms (living and dead corals covered with alga, coral rubber 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 rubber reflectance spectra showed the most variation in shape and magnitude in comparison with the other groups. Within dead coral had the the least variation in spectral shape.The results of study by Holden and LeDrew (1998) showing that the healthy cluster include 2 bleached spectra and 2 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 rubber 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 groupings (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 scovered 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 propably 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 rubber can present such a range of colors, making spectral discriminatin 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 chlorophill-*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 rubber also shows variability at these study.

We developed spectral library to determine whether live coral, dead coral covered with algae and coral rubber covered with algae are spectrally discriminable and how to achieve discrimination. More investigation is required to statistically determine the degrees to which various categories groupings are spectrally discernable. Basically, every material has different structure or particle composition and this difference influences its electromagnetic response pattern. We have shown that basic live corals, dead corals and coral rubber have characteristic reflectance, that within them, and that they are spectrally separable from each other.It was difficult to find a completely dead coral without colonization by algae. Dead coral are not actually pure because trace amounts of macroalgae were visible on the surface. The stage of dead coral is temporary and the affected corals will either recover to their normal pigmentation or die and be colonized by macroalgae (Holden and LeDrew, 2001). However, dead corals and coral rubber 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 rubber more complicated.

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