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HYPERSPECTRAL DISCRIMINATION AND SEPARABILITY ANALYSIS OF CORAL REEF COMMUNITIES IN REDANG ISLAND

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Abstract: An assessment of the spectral separability between different reef species was undertaken using underwater hyperspectral measurements. In-situ upwelling and downwelling radiances were collected for eight substrates of Redang Island reef communities, including five corals, algae and sediments. Underwater spectral measurements ranging from 350 to 800 nm were taken 0.25 m above the substrate using a Satlantic HyperOCR spectroradiometer. Hyperspectral reflectance and derivative datasets were analysed using the stepwise discriminant function analysis to determine the best discriminating wavelength for each species at Chagar Hutang, Redang Island. Results showed that major reflectance features of reef species were identified by two distinctive peaks at 575 and 610 nm. Stepwise wavelength selection revealed that reef species could be well-distinguished using the derivative dataset (15 non-contiguous wavelengths) compared to hyperspectral reflectance (4 non-contiguous wavelengths). These preliminary results are encouraging and demonstrated the possibility to spectrally distinguish different types of coral reef community using hyperspectral remote sensing.

KEYWORDS: Coral reef, hyperspectral, reflectance, discrimination, remote sensing.

Introduction

To extract meaningful information from remotely-sensed data, the techniques used must be developed to relate the signals received by a remote sensor to the optical properties of the reef community and its associated habitats (Hochberg and Atkinson, 2003). Theoretically, coral reef benthic communities exhibit unique characteristics of spectral reflectance that provide the opportunity in identification and discrimination of them using remote sensing (Hochberg and Atkinson, 2000; Lubin et. al., 2001; Kuster and Jupp, 2006; Kuster et. al. 2006). However, in identifying the specific benthic community and the interpretation of reflected signal is difficult to achieve using the remote-sensing system. It is because coral-reef ecosystems are optically, spatially and temporally complex and subsequently coral-reef benthic-community mapping and interpretation is an extremely difficult task (Holden and LeDrew et. al., 1995; Mumby et. al., 2004). In situ spectroradiometric measurements of spectral properties play an important role in the development of remote-sensing application. Therefore, the understanding toward the basic principle of spectral properties of major coral reef communities is essential before coral species identification can be made.

New hyperspectral remote-sensing technologies were developed to improve the spatial and spectral resolution to be employed in mapping reef benthic communities. For further characterisation of the benthic community, reflectance properties are essential. The objective of this study is to determine the hyperspectral properties of the basic benthic community types (coral, algae and sand), while it is certainly possible to further classify the bottom types to lower taxonomic levels.

Furthermore, the significant wavelengths in discriminating among benthic communities will also be identified using the stepwise discriminant function analysis (DFA). The hyperspectral separation is an important step toward coral-reef benthic-community mapping using hyperspectral remote sensing.

Materials and Methods

Hyperspectral reflectance measurements

The hyperspectral reflectance measurements were collected during field sampling at Chagar Hutang (05°48'15.17"N, 103°00'8.78"E) which is located in the north of Redang Island (Figure 1). Spectral downwelling irradiance (Ed) and upwelling radiance (Lu) with a 60º field of view were collected using the Satlantic HyperOCR spectroradiometer which incorporates a 256 channel photodiode array. The sensor with a spectral range from 350 to 800 nm and ~3 nm sample interval was operated through a portable computer from the boat. Samplings were carried out on cloud-free days wherever possible within 3 hours of solar noon.

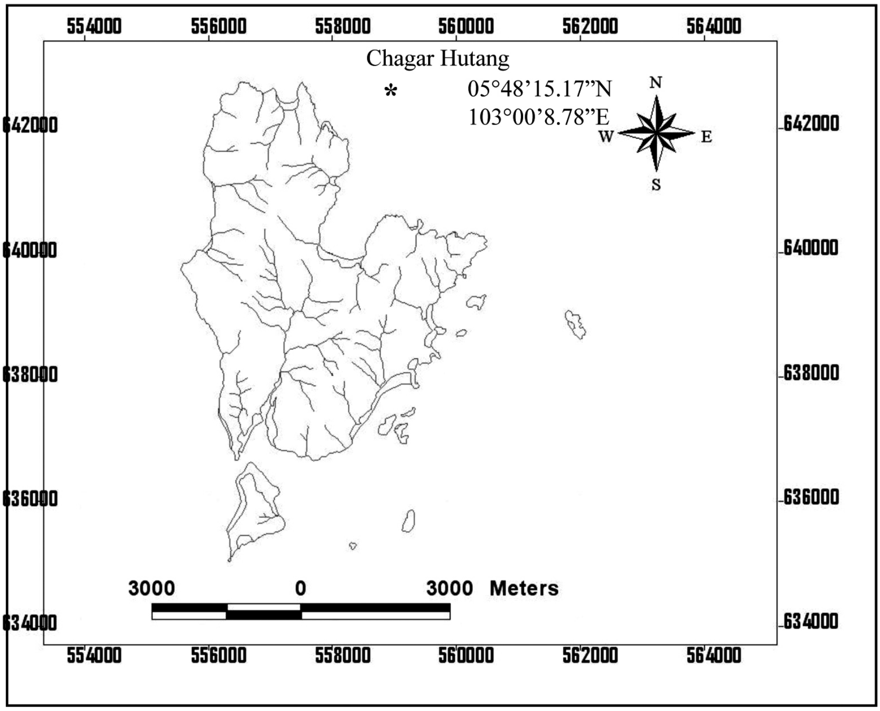


Figure 1 Sampling site at Chagar Hutang, Redang Island

In this study, hyperspectral reflectance of 8 substrate reef communities, including five coral species (*Platygyra sinensis, Porites porites, Acropora famosa, Pocillopora damicronis* and *Acropora hycinthus*), turf algae and sediments (coral rubbles and carbonate sand) were collected. For each target, at least five hyperspectral measurements of E_d and L_u were made within a 1-2 second sampling interval over a length of 10 seconds. Reflectance measurements were consistently taken with a nadir view approximately 0.25m above the substrate in order to cover a specific target area of approximately 0.065 m^2. Underwater photographs of each target were taken for species identification and to describe the surrounding feature type and substrate for additional information.

Spectral processing and analysis

The pre-processing of hyperspectral data was carried out using the Prosoft 7.79 software and remote-sensing reflectance (Rrs, λ) or hyperspectral reflectance were computed from the ratio of reflected radiance (L_u) off specific bottom target to subsurface downwelling irradiance (E_d). All spectra were linearly interpolated to 1 nm interval over the wavelength range from 400-700nm and smoothed using the Savitzky-Golay least squares method (Savitzky-Golay, 1964) to improve the overall noise reduction. Spectral reflectance from 701 to 800 nm which was strongly affected by errors, especially from bottom reflectances, were discarded in this analysis. First derivatives then were calculated using the common Savitzky-Golay smoothing method.

In this study, the hyperspectral reflectance and derivative datasets were analysed using the stepwise discriminant function analysis (DFA) of SPSS program to determine the best discriminating wavelength to separate benthic communities. The DFA were linear combinations of the non-redundant wavelength that best separated the group. The stepwise selection reduced the data set from 300 contiguous wavelengths (derivative dataset) or 90 contiguous wavelengths (hyperspectral reflectance dataset) to less then 20 non-contiguous wavelengths.

This analysis identified the variables that would maximise differences between statistical-species group but at the same time minimise within-group differences. In this analysis, the independent spectral variables were entered into the model if they met a certain significance level of F test during each run. In order to avoid overfitting and to allow adequate discrimination, the α-level of 0.05 was chosen as the significant level for variable to entry into the model. The significant variables produced during the stepwise discriminant analysis were then used by discriminant procedure for calculating the separability accuracy between each dataset. The separability power between variables of different species was measured by Wilk's Lambda test statistic. Cross validation and variance of canonical variables for each species were then calculated in order to show the separation accuracy. Plots of canonical variables resulting from discriminant procedure were visually used to view and validate the results.

Results and Discussion

General characteristics of coral species reflectance

The mean hyperspectral reflectances of 5 coral species, turf algae and sediments (carbonate sand and rubbles) are shown in Figure 1. All features show a relatively lower value at the blue region (400 – 500 nm) and the lower section of green spectrum (500 to 550 nm). Reflected light was greatest at the upper section of green spectrum (550 to 600 nm) and decreased, particularly over the 600 to 670 nm range. The spectra also reveal a small peak at 610 and 650 nm that result from natural chlorophyll fluorescence emitted by zooxanthellae. At the visible range, the higher energy from incoming radiation caused this shorter wavelength to be less susceptible to environmental influences and it subsequently produced a smooth response of reflectance (Mohd-Suffian, 2005). Hyperspectral reflectances were generally lower in the shorter wavelength region (400-500nm) and in most reflectance patterns were not distinctive features between benthic communities.

Results of benthic communities in the visible region (Table 1) showed that chlorophyll concentration dominates the spectral reflectance. The magnitude differences of hyperspectral reflectances were greater in green region (2.35%) followed by the red (1.60%) and blue (1.60%) region. All benthic substrate exhibited decreasing radiance absorption (increased in reflection) from blue-to-red visible wavelength except in bare carbonate sand which has lowest absorption at green visible wavelength. The lowest absorption by photosynthetic organisms at red wavelength region might be due to the removal of the entire red light component of sunlight by the seawater (Minghelli-Roman et al., 2002).

Carbonate sand had the highest mean-spectra reflectance value (2.5%) and turf algae was the lowest (0.7%). All the healthy corals had lower reflectance (1.1%) and were easier to discriminate from carbonate sand. These results are in agreement with observations reported by many previous studies (eg. Holden and LeDrew, 1998; Karpouzli et al., 2004; Hochberg and Atkinson, 2000). This indicated that bare carbonate sand could be easily separated from other benthic types on the basis of brightness alone. The sediment spectra indicated the presence of benthic microalgae growth within the mixed sand and coral rubbles.

Table 1: The mean hyperspectral reflectances (%) of 8 benthic communities

	Visible Wavelength (nm)		
Benthic Communities	**Blue (400-520 nm)**	**Green (520-600 nm)**	**Red (600-700 nm)**
Platygyra sinensin	0.5376	1.1419	1.4272
Porites porites	0.7523	1.5275	2.1455
Acropora famosa	0.5761	0.8763	1.1835
Pocillopora damicronis	0.6213	0.8253	1.1340
Acropora hycinthus	0.7845	1.4907	2.1044
Turf Algae	0.3093	0.5991	1.1755
Sediment	0.7044	1.2533	1.6424
Carbonate Sand	1.8755	2.9458	2.7301

The averaged hyperspectral reflectance curves of coral species exhibited differences in magnitude but were similar for the overall shape. Most features except for carbonate sand show two peaks or shoulders; one around 570 nm and another one around 610 nm. For carbonate sand and rubbles, they show a similar broad peak at 580 and 650 nm, but carbonate sand exhibited a third peak near 690 nm. The results are contrary with previous study of Holden and LeDrew (1998) that found a triple-peaked pattern on corals reflectance. This pattern indicated that corals share characteristic reflectance patterns, because they are related to symbiotic zooxanthellae. Among five coral species, *Pocillopora damicronis* showed a different reflectance pattern. The species shows a broad plateau pattern of reflectance between 400 and 650 nm and no apparent absorption features were found within this range. All healthy photosynthetic corals and algae showed a minimum reflectance at approximately 670nm. This feature might be related to the presence of chlorophyll-a (Karpouzli et al., 2004) or caused by absorption of red light by chlorophyll-a (Minghelli-Roman et al., 2002). Peaks in first derivative (figure 3) of corals except for *Pocillopora damicronis* showed similarities in shape and pronounced peaks were observed at 440, 470, 510, 560, 600 and 645 nm. Carbonate sand and rubbles displayed a very different pattern of derivative spectra where local maxima and minima were observed at about 680 and 660 nm, respectively.

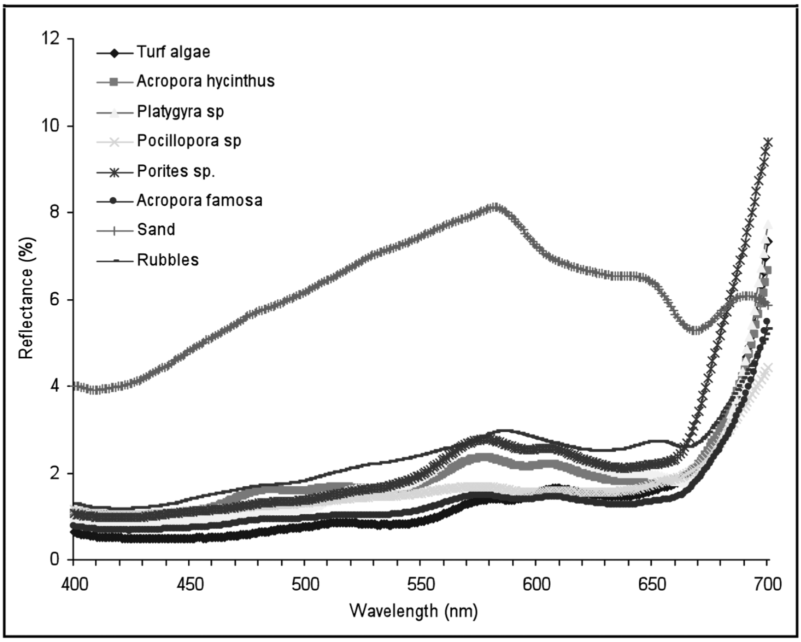


Figure 2: Mean apparent remote sensing reflectance (%) of coral reef benthic communities (5 healthy coral species, turf algae, rubbles and carbonate sand).

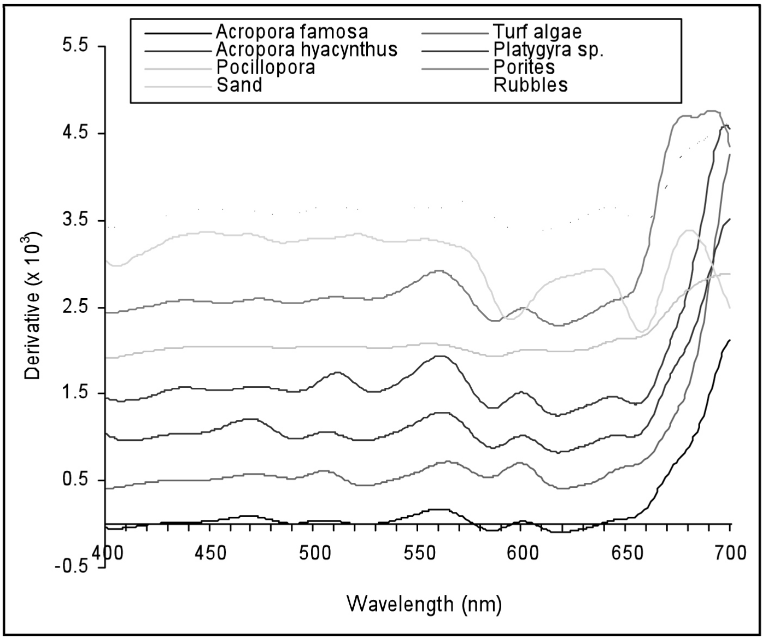
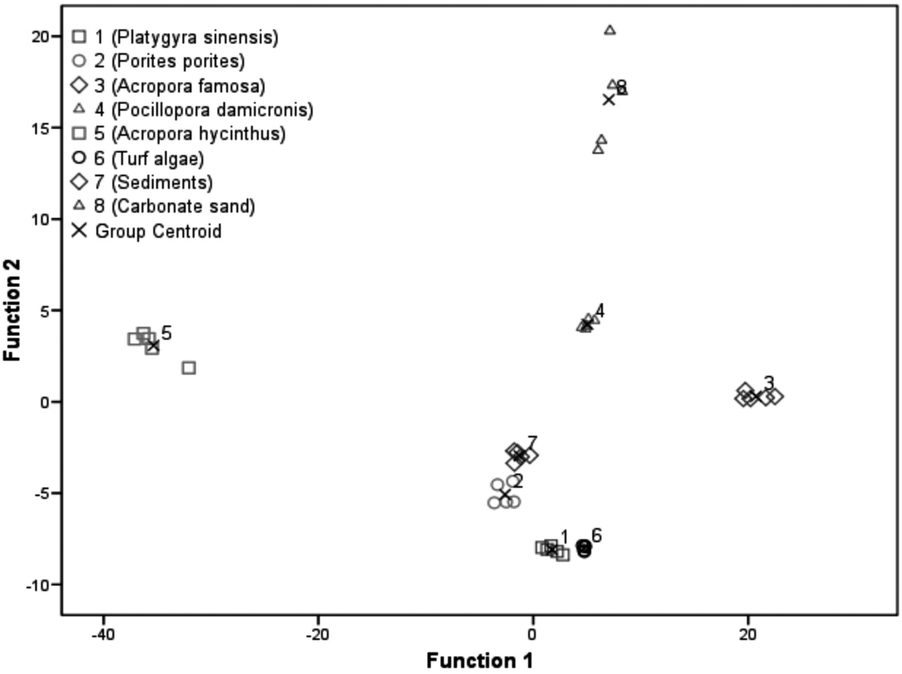


Figure 3: Mean first derivatives spectra for coral, turf algae, carbonate sand and rubbles. All reflectance spectra were offset by 0.5.

A



B

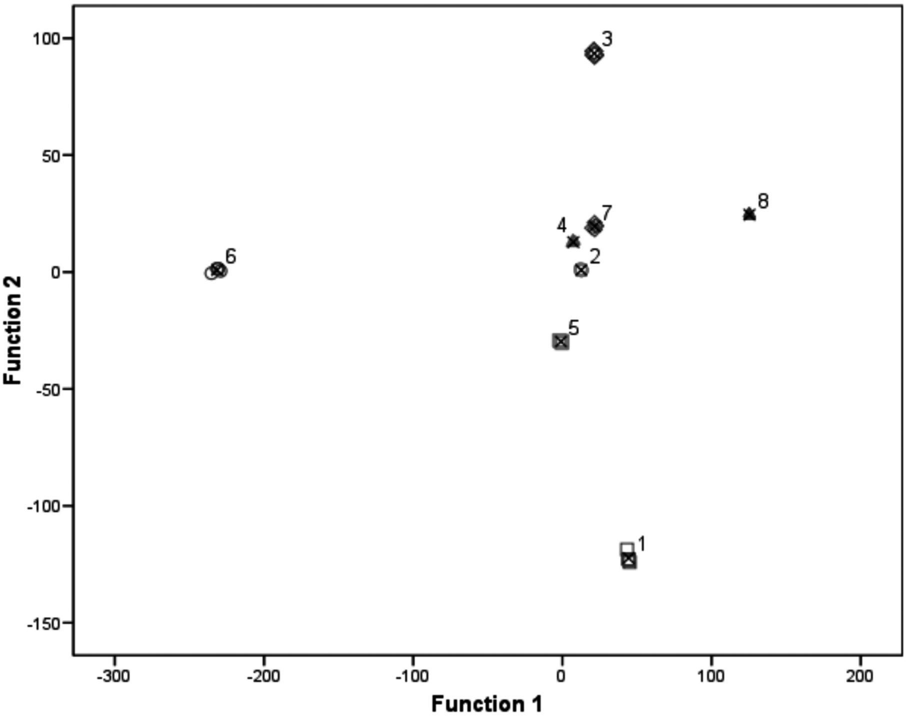


Figure 4: Scores from the discriminant function analysis projected into the discriminant function space of the two first functions that best separate the benthic communities. **A** – Hyperspectral reflectance datasets; **B** – Derivative datasets.

Hyperspectral separability among coral-reef communities

Overall, discriminant classification accuracies of 8 benthic communities for hyperspectral reflectance and derivative datasets were 97.5% and 100%, respectively. The wavelength from 400-700nm were used in stepwise discriminant analysis to determine the hyperspectral separabality among coral, algae and carbonate sand. The discriminant was achieved with the hyperspectral derivative datasets with 15 non-contiguous wavelengths (445, 457, 466, 493, 516, 531, 538, 552, 571, 599, 601, 639, 652, 653, 660 nm) were selected by the stepwise discriminant analysis. However, only four wavelengths (462, 476, 606, 697nm) were selected using hyperspectral reflectance datasets, highlighting the need for hyperspectral derivative data compared with reflectance data. The use of derivative techniques to enhance spectral differences between and within taxonomic groups proved to be very effective, similar to findings by Karpouzli et al. (2004). Smoothing of hyperspectral curves such as derivative analysis plays a very important role, especially in studies where the first and second differences of spectral data are analysed. Since these differences are taken across each spectrum at relatively small intervals, very small local peaks or valleys in the spectrum can affect them. However, derivatives of spectral data should be relatively insensitive to variations in illumination intensity caused by sun angle, cloud cover and topography (Tsai and Philpot, 1998).

The canonical discriminant function plot served as a visual indicator of hyperspectral separability between coral-reef communities. The principle action of discriminant function 1 when using hyperspectral derivative (Figure 4) effectively separated the coral, algae and carbonate sand and discriminant function 2 improved greatly the separation of benthic types. From Figure 4, carbonate sand and algae seem to form a very distinct type compared to corals in both datasets, suggesting the easiness to distinguish from other species. However, spectral discrimination using derivative dataset proved to be more accurate with the canonical variance for all species are much higher than using the hyperspectral dataset. Turf algae and carbonate sand recorded the highest pooled variance for the two canonical variables with -231 and 125, respectively. These canonical variable plots and variances are very useful for visualising and interpreting the spectral characteristics of each species. However, one should realise that canonical variables are transformed variables and do not represent the physical reflectance quantities found in real-world measurements.

Conclusion

Overall, the result from this study revealed that hyperspectral reflectance of coral-reef benthic communities exhibited the typical reflectance in the green visible wavelength (520-600nm) with greater differences in magnitude of 2.35%. This suggested that the green visible wavelength has potential for discriminating the benthic communities. The used of derivative techniques to enhance spectral differences between and within taxonomic groups proved to be effective in distinguishing different types of coral-reef communities (coral, algae and carbonate sand) using hyperspectral remote sensing. This study also established the hyperspectral derivative dataset that best discriminate benthic communities using the stepwise discriminant-function analysis compared to hyperspectral reflectance dataset. Furthermore, it is possible to apply that discrimination to remote-sensing imagery.

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