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Spectral characteristics of coral reef benthic compositions in Gulf of Mannar

Kandasami Nimalan[1,*], Muniappan Thanikachalam[1] and Tune Usha[2]

[1]*Department of Civil Engineering, S.A. Engineering College, Chennai, India.*
[2]*National Centre for Coastal Research, NIOT Campus, Pallikaranai, Chennai, India.*
**Corresponding author. e-mail: nimalansk@saec.ac.in*

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Spectral characteristics of nine coral species (*Acropora Nobilis*, *Acropora Hyacinthus*, *Acropora Varibalis*, *Favia Speciosa*, *Favia Stelligera*, *Porites Lobdata*, *Porites* sp., *Pocillopora Domicornis* and branched dead corals), two seagrass species (*Zosteraceae* and *Posidoniaceae*), two sand benthic communities (sand mixed with coral rubble and carbonate sand), reef vegetation and sea moss were recorded using RAMSES-TriOS Hyperspectral radiometer from Mandapam group of islands, Gulf of Mannar, India. Based on the reflectance features, coral reef benthic compositions were categorized as brown mode and blue mode. Brown mode of corals was identified by a triple peaked pattern exhibiting local maxima or shoulders near 575, 600 and 650 nm. The blue modes of corals were identified by a plateau-like shape between 600 and 650 nm. The non-coral benthic compositions such as seagrass and sea moss can be identified by a peak between 550 and 560 nm. Results exhibited that, most of the coral reef benthic compositions falling under either blue mode or brown mode of corals and the patterns of spectral signatures exhibited in this region are matching with existing global signatures.

Keywords. Coral reefs; sea grass; sand; spectral characteristics.

1. Introduction

Monitoring changes in the distribution, abundance and health of coral reef species is one of the important aspects of coral reef ecology (Sarah Hamylton 2011). The current options for remote sensing based coral reef mapping and monitoring are dominated by high resolution (Ex: AVIRIS, Sentinel-2) and moderate resolution (Landsat-7, Landsat-8) sensors. High spatial resolution sensors offer many benefits, and the outcomes from these kinds of sensors are widely used for mapping of coral reefs at local levels. Even though remotely sensed imageries provide many benefits to monitor the coral reef ecosystem, the knowledge of *in-situ* spectral characteristics of individual end members is essential as they provide base for analyzing the data obtained through remote sensing systems. Also, this kind of *in-situ* spectral characteristics integrated with satellite imageries can often be used to develop accurate mapping even at species level and this can also be used to identify health condition of coral reefs. Along with all other benefits, spectral signatures collected from field investigations are very much essential for (a) image calibration; (b) to develop semi-analytical models; (c) to develop and validate suitable algorithms for benthic habitat mapping; and (d) to identify the composition of coral communities and examining their relationship with other environmental stresses such as climate change (James and Susan 2001).

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On global scale, Hochberg *et al.* (2004) developed a spectral library of coral reef benthic compositions which comprises of around 13,100 numbers of spectra collected from different regions around the world namely St. Croix, Puerto Rico, Florida Keys, Oahu, Hawaii, Maui, Hawaii, Rangiroa, French Polynesia, Moorea, French Polynesia, Palau, Bali, Indonesia, Mayotte, Comoros, and Waikiki Aquarium. On a regional scale, number of researchers have measured the spectral reflectance of coral reef benthos and their substrates at various locations (Mumby *et al.* 1997; Holden and LeDrew 1998a, b; Hochberg and Atkinson 2000; Andrefouet and Riegl 2004; Hochberg *et al.* 2004; Karpouzli *et al.* 2004). In the Indian context, only a few studies have been conducted. Nandini (2012) has collected spectral characteristics of different coral reef benthic compositions from Paga and Laku Point reefs, Gulf of Kachchh, and Mohit *et al.* (2018) have collected spectral characteristics of different coral reef benthic compositions from Pirotan Reef, Gulf of Kachchh, India.

Even though the researchers are acquiring spectral signatures from the field, uniqueness of the spectral signature ensures further applicability of them. Hochberg *et al.* (2003) showed that 12 pure end-members found in the coral reef environments contained their distinct spectral reflectance features that are consistent across biogeographic regions. Holden and LeDrew (2000) measured 133 *in-situ* reflectances of various coral reefs in Fiji, Indonesia. They performed 181 individual *t*-tests for each of the classes and determined that there is no significant spectral difference between geographical locations within each class. Muniappan and Kandasami (2019) have reported that there is also no spectral difference attributable to climatic conditions and water quality. In contrast, Ian *et al.* (2011) reported that the unique characteristic of spectral reflectance of coral reefs would only be valid to particular corresponding reef, because, the spectral characteristics of any corals are the function of up-welling light flux from skylight, sunlight, sun glint, water column attenuation, backscatter and environmental conditions at that particular location.

Hence, understanding the spectral characteristics of various coral reefs benthic compositions is very much important for routine monitoring and regular management of the ecosystem. Therefore, the present study investigates the spectral characteristics of nine coral species namely *Acropora Nobilis, Acropora Hyacinthus, Acropora Varibalis, Favia Speciosa, Favia Stelligera, Porites Lobdata, Porites* sp., *Pocillopora Domicornis* and branched dead corals, two seagrass species namely *Zosteraceae* and *Posidoniaceae*, two sand benthic communities namely, sand mixed with coral rubble and carbonate sand, reef vegetation and sea moss from Mandapam group of islands, Gulf of Mannar, India. To date, this is the first of its kind of study exploring the trends of spectral signatures of coral reef benthic compositions in this region.

2. Materials and methods

2.1 *Study area*

Government of India has established the Gulf of Mannar (GoM) Biosphere Reserve in 1989, which is one among the four major reef areas in India, located on the south-eastern coast. Reefs in the GoM have developed around 21 uninhabited islands that lie between the latitude of 8°47′–9°15′N and longitude of 78°12′–79°14′E covering an area of 623 ha along the 140 km stretch between Tuticorin and Rameshwaram in the state of Tamil Nadu, India. As many as 133 species of corals and their reef of fringing and patchy type are present at 5 m depth around the islands and the average distance of these islands from the mainland is about 8 km (figure 1). This area is biologically rich and highly productive seas of the world and its biodiversity is considered globally significant.

2.2 *In-situ measurements*

A total of 30 different sites at GoM were sampled for this analysis, which consist of different benthic communities and different bottom depths varying from 0.5 to 3 m. The sites were chosen in such a way that it covers homogeneous benthic coverage to certain extent to avoid influence of neighbouring benthic community in radiometric measurements. The radiometric measurements of up-welling radiance (E_u), down-welling radiance (E_d) and up-welling irradiance (L_u) for each end member were recorded using RAMSES-TriOS Hyperspectral radiometer, ranges between the wavelengths of 350 and 900 nm at a bandwidth of 3 nm and resampled to 1 nm. Interpolation technique is used to resample the radiance value from 3 nm to 1 nm. Compared to other radiometers, the TriOS performed very well in the assessment of *in-situ* radiometric capabilities for coastal water remote sensing applications, showing absolute of relative percent differences (AD) in $R_{\rm rs}$ of 5.9%, 3.9%, and 7.2% at 443, 555, and 665 nm, respectively (Zibordi *et al.* 2012) and also none of the TriOS spectra showed strong influence of direct skylight (Annelies *et al.* 2012). In this study, measurements are recorded for each sample with the help of one radiance and two irradiance sensors. The $L_{\rm u}$ and $E_{\rm u}$ sensors are kept pointing downward to measure the upwelling radiance and irradiance from the object, whereas $E_{\rm d}$ sensor is kept pointing upward to measure the down-welling irradiance from the sun. These irradiance ($E_{\rm d}$ and $E_{\rm u}$) radiometric sensors are kept parallel to each other but facing opposite sides such that one is looking downward towards the end-member and the other is looking upward towards the sea surface. Intense care is taken to avoid boat shadowing and instrument self-shadowing effects during the deployment. For the most precise spectral reflectance measurements, sampling should always occur when the sun is highest in the sky. Based on this, Holden and Ledrew (1998a, b) have conducted their field measurements between 10:30 and 13:15 local time and all the measurements carried out in this study were recorded between 10:00 and 13:00 hours, prevailing low tide conditions within the solar zenith angle of $< 30°$ and sensor viewing angle of 35°–40° (since the light entering the water at large angles bends towards the vertical, creating the circular window of light. Rays exceeding the critical angle of $\theta_c = 48.6°$ are from upwelled light (very weak) that is reflected downward at the sea surface) and it is also made sure that there are no clouds in the path (clear and stable sky condition) between sunlight and end member during the measurements. The measurements for each endmember were carried out under two different conditions: (i) *in-situ* condition (influence of water column will be there) and (ii) exposed condition (influence of water column will not be there). The advantage with making in water measurement (*in-situ*) is, it avoids surface reflected light and the advantage with making above surface (exposed) is, it avoids self-shading of the instrument. Contrary to other works, the influence of water column is included in the measured spectra, incorporating additional revealing to the study.

2.3 *Spectral analysis*

Subsurface remote sensing reflectance ($r_{\rm rs}$) is the measure of ratio between the radiance exhibited by a target object's upwelling radiance ($L_{\rm u}$) to the sun irradiance ($E_{\rm d}$). It is therefore defined by:

$$r_{\rm rs} = L_{\rm u}/E_{\rm d}. \quad (1)$$

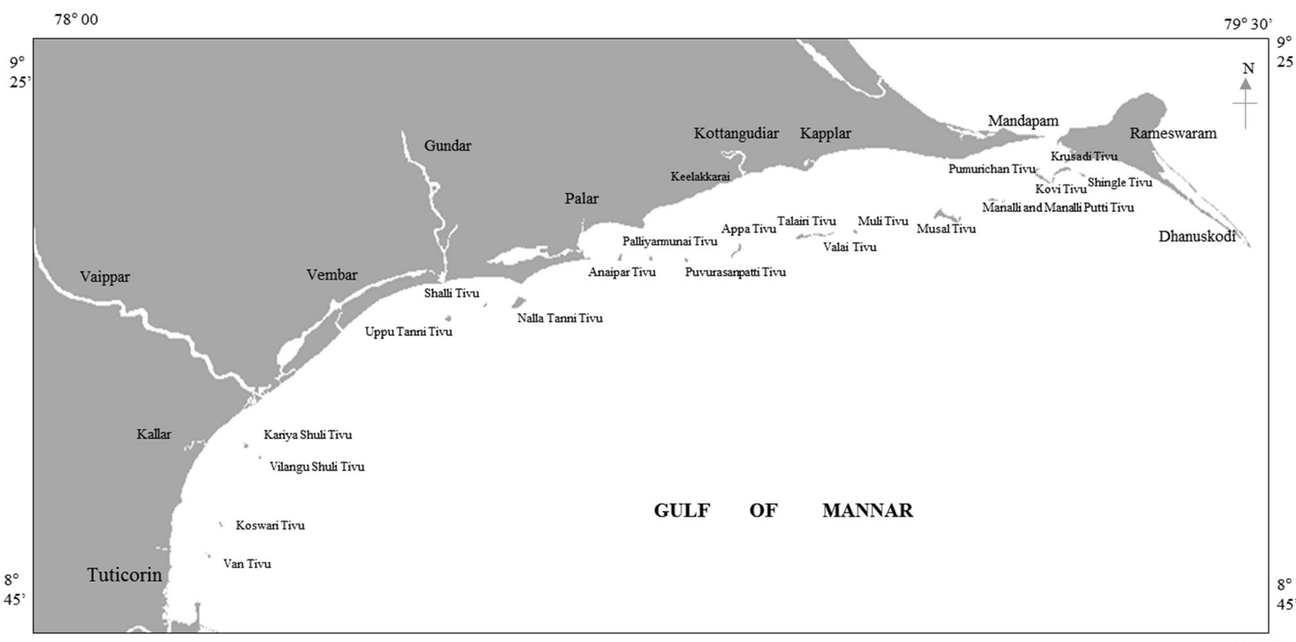

Figure 1. Map showing the Gulf of Mannar islands and its location.

Remote sensing reflectance (R_{rs}) is the measure of $1 - r_F/n^2_w$ (approximately equal to 0.545) times of subsurface remote sensing reflectance, where, r_F is the Fresnel reflectance of the surface as seen from the water (0.02–0.04) and n_w is the real part of the index of refraction of sea water (1.34). It is therefore defined by (Mobley 1999):

$$R_{rs} = 0.545 \times r_{rs}. \quad (2)$$

3. Results and discussions

Necessary processing steps were carried out using equations (1–2) to retrieve the spectral characteristics of measured *in-situ* data and that has been resampled to 1 nm interval across a spectral range between 350 and 900 nm. The process of resampling the spectral signature was carried out using interpolation technique. Spectral reflectance signature for each end-member is obtained by averaging the number of measurements made for that particular end-member and only visible portion of spectrum were considered for further analysis due to the light attenuation in the water column for wavelengths shorter than 400 nm and longer than 700 nm.

Categorization of spectral signature of coral reef benthic composition plays a vital role. Based on shape of the spectral signature, endmembers were grouped (in both *in-situ* and exposed condition of measurements) under four different categories. Group-A is categorized as Brown corals (*Acropora Nobilis, Acropora Hyacinthus, Acropora Varibalis, Favia Speciosa, Favia Stelligera, Porites Lobdata, Porites* sp., and Reef vegetation) exhibiting a depressed reflectance between 400 and 550 nm and by positive reflectance maxima or shoulders near 575, 600, and 650 nm first reported by Hochberg *et al.* (2004) and is depicted in figure 2(A) for exposed and figure 3(A) for *in-situ* condition of measurements. The species of *Acropora Nobilis, Acropora Hyacinthus, Porites Lobdata* and *Porites* sp., reported as brown corals by Hochberg *et al.* (2004) are matching with the spectral signatures of this region and other species namely *Acropora Varibalis, Favia Speciosa, Favia Stelligera* and reef vegetation which are not reported by Hochberg *et al.* (2004) can

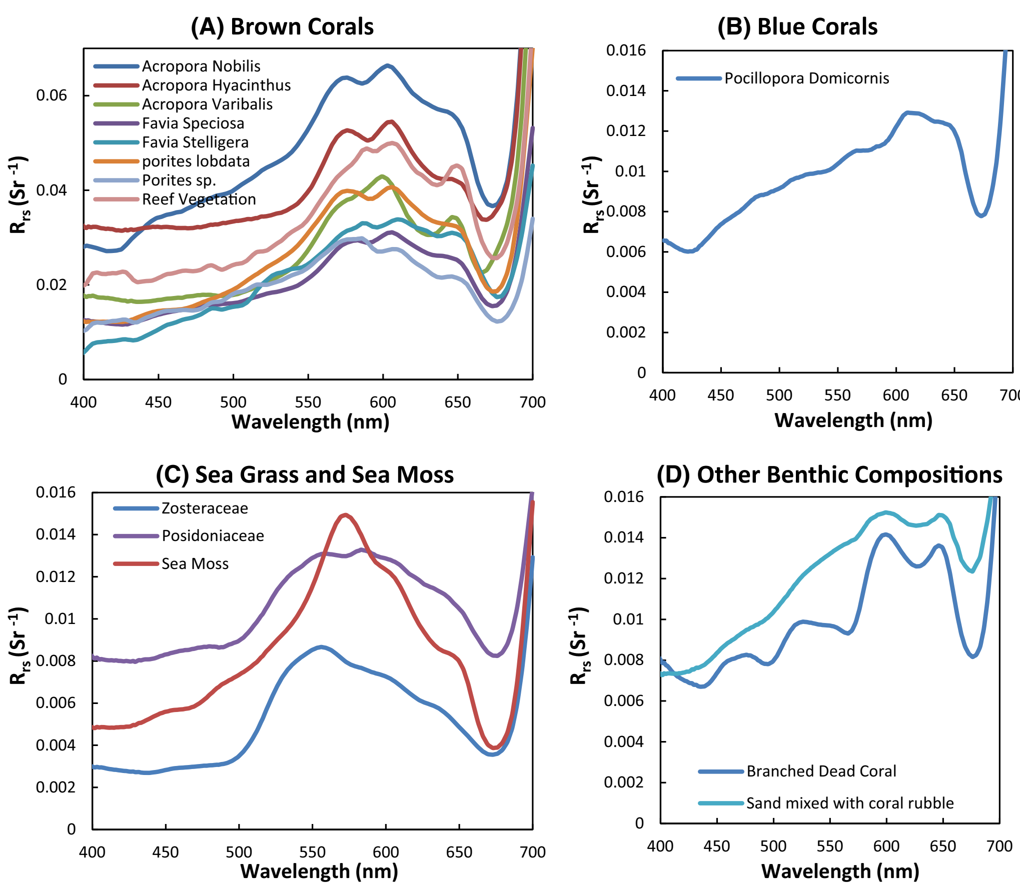

Figure 2. Remote sensing reflectance (R_{rs}) characteristics of various end members collected based on exposed measurement condition.

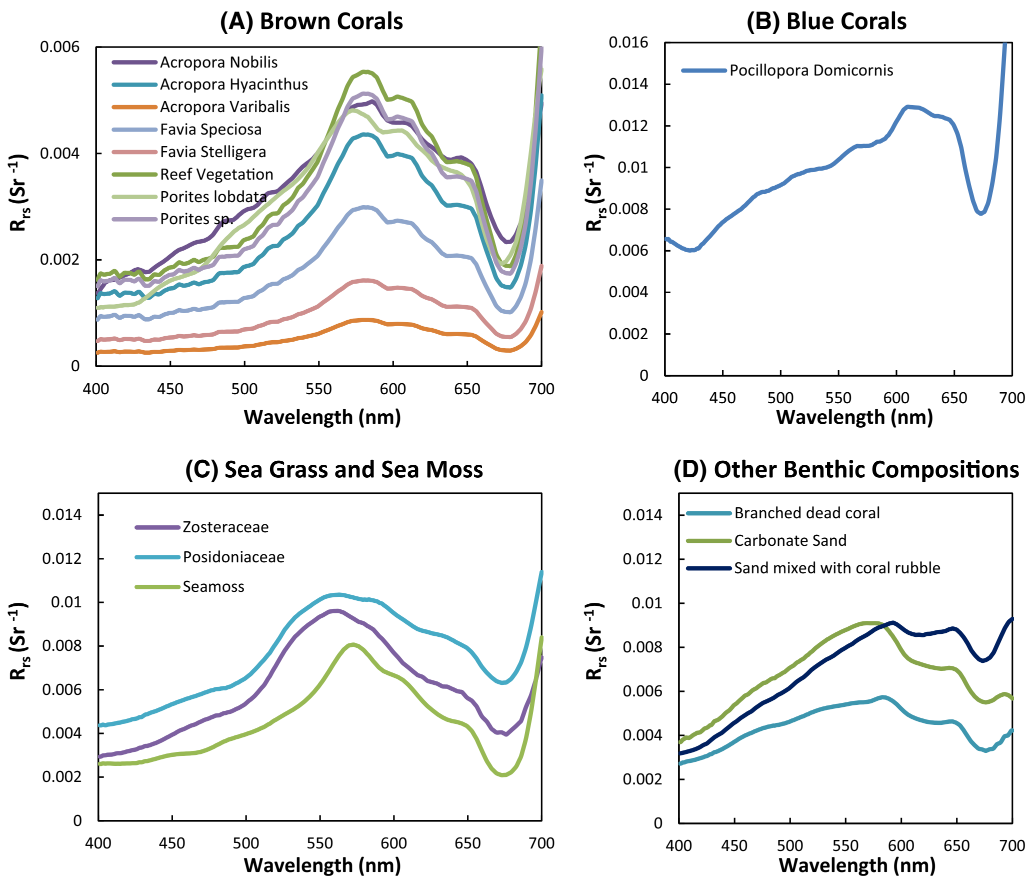

Figure 3. Remote sensing reflectance (R_{rs}) characteristics of various end members collected based on *in-situ* measurement condition.

also be categorized as brown corals due to the similar patterns of spectral signatures. Usually, the coral colonies that visually appear in brown, red, yellow or green are said to have properties of brown mode.

Group-B is categorized as Blue corals exhibiting a plateau-like shape between 600 and 650 nm reported by Hochberg *et al.* (2004) and is depicted in figure 2(B) for exposed and figure 3(B) for *in-situ* condition of measurements. The species of *Pocillopora Domicornis* in this region is exhibiting the characteristics of blue corals, but is not reported by Hochberg *et al.* (2004) at global spectral signature. Usually, the coral colonies that visually appear in purple, blue, pink or grey are said to have properties of blue mode. Thus, the major difference between the brown and blue mode of coral is absence of 575 nm feature in blue mode of corals. Also one has to understand the fact that, the blue and brown mode does not mean that corals appear in that colour, instead, it is merely the parameter which is used to describe them. With respect to the relationship between blue mode and brown mode of corals, spectral characteristics exhibited by most of the coral colonies in this study either exhibits blue mode or brown mode of spectral patterns. Group-C is categorized as sea grass and sea moss exhibiting a peak between 550 and 560 nm reported by Karpouzli *et al.* (2004) and is depicted in figure 2(C) for exposed and figure 3(C) for *in-situ* condition of measurements. The sea grass species of *Zosteraceae* and *Posidoniaceae* and sea moss is exhibiting their peaks around 550, 556 and 560 nm, respectively. Group-D is categorized as other benthic compositions and is depicted in figure 2(D) for exposed and figure 3(D) for *in-situ* condition of measurements. This category of benthic compositions consists of branched dead coral, carbonate sand and sand mixed with coral rubble.

From the results, it can also be inferred that; the dominant features that can be used to discriminate coral reef benthic compositions usually lie in the wavelength region of 500–700 nm of Electro Magnetic Radiation (EMR). All the end-members exhibit a narrow chlorophyll absorption feature near 675 nm (Enriquez *et al.* 2005) in measurements recorded under both submerged and exposed conditions. The effect on spectral measurement due to the water column attenuation is evident by a noticeable reduction in reflectance towards the red wavelengths beginning around 575 nm (Ian *et al.* 2011) in spectral signature of all the end members recorded at submerged condition. It can also be noted that all the end-members exhibit a sudden rise in their magnitude after visible region (>700 nm) of EMR in measurements recorded based on exposed condition.

4. Conclusion

This study attempts to analyse the spectral characteristics of nine different coral reef species along with several of its associated benthic compositions recorded from various islands of Gulf of Mannar, India. Results revealed that several coral species either falls under the broad category of Brown mode or Blue mode. It can also be noted that irrespective of water column conditions, (i) all the coral reef benthic compositions tend to have their reflectance minimum around 674 nm (this phenomenon is due to the strong absorption of chlorophyll in that portion of EMR). (ii) Influence of water column can be seen in the rise of magnitude in the longer wavelengths of EMR for the measurements recorded based on exposed condition.

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Author statement

Kandasami Nimalan performed the *in-situ* radiometric measurements, analyzed the data, designed the figures and wrote the manuscript in consultation with Muniappan Thanikachalam, and Tune Usha. Muniappan Thanikachalam has received the grant, involved in radiometric measurements and guided in manuscript preparation. Tune Usha provided critical feedback and helped shape the research and all authors discussed the results and commented on the manuscript.

References

Andrefouet S and Riegl B 2004 Remote sensing a key tool for interdisciplinary assessment of coral reef precesses; *Coral Reefs* **23** 1–4.

Annelies H 2012 Intercomparison in the field between the new WISP-3 and other radiometers (TriOS Ramses, ASD FieldSpec, and TACCS); *J. Appl. Remote Sens.* **6** 1–21.

Enriquez S, Mendez E R and Iglesias Prieto R 2005 Multiple scattering on coral skeletons enhances light absorption by symbiotic algae; *Limnol. Oceanogr.* **50(4)** 1025–1032.

Hamylton Sarah 2011 Estimating the coverage of coral reef benthic communities from airborne hyperspectral remote sensing data: Multiple discriminant function analysis and linear spectral unmixing; *Int. J. Remote Sens.* **32(24)** 9673–9690.

Hochberg E J and Atkinson M J 2000 Spectral discrimination of coral reef benthic communities; *Coral Reefs* **19** 164–171.

Hochberg E J and Atkinson M J 2003 Capabilities of remote sensors to classify coral, algae and sand as pure and mixed spectra; *Remote Sens. Environ.* **85** 174–189.

Hochberg E J, Atkinson M J, Apprill A and Andréfouët S 2004 Spectral reflectance of coral; *Coral Reefs* **23** 84–95.

Holden H and LeDrew E 1998a Hyperespectral identification of coral reef features; *Int. J. Remote Sens.* **20(13)** 2545–2563.

Holden H and LeDrew E 1998b Spectral discrimination of Healthy and Non-Healthy corals based on Cluster Analysis, Princiapal Component Analysis, and Derivative Spectroscopy; *Remote Sens. Environ.* **65** 217–224.

Holden H and LeDrew E 2000 Accuracy assessment of hyperspectral classification of coral reef features; *Geocarto Int.* **15(2)** 7–14.

James A Goodman and Susan L Ustin 2002 Acquisition of underwater reflectance measurements as ground truth; 12th International workshop on Airborne Visible/Infrared Imaging Spectrometer.

Karpouzli E, Malthus T J and Place C J 2004 Hyperspectral discrimination of coral reef benthic communities in the western Caribbean; *Coral Reefs* **23** 141–151.

Leiper Ian, Phinn Stuart and Dekker Arnold G 2011 Spectral reflectance of coral reef benthos and substrate assemblages on Heron Reef Australia; *Int. J. Remote Sens.* **33(12)** 3946–3965.

Mobley C D 1999 Estimation of the remote-sensing reflectance from above-surface measurements; *Appl Optics* **36** 7442–7455.

Mohit A, Ashwin G, Nandini C and Ramesh P 2018 Benthic coverage and bottom topography of coral reef environment over Pirotan Reef, Gulf of Kachchh Region India; *Geocarto Int.* **34** 1–18.

Muniappan Thanikachalam and Kandasami Nimalan 2019 Analysis on variations in spectral reflectance characteristics of coral reef benthic compositions from Gulf of Mannar, Tamil Nadu, India; *Indian J. Ecol.* **46(1)** 76–82.

Mumby P J, Green E P, Edwards A J and Clark C D 1997 Coral reef habitat mapping: How much detail can remote sensing provide; *Mar. Biol.* **130(4)** 193–202.

Nandini Ray Chaudhury 2012 Spectral characteristics of selected hermatypic corals from Gulf of Kachchh, India; *Int. Arch. Photogramm. Remote Sens. Spat. Infor. Sci.* **XXXIX(B8)** 333–338.

Zibordi G 2012 *In-situ* determination of the remote sensing reflectance: An intercomparison; *Ocean Sci. Discuss.* **9** 787–833.

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