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# Estimating the fractional abundance of coral reef benthic compositions using linear spectral unmixing

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**Abstract**
The present work is focused on providing the application of linear spectral unmixing technique to Landsat-8 images of Operational Land Imager (OLI) bands in coral reef environment at Gulf of Mannar (GoM) islands along the coast of Tamilnadu, India. The spectral characteristics of benthic compositions namely sand, seagrass, branched corals and mass corals in the GoM are recorded *in-situ* using RAMSES-TriOS Hyperspectral radiometer and the signatures recorded from *in-situ* have been used as input for linear spectral unmixing technique. The results of linear spectral unmixing provide the fractional abundances of coral reef benthic communities in the Islands of GoM region. Such maps can be used to characterize the landscape structure and composition of reefs, which can in turn be linked to environmental and human impacts. This kind of approaches is cost-effective and acts as a valuable tool for the evaluation and periodical monitoring of coral reef community.

**Keywords:** Coral reef. Landsat-8, fractional abundance, Gulf of Mannar, spectral unmixing

## 1. Introduction

Monitoring changes in the distribution and abundance of coral reef species is one of the important aspects of coral reef ecology. Generally, the amount of; coral cover, disease monitoring, distribution and their abundance is assessed in field surveys using quadrat; random point sampling; photo and video transect techniques [17]. But, this kind of field surveying methods are costly, time consuming and labour intensive. Hence, this makes the field surveying methods as unfeasible for continuous monitoring and management of coral reefs, especially in larger areas. Remotely sensed imagery can be act as a tool for quantitative and systematic monitoring of coral reef at broad synoptic scale [26] and many studies have explored the potential of remote sensing in mapping, monitoring and finding the abundance of coral reefs and their benthic compositions [1, 4, 8, 10, 11, 14, 21]. The current options for satellite based coral reef mapping and monitoring is dominated by high spatial resolution multispectral instruments and moderate resolution instruments [12]. High spatial resolution images offer many benefits, and these kinds of images are widely used for mapping of coral reefs at local levels [27]. However, the expense of high resolution satellite imagery and infrequency of data acquisition, make it unsuitable for repeated monitoring of coral reefs. When it comes to moderate resolution instruments, the Landsat series has produced some useful results [2]. Landsat-8 in particular, has good capability for techniques based on radiative transfer models [7] and also, the Landsat series provides a continuous datasets from early 1980's [5] and freely available data of them provides the possibilities for routine monitoring and management of coral reefs. The signal detected by a sensor into a single pixel is frequently a combination of numerous disparate signals. Due to the high level of spatial heterogeneity, complex of coral reef environments, even at a sub-metre scale, an image pixel from a high spatial resolution satellite image sensor (The spatial resolution of satellite image used for this study i.e., Landsat-8 is 30m) will mostly be comprised of multiple coral reef benthos and substrate types, resulting in a mixed end-member spectral reflectance signature [15]. An effective approach to find the relative abundance of coral reef benthos is to use the linear spectral unmixing technique. Linear Spectral Unmixing is a tool to decompose the pixels into the abundance of its components. The reflectance at each pixel of the image is assumed to be a linear combination of the reflectance of each endmember present within the pixel. The number of endmembers must be less than the number of spectral bands and all of the endmembers in the image must be used.

The efficiency of linear spectral unmixing techniques has been evaluated for small-scale assemblages of coral reef substrata by Goodman and Ustin & Hedley *et al*. Sarah Hamylton have used Hyperspectral data to estimate the coverage of coral reef benthic communities using linear spectral unmixing. This current research utilises the Linear Spectral unmixing to the Landsat-8 image in-order to determine the relative abundance of benthic compositions in various study sites based on the characteristics of spectra collected from *in-situ.*

## 2. Study Area

Government of India has established the Gulf-of-Mannar Biosphere Reserve, in 1989, is one among the four major reef areas in India, located on the South-Eastern coast. Reefs in the GoM are developed around 21 uninhabited islands that lies between the latitude of $8^0$ 47' N to $9^0$ 15'N and longitude of $78^0$ 12'E to $79^0$ 14'E covering an area of 623 ha along the 140 km stretch between Tuticorin and Rameswaram in the state of Tamil Nadu, India.

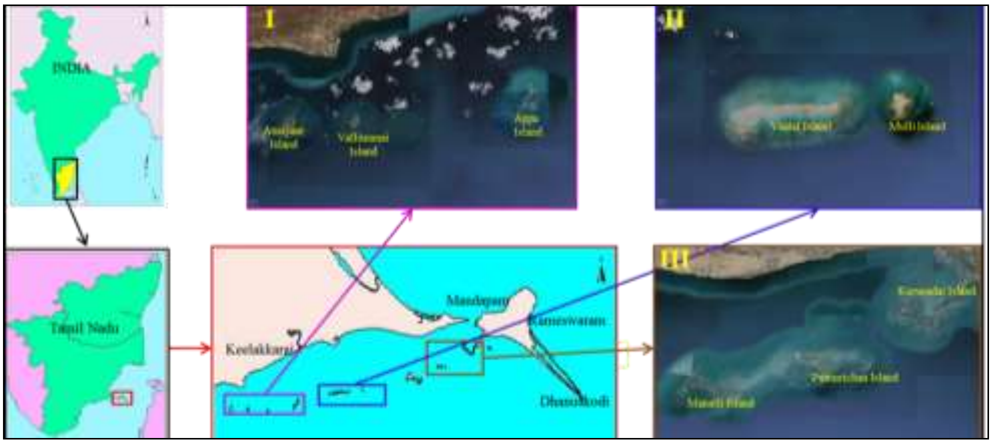


**Fig 1:** Location of Gulf of Mannar in Tamil Nadu, India, and a Google earth image depicting the study sites of I, II & III.

As many as 133 species of corals and its reef of fringing and patchy type are present at 5 m depth around the islands. This area is remarkable for its faunal and floral wealth, especially the coral reefs and its associates [24]. Fig.1 shows the Location of GoM in Tamil Nadu, India, and a Google earth image depicting the study sites of I, II & III.

## 3. Materials and Methods

### 3.1 Processing Overview

An overview of the processing procedure is described in Fig.2. This approach for deriving fractional abundance of coral reef benthic communities using landsat-8 imagery includes pre-processing routines, Such as atmospheric and water column correction. The atmospherically corrected images doesn't reveal any significant sun-glint effect, therefore no sun-glint correction is applied to the images.

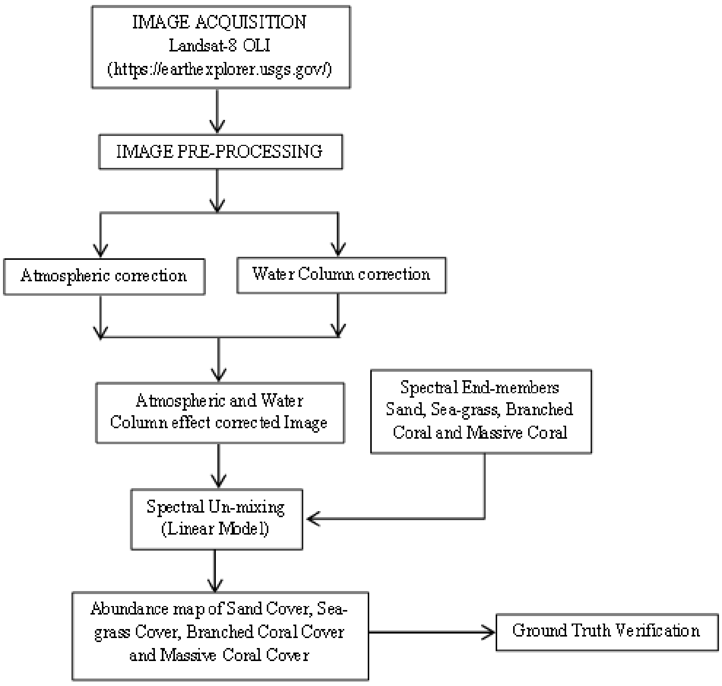


**Fig 2:** Overview of Image processing procedure.

The spectral end-members representing carbonate sand, sea-grass, branched coral and massive corals recorded from *in-situ* are used as input for spectral un-mixing using linear model for deriving the per-pixel contribution of each of the spectral end-members, and thus an abundance fraction map of those benthic compositions.

### 3.2 Landsat Imagery

Landsat imagery of the study area was acquired on two different dates; the image of Group-I and Group-III was acquired on 25 March 2017 and the image of Group-II was acquired on 05 February 2017 by NASA's Landsat-8 satellite mission with OLI payload. The satellite images were downloaded from United States Geographical Survey website (https://earthexplorer.usgs.gov/).

### 3.3 Image Pre-processing

The total signal received by satellite sensors are dominated by radiance contributed through atmospheric scattering [27]. Thus, atmospheric correction is essential to retrieve signals from the sea. The atmospheric correction for the images presented in this study is performed using default approach given in NASA SeaDAS 7.2. The atmospherically corrected images doesn't reveal any significant sun-glint effect, therefore no sun-glint correction is applied to the images. A fundamental challenge for remote sensing of coral reefs is the existence of the water column above the bottom features of interest (i.e., the benthic habitat) [27].

The water column correction for the images presented in this study is performed using Lyzenga's [18] algorithm. This algorithm calculates the "depth invariant bottom index", which corrects for water column effect using pairs of multispectral bands instead of calculating bottom reflectance for each band. Lyzenga's algorithm is currently one of the most popular approaches for water column correction among others and the use of this methodology has resulted in increased mapping accuracy by digital classification processes [23].

### 3.4 End-member Collection

End-members are spectra that are chosen to represent pure surface materials in a spectral image. The End-members selected for Gulf of Mannar included sand, sea-grass, branched coral and massive coral. The characteristics of each end-member were based on measurements of *in-situ* data collected from various locations throughout the Gulf of Mannar in March-2017, August-2017 & March-2018. Data were acquired using RAMSES-TriOS Hyperspectral radiometer ranges between the wavelengths of 350 nm – 900 nm at a bandwidth of 3 nm encased in a custom underwater housing. Individual reflectance measurements were grouped by species and substrate type and then consolidated into the components of sand, sea-grass, branched coral and massive coral. The spectral properties of individual coral reef species and its associated features in Gulf of Mannar were discussed by Kandasami Nimalan *et al*. Fig.3 shows the spectral characteristics of end-members considered in this study.

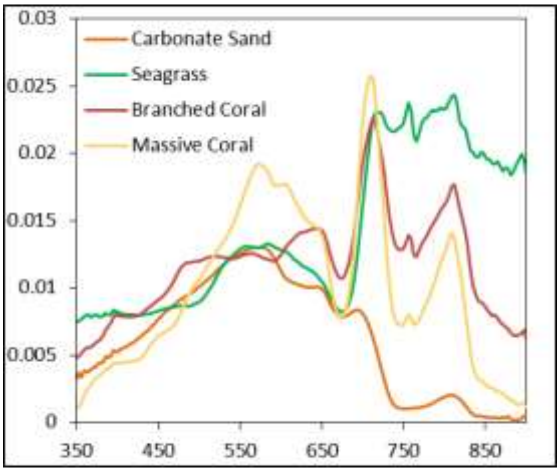


**Fig 3:** Spectral Signatures of Carbonate Sand, Sea-grass, Branched Coral and Massive Coral.

### 3.5 Linear Spectral Unmixing

Constrained linear unmixing model is used to achieve a classification of benthic composition. In spectral unmixing, each pixel in the image is assumed to be a linear combination of the selected spectral endmembers, where the fractional spectral contribution from each endmember is equivalent to the fractional spatial contribution of the corresponding reef component. The result of the unmixing is a measure of the membership of the individual endmember to the source spectrum. This measure is called the endmember's abundance. The unmixing algorithms are based on the following linear mixing model, which assumes that a spectrum is a linear superposition of end-members (https://seadas.gsfc.nasa.gov/help/).

$$R_k = \sum_{i}^{n} a_i \, . E_{i,k} + \varepsilon_k$$

$$RMSE = \sqrt{\left(\sum_{k}^{m} \varepsilon_k^2\right)^{-m}}$$

$R_k$ = Reflectance of source at wavelength $k$

$E_{k,i}$ = Reflectance of endmember $i$ at wavelength $k$

$a_i$ = Abundance of endmember $i$

$\varepsilon_k$ = Error at wavelength $k$

RMSE = Root Mean Square Error of the $\varepsilon_k$

$N$ = Number of endmembers

$M$ = Number of the wavelengths in the discrete spectrum

## 4. Results and Discussions

The purpose of generating True Colour Composite (TCC) image is to resemble closely what would be observed by the human eyes. The TCC for the study area is generated with Landsat-8 images by assigning R-655 nm; G-561 nm; B-482 nm and is shown in Fig.4A.

In contrast to a true-colour image, a false-colour image sacrifices natural colour rendition in order to ease the detection of features that are not readily discernible. The display colour assignment for any band of an image can be done in an entirely arbitrary manner. In this case, the colour of a target in the displayed image does not have any resemblance to its actual colour. The choice of spectral bands is governed by the physical properties of the object under investigation. The False Colour Composite (FCC) image for this study is generated by assigning the R-1609 nm; G-2201 nm; B-865 nm since the best wavelength region for discriminating land from water is the near-infrared and middle-infrared regions at wavelengths between 740 – 2500 nm [16] and is shown in Fig.4B. In this display scheme, the land and cloud portions are masked out and appears in grey colour, coral reefs in the study area appears on the bluish colour and water portion appears in black colour.

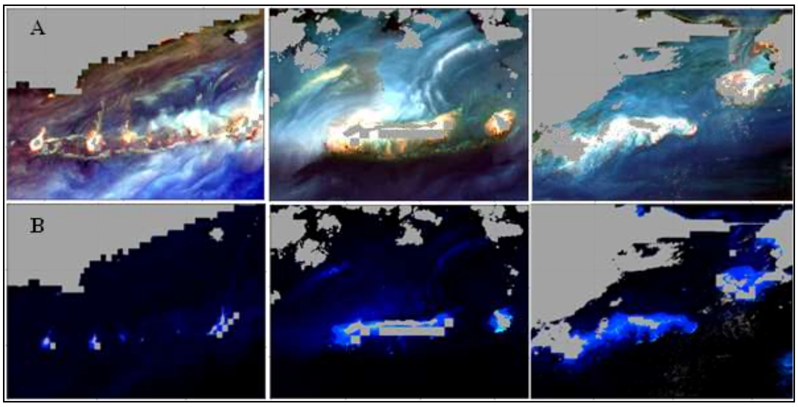


**Fig 4:** A, True Colour Composite Image of various islands represented in the study area; B, False Colour Composite Image of various islands represented in the study area.

### 4.1 Spectral Unmixing

Spectral Unmixing is the procedure by which the measured spectrum of a pixel is decomposed into a collection of spectral endmembers and a set of corresponding fractional abundances within the pixel [6, 19, 20].

Spectral unmixing offers a fundamentally different habitat map product to a conventional per-pixel classification. A per-pixel classification generates a single habitat map that identifies the dominant benthic component inside each pixel's field of view in accordance with its overall spectral properties, whereas an unmixing classification generates several maps depicting the relative contribution from each benthic component inside the study area [26]. Spectral unmixing results are highly dependent on the input endmembers; changing the endmembers leads to changes in the results. The number of endmembers must be less than the number of spectral bands and all of the endmembers in the image must be used. In this study, the number of spectral bands available is 5 (443 nm, 482 nm, 561 nm, 655 nm & 865 nm) and the number of endmembers considered is 4 (Carbonate Sand, Sea-grass, Branched Coral and Massive Coral). This satisfies the criteria of number of endmembers must be less than the number of spectral bands. The result produced using linear spectral unmixing technique is depicted in Fig. 5.

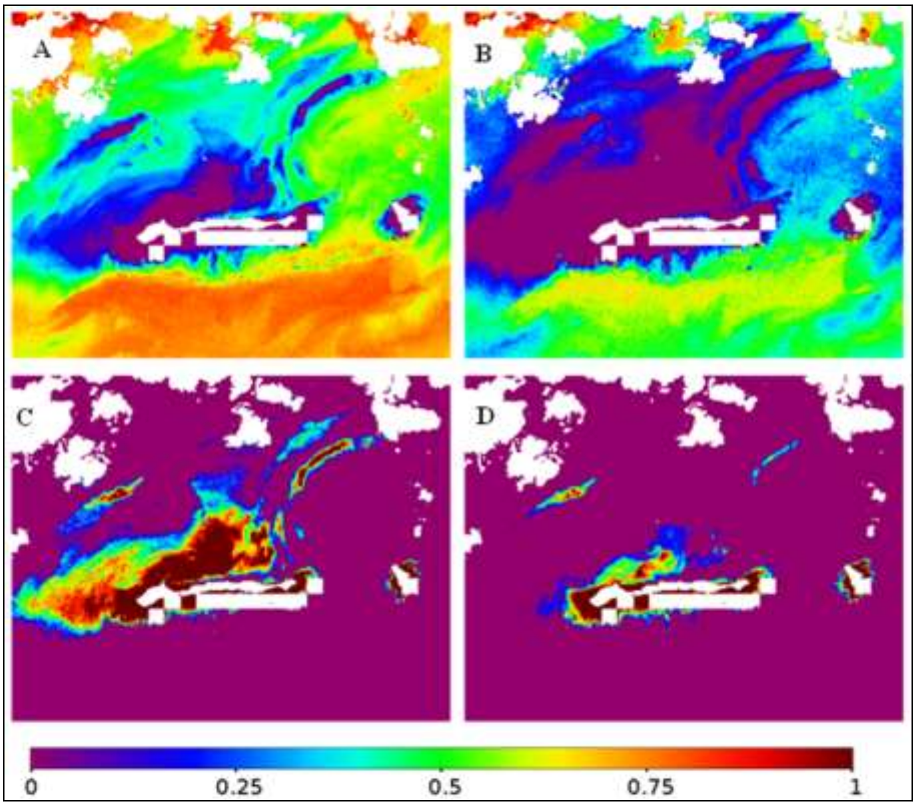


**Fig 5:** Fractional abundance of various benthic compositions; A, Sand; B, Sea-grass; C, Branched Coral; D, Massive Corals.

The image is classified as four categories; category-A depicts the Fractional abundance of sand in corresponding study site; category-B depicts the Fractional abundance of sea-grass in corresponding study site; category-C depicts the Fractional abundance of branched corals in corresponding study site; and category-D depicts the Fractional abundance of massive corals in corresponding study site. Individually, each of these maps illustrates the distribution of a single component of the reef community, while together they represent the overall habitat composition.

In this display scheme, the land and cloud portions are masked out and land portions will be appears in grey colour and cloud cover will be appears in white colour. This kind of abundance maps provides information on habitat structure and composition at a local scale and as well as provides the estimates of habitat diversity. Also, this kind of mapping enables large-scale, multi-site mapping of coral reefs [3, 25]. It can be observed that, the spatial distribution of branched coral is comparatively higher than the spatial distribution of massive corals. Areas at where, the spatial distribution of coral reef is dominant benthic coverage, those are the sites that are important and care must be taken for protection of those areas. Comparison of different benthic compositions provided the insight on processes that takes place with one other. In places where the fraction abundance of branched and massive corals is predominant (mostly around the islands) the fraction abundance of seagrass is null and vice versa.

### 4.2 Ground Truth

Field surveys were performed at March-2017, August-2017 & March-2018 across the Gulf of Mannar Islands. A total of 7 control points were visited during the March-2017 (Concurrent to Landsat-8 Image Acquisition). Each point was located with the help of GPS co-ordinates and the benthic components present in the particular point (Sea-grass, Branched Coral and Massive Coral) were visually examined by group of experienced professionals. Fig.6 shows the field pictures of various benthic compositions present in GoM.

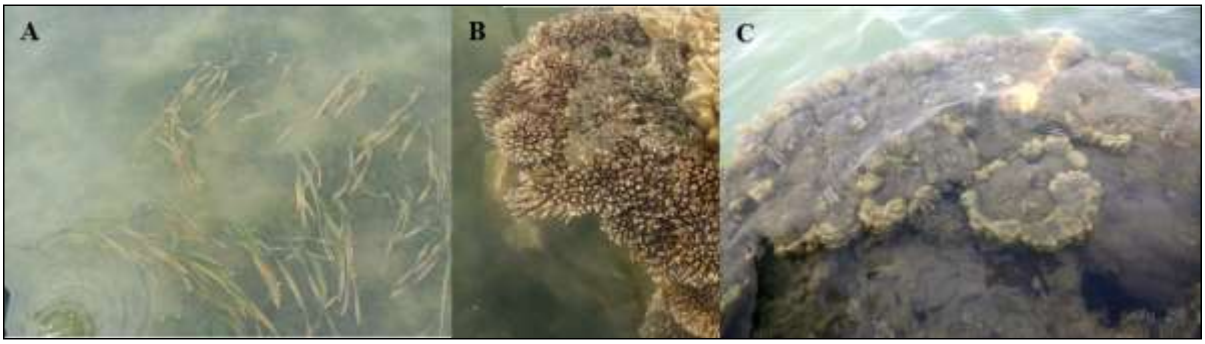


**Fig 6:** Field pictures of **A,** Sea-grass; **B,** Branched Corals; and **C,** Massive Corals.

## 5. Conclusion

This study provides the comprehensive way for assessing the abundance fraction of various benthic coverage's (sand, sea-grass, branched corals and massive corals) using linear spectral unmixing analysis. The results can be utilised in a practical manner to generate estimates of the various components present in coral reef community. Such maps can also be used to characterize the landscape structure and composition of reefs, which can in turn be linked to environmental and human impacts. However, the broad width of these sensor's spectral bands limits accurate discrimination of more specific benthic features, since many biotic features (coral, seagrass and macroalgae) have similar reflectance characteristics, and it is suggested that hyperspectral sensors can better differentiate such features [13]. In turn, these kinds of remote sensing approaches are cost-effective and act as a valuable tool for the evaluation and periodical monitoring of coral reef community.

## 6. Acknowledgements

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### Conflict of interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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