Spectral response of marine submerged aquatic vegetation: a case study in Western Australia coast

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Abstract— **Marine submerged aquatic vegetation (SAV) plays a vital role as habitats, nursery and feeding grounds for a wide range of marine aquatic and terrestrial life. Recently, remote sensing techniques have been successfully applied in marine benthic mapping in coastal waters. However, the majority of these techniques have focused on either seagrasses meadows or coral reefs. There are a few studies that have been published validating a methodology for mapping SAV on brown macroalgae (*Sargassum* spp., *Ecklonia* spp.), seagrasses, and/or other macroalgae groups by spectral response from remote sensing. Hence, we studied the *in-situ* optical properties of living macroalgae, seagrasses, and rubble. The spectral characteristics of varied SAV groups were measured using the high resolution FieldSpec® 4 Hi-Res portable spectroradiometer. The study site selected was the Shoalwater Islands Marine Park, Rockingham, Western Australia as it is one of the fifteen biodiversity hotspots in Australia. Correlation and Principle Component Analysis were employed to evaluate the differences between SAV groups. The results have documented the spectral features of SAV and their associated habitats in Shoalwater Islands Marine Park, Western Australia, and developed a spectral library to distinguish among seagrass species and algae groups (green, red, and brown benthic macroalgae). The implications of this study will contribute to estimate and detect the distribution and seasonal variation of SAV on a broader scale.**

Keywords— spectral reflectance, macroalgae, coral rubble, SAV, marine submerged aquatic vegetation

I. Introduction

Marine submerged aquatic vegetation (SAV) is an important component of the coastal inter-tidal and sub-tidal ecosystems due to their ecological and conservational values [1], [2]. In coastal and estuarine areas, SAV is well-defined as a combination of seagrasses, oligohaline grass, benthic macroalgae, and floating macroalgae that covers from 10 to 100% substrates. In this study, we focused on the two main abundant SAV groups of seagrasses and benthic macroalgae, which play an important role in coastal marine ecosystems in Western Australia (WA). There are three basic groups of reef macroalgae that consist of turf algae, crustose calcareous algae, and fleshy macroalgae. Of those, turf algae and macroalgae are the main sources of carbon fixation and provide primary productivity for reef organisms [3]. Based on the characteristics of pigment composition we have divided the benthic macroalgae groups into three sub-groups consisting of red, green, and brown macroalgae.

However, the evaluation of large scale SAV distribution, seasonal fluctuations, and the effect of environmental factors is quite demanding due to the limited study areas and the combination of interdisciplinary knowledge [4]. Therefore, remote sensing has been used as a useful tool for SAV monitoring in both freshwater and saltwater environments [5]. A number of techniques have been widely adopted for the classification of marine habitats using *in-situ* substrate reflectance [6], [7]. There are two common techniques of remote sensing now includes access to specific study objectives and spectral reflectance. *i)* Understand the characteristics of spectral reflectance of SAV objects to distinguish them; *ii)* Based on the ground truthing data to extract the spectral reflectance from remote sensing data. The spectral reflectance of SAV has an important role in the analysis and interpretation of habitat classification. However, the collection of SAV specimens and their spectral reflectance, with measurements of the optical properties of water in the field are time and labor-intensive and may also be affected by weather conditions (e.g. [5], [8], [9]). Therefore, the establishment of a spectral reflectance library of SAV spectral is necessary to assess the distribution of coastal marine SAV in larger scale remotely sensing.

There have been a number of studies analyzing many spectral reflectance characteristics of marine benthos objects. However, these studies have focused on the spectral reflectance of the sea surface [9], [10], [11], [12], planktonic algae such as pelagic *Sargassum* [13], [14], [15], analyzing the spectral reflectance of coral reef benthos such as live and dead corals [7], [8], [16], [17], fresh water SAV [5], [6], [18], seagrasses [15], [18], [19], [20], [21] and terrestrial mangroves [22], [23], [24], [25]. At present, there are a few studies that document the spectral reflectance of the coastal substrate components including seagrass, macroalgae, and their substrates (sandy, coral, and limestone rocks) [8], [26]. Therefore, the major objective of the present study aimed to gather optical data of macroalgae (red, green, and brown), seagrasses, and sediment characteristics in coastal waters in order to support the selection of spectral bands and bandwidths for different environmental conditions such as clear water and high turbidity water bodies and to choose suitable satellite sensors for different benthos. This study may contribute as the primary spectral reflectance profile library for marine macroalgae with a comprehensive data on SAV species components and their associated substrates to provide input foundation information

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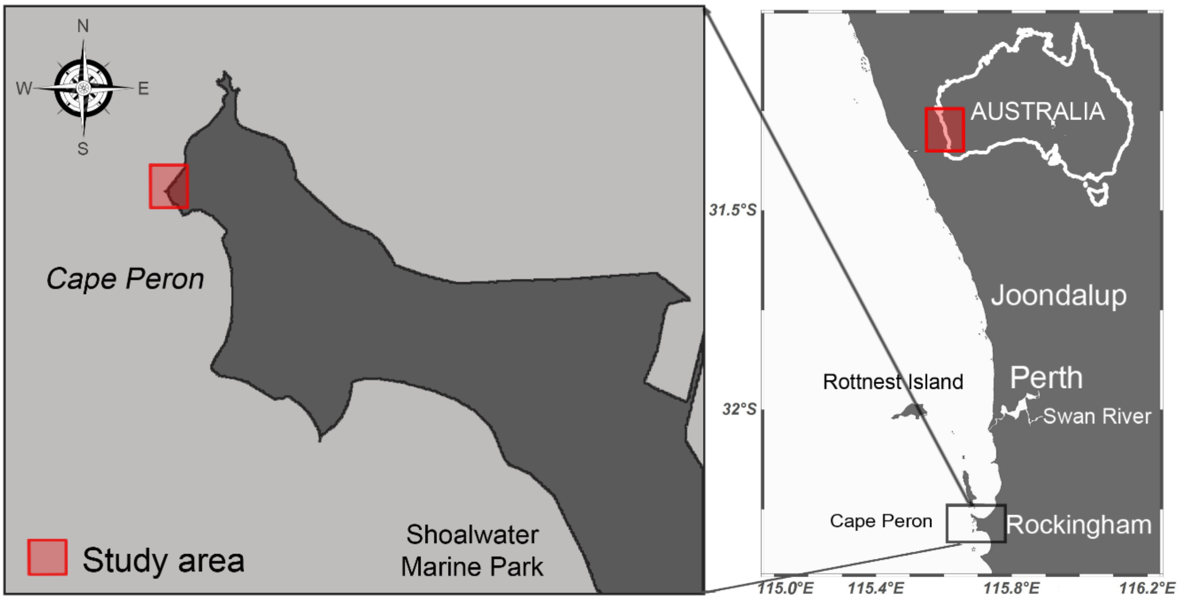

Fig. 1. Location of the study area, Cape Peron in indicated in the red box and is part of the Shoalwater Islands Marine Park, Western Australia coast

for remote sensing studies that assess the distribution and seasonal variation of coastal marine SAV ecosystems.

II. Data & Methods

A. Study Area and Sample Collection

Twenty-two (22) submerged coastal aquatic plants species that included red, green, brown macroalgae, and seagrasses (Table I) were collected from Cape Peron, Western Australia (32.2715 °S, 115.6865 °E) to measure their *in-situ* spectral reflectance (Figure 1). Cape Peron belongs to the Shoalwater Islands Marine Park, Rockingham, WA and is one of the fifteen biodiversity hotspots in Australia.

SAV samples were collected by free-diving at inter-tidal and sub-tidal areas of Cape Peron at the depth range from 0.5 to 2.0 m. The collected samples were stored in chilled containers and transferred to Curtin Aquatic Research Laboratory within two hours. The fresh SAV samples were overnight stocked in bulk tanks with the filtered seawater and aeration. The spectral reflectance of the SAV samples was measured the following day under clear sky conditions.

B. Spectral data collection

In air spectral reflectance profiles were acquired at wavelengths between 350 to 2151 nm at 1 nm resolution. The FieldSpec® foreoptic via the pistol grip was clamped to a retort stand 30 cm directly above the test sample at a small angle off nadir. At this distance the 25º field of view of the foreoptic completely captured the area occupying the benthic sample. The reflectance measurements were carried out by the high resolution FieldSpec® 4 Hi-Res portable spectroradiometer on a cloudless day between 10:00 am and 2:00 pm local hours. A white spectralon plate was used as the reference and optimization was done first before recording the reflectance of each sample. The spectral reflectance profiles were measured at the outdoor experiment facility of the Physics Department, Curtin University, Australia.

C. Data Analysis

The spectral data were transferred into the statistic package to analysis. Correlation and spectral clustering were employed to evaluate the differences between SAV groups. One-way ANOVA was used to determine any significant different SAV pair at each wavelength band. Principle Component Analysis (PCA) technique was done with IBM-SPSS 20 factor analysis.

Table I. THE CHECK LIST OF COLLECTED SUBMERGED AQUATIC SPECIES FROM THE SHOALWATER ISLANDS MARINE PARK

SAV groups	Species	Acronym
Brown macroalgae	*Sargassum linearifolium* *Sargassum spinuligerum* *Ecklonia radiata* *Colpomenia sinuosa*	*Sal* *Sas* *Ecr* *Cos*
Red macroalgae	*Asparagopsis armata* *Hypnea ramentacea* *Ballia* sp. *Amphiroa anceps* *Euptilota articulata* *Ballia callitrichia* *Metagoniolithon stelliferum*	*Asa* *Hyr* *Bas* *Amp* *Eua* *Bac* *Mes*
Green macroalgae	*Ulva australis* *Entermorpha sp.* *Codium duthieae* *Caulerpa germinata* *Caulerpa flexis* *Bryopsis vestita*	*Ula* *Ens* *Cod* *Cag* *Caf* *Brv*
Seagrass	*Amphibolis antartica* *Posidonia* sp.	*Ama* *Pos*
Sand/sediment	Sediment Sediment/Rubble Limestone rocks with red coralline algae covering	Sed Ser Lir

III. Results & Discussion

A. The Spectral Characteristics of SAV

The comparison of the measured spectral reflectance value of SAV groups and their associated substrate revealed the significant spectral reflectance and absorption regions. There are significant differences in reflectance spectra characterizing red, green, brown macroalgae, and seagrass (Fig. 2).

- The red macroalgae contained reflectance peaks in the red spectral regions (580 nm) and strong absorption features in blue and green spectral regions (Fig. 2a).
- The green macroalgae had common absorption features with peaks at blue spectral regions (450 nm) and maximizes spectral reflectance in the green spectral regions (550 nm). Of those, *Ulva australis* and *Bryopsis vestita* have spectral reflectance value of 0.06 and 0.09, respectively, and greater than the four remaining species in the group with the spectral reflectance peaks value of 0.04 (Fig. 2b).
- The brown macroalgae had strong spectral absorption peaks in the blue and green spectral regions (400-550 nm). The spectral reflectance peaks were observed between 600 and 650 nm. In particular, *Colpomenia sinuosa* has the highest spectral reflectance with value of 0.065. Following *Ecklonia radiata* the spectral reflectance peak valued at 0.04. Meanwhile, the lower peak reflectance values of two *Sargassum* species' spectral absorption and reflectance reaches 0.03 (Fig. 2c).
- There was a significant difference in spectral profiles between *Posidonia* sp. and *Amphibolis antartica. Posidonia* sp. had maximum spectral absorption in blue and green spectral regions (450-550 nm) and maximum reflectance in the red spectral region (600-650 nm). While, *Amphibolis antartica* had spectral absorption in blue spectral regions (400-500 nm) and spectral reflectance peak in green spectral region (550 nm) (Fig. 2d).

B. Factors Affecting the SAV Spectral Characteristics

The score plot (Fig. 3) represents the first two eigenvectors from the PCA that cumulatively explained 92.3% of the spectral variance. In this figure red macroalgae are predominantly constrained on the lower left hand area of the plot. The first two components of the PCA analysis have high effectiveness in separating the data between macroalgal groups. The classification revealed that there are undoubtedly distinctions between SAV groups based on their spectral characteristic and pigment composition [26]. There were only a few species of seagrasses and red macroalgae, *Asparagopsis armata* misclassified. For example, the *Posidonia* sp. was classified as near green macroalgae, while *Amphibolis antartica* had spectral characteristics similar to the red macroalgae. In addition, the red macroalgae, *Asparagopsis armata* was hierarchical near the brown macroalgae group (Fig. 3).

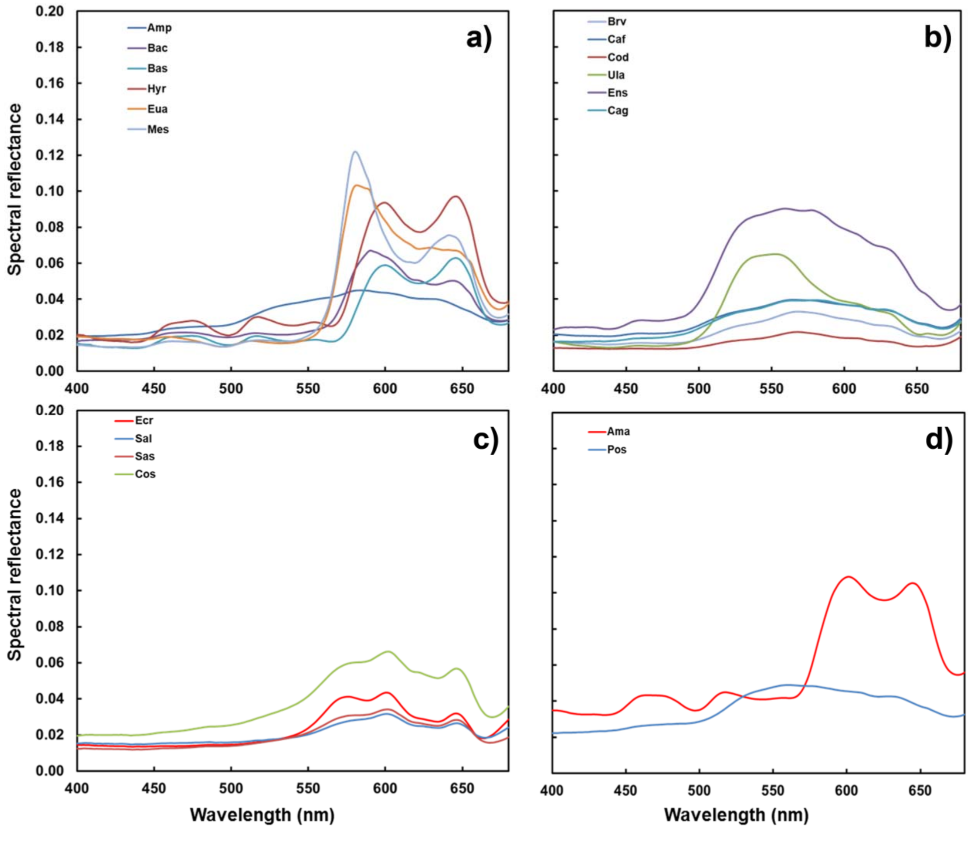

Fig. 2 The selected mean *in-situ* reflectance signature of marine submerged aquatic vegetation (SAV) group of (a) red algae (b) green algae, (c) brown algae, and (d) seagrass at visible wavelengths (400 – 680 nm) (n = 20)

The primary analysis showed that the SAV groups can be accurately classified from remote sensing data based on their spectral reflectance profiles [27]. PCA results showed the significant differences between SAV groups as well as their associated bottom substrates. The separation of different macroalgae species within the same group is feasible and proven accurate through the t-test. However, the problem with this analysis is based on the hyperspectral measurements at 1 nm. While, multispectral satellite sensors such as WorldView-2 (WV-2) and Landsat are only few wavebands which will not capture those reflection peaks. The other issue is that there is an impeding water column between the benthos and the sensor. Since the 1970s, it has been known that the water column, especially the depth, greatly reduce the capability of remote sensing to distinguish between benthic classes at depth [28].

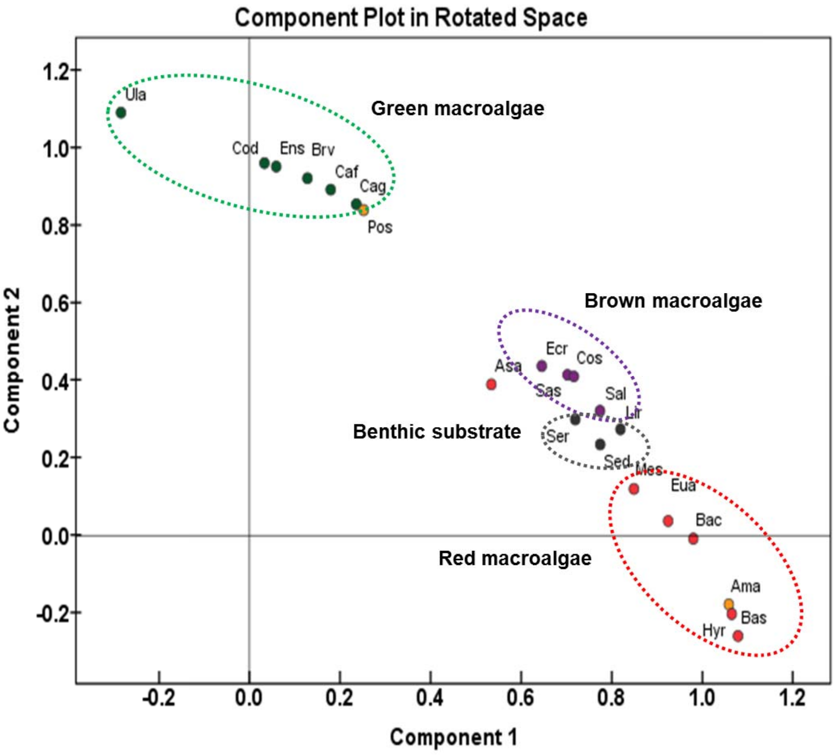

Fig. 3. PCA component 1 and 2 scatter plot labelled by marine submerged vegetation (SAV) group. Five groups of SAV are indicated by different circles (i) red algae in red circles, (ii) benthic substrate in black circles, (iii) brown algae in violet circles, (iv) seagrasses in orange circles, and (v) green algae in green circles.

The collection of SAV samples for establishes the spectral reflectance library should be considered to the seasonality of SAV species. The difference in the spectral profiles of two seagrasses species in this study is a typical example. There were only two seagrass species in this group, but each species had the different absorption characteristic and spectral reflectance. *Amphibolis antartica* had spectral characteristics similar to the green macroalgae, while *Posidonia* sp. had similar spectral characteristics to red macroalgae. This can be explained by biological characteristics of SAV in sample collection time. Notably, at the time of sampling, *Posidonia* sp. species was the end of the growing season [29], [30] and the sample of *Posidonia* sp. samples were collected just the above-ground, which could be the remain of plant senescence part. Therefore, there were modified pigment compositions of *Posidonia* sp. itself in different phenology phases of SAV.

The challenge arises when there is a water column which modulates the spectral reflectance of the benthos and where different substrates start to look the same, thereby significantly reducing the capability of remote sensing. The other issue is that the majority of benthic habitat classifications are done with high spatial resolution satellites that only have a handful of spectral bands in the visible domain, such as WV-2, IKONOS, QuickBird, and Landsat 7, 8. The lower spectral resolution has often led to a lower ability to differentiate between the classes. Hence, combined with the effects of variable water column and we have a very difficult problem to solve.

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