Multispectral Resampling of Seagrass Species Spectra: WorldView-2, Quickbird, Sentinel-2A, ASTER VNIR, and Landsat 8 OLI

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Abstract. Although spectrally different, seagrass species may not be able to be mapped from multispectral remote sensing images due to the limitation of their spectral resolution. Therefore, it is important to quantitatively assess the possibility of mapping seagrass species using multispectral images by resampling seagrass species spectra to multispectral bands. Seagrass species spectra were measured on harvested seagrass leaves. Spectral resolution of multispectral images used in this research was adopted from WorldView-2, Quickbird, Sentinel-2A, ASTER VNIR, and Landsat 8 OLI. These images are widely available and can be a good representative and baseline for previous or future remote sensing images. Seagrass species considered in this research are Enhalus acoroides (Ea), Thalassodendron ciliatum (Tc), Thalassia hemprichii (Th), Cymodocea rotundata (Cr), Cymodocea serrulata (Cs), Halodule uninervis (Hu), Halodule pinifolia (Hp), Syringodium isoetifolium (Si), Halophila ovalis (Ho), and Halophila minor (Hm). Multispectral resampling analysis indicate that the resampled spectra exhibit similar shape and pattern with the original spectra but less precise, and they lose the unique absorption feature of seagrass species. Relying on spectral bands alone, multispectral image is not effective in mapping these seagrass species individually, which is shown by the poor and inconsistent result of Spectral Angle Mapper (SAM) classification technique in classifying seagrass species using seagrass species spectra as pure endmember. Only Sentinel-2A produced acceptable classification result using SAM.

Keywords: seagrass, species, resampling, spectral resolution, multispectral

1. Introduction
Presently, multispectral image is still the primary source of remote sensing data for seagrass mapping [1]. However, the limited number of spectral band of multispectral image limit the possibility of accurate seagrass mapping, especially when mapping their species composition. Mapping seagrass species is a challenging task, either using multispectral or hyperspectral image [2]. Sub-pixel species composition mixing adds the complexity of benthic habitat mapping using remote sensing image...
and this includes seagrass species mapping. Several seagrass species may present together and create mix-species seagrass beds, for instance, smaller species such as *Cymodocea rotundata* (Cr) frequently present under bigger species such as *Enhalus acoroides* (Ea) [5].

Seagrass species is spectrally-different [6][7][8]. However, the difference is primarily not in the spectra shape but in the absolute reflectance value [8]. This becoming an issue for spectral-based algorithm such as Spectral Angle Mapper (SAM), which utilized spectra shape instead of the variation in the absolute reflectance [9]. Furthermore, the limited band of multispectral image simplifies the spectra shape of seagrass species and generalizes the unique absorption feature of different seagrass species. Therefore, it is important to quantitatively assess the possibility of mapping seagrass species using multispectral images by resampling seagrass species spectra to multispectral bands. In addition, it is also important to assess to which extent seagrass species spectra can be used as the input endmember for SAM algorithm for seagrass species classification using multispectral image.

2. Study Area and Image Data

This study was conducted in Karimunjawa Islands National Park, Jepara Regency, Central Java. Astronomically, the National Park is located between 110°23'32'' – 110°31'29'' E and 05°45'06'' – 05°54'59'' S. Karimunjawa main islands consist of land and open water areas about 7.645 ha, especially 3.097 ha for shallow sea water area. Figure 1 shows the location study area. Shoreline typology of Karimunjawa islands consist of sandy shore and mangrove habitat. Shallow water area up to the depth of 20 m consist of seagrass, coral reef, and bare substratum. Seagrass can be found mainly in optically-shallow water near the shoreline, with *Enhalus acoroides* (Ea), *Cymodocea rotundata* (Cr), and *Thalassia hemprichii* (Th) as the most dominant species. Based on Karimunjawa Islands National Park report, there are nine seagrass species found in Karimunjawa Islands [10].

![Figure 1. Sentinel-2A image of Karimunjawa and Kemujan Island in study area. Small islands surrounding these two main Islands are also visible.](image)

This study used five multispectral images that have been frequently used for remote sensing-based seagrass mapping [1][2][3][11][12]. These images are WorldView-2, Quickbird, Sentinel-2A, ASTER VNIR, and Landsat 8 OLI. These images representing remote sensing data with different spatial resolution that still able to detect seagrass patch. Spectral bands specification of these images is provided in Table 1. Atmospheric correction was performed using Dark-Object Subtraction (DOS) method as described in [13] for WorldView-2, ASTER VNIR and Landsat 8 OLI, while Fast Line-of-Sight Atmospheric Analysis of Hypercubes (FLAASH) method was applied to Quickbird image.
Sentinel-2A was atmospherically-corrected using Sen2Cor module. Afterward, sunglint correction was performed on all images using method developed by [14].

| Image          | Acquisition Date (dd/mm/yyyy) | Bands (Wavelength in nm) | Central Wavelength (nm) | Pixel Size (at nadir) | Radiometric resolution |
|----------------|-----------------------------|--------------------------|-------------------------|-----------------------|------------------------|
| WorldView-2    | 24/05/2012                  | Coastal (400 - 452)      | 427.0                   | 1.84 m                | 11 bits                |
|                |                             | Blue (448 – 510)         | 278.0                   |                       |                        |
|                |                             | Green (518 – 586)        | 546.0                   |                       |                        |
|                |                             | Yellow (590 – 630)       | 608.0                   |                       |                        |
|                |                             | Red (632 – 692)          | 659.0                   |                       |                        |
|                |                             | RedEdge (706 – 746)      | 724.0                   |                       |                        |
|                |                             | NIR1 (772 – 890)         | 831.0                   |                       |                        |
|                |                             | NIR2 (866 – 954)         | 915.0                   |                       |                        |
| Quickbird      | 23/08/2004                  | Blue (430 – 545)         | 477.2                   | 2.44 m                | 11 bits                |
|                |                             | Green (466 – 620)        | 555.7                   |                       |                        |
|                |                             | Red (590 – 710)          | 658.1                   |                       |                        |
|                |                             | NIR (715 – 918)          | 803.1                   |                       |                        |
| Sentinel-2A MSI| 19/05/2017                  | Blue (458 – 523)         | 490.0                   | 10 m                  | 12 bits                |
|                |                             | Green (543 – 578)        | 560.0                   |                       |                        |
|                |                             | Red (650 – 680)          | 665.0                   |                       |                        |
|                |                             | NIR (785 – 900)          | 842.0                   |                       |                        |
| ASTER VNIR     | 26/08/2004                  | 1 (520 – 600)            | 556.0                   | 15 m                  | 8 bits                 |
|                |                             | 2 (630 – 690)            | 661.0                   |                       |                        |
|                |                             | 3N (780 – 860)           | 807.0                   |                       |                        |
| Landsat 8 OLI  | 18/05/2017                  | Coastal (435 – 451)      | 442.9                   | 30 m                  | 16 bits                |
|                |                             | Blue (441 – 515)         | 482.1                   |                       |                        |
|                |                             | Green (525 – 600)        | 561.4                   |                       |                        |
|                |                             | Red (630 – 680)          | 654.6                   |                       |                        |
|                |                             | NIR (845 – 885)          | 864.6                   |                       |                        |

3. Method

3.1. Sample Collection and List of Species

Seagrass species sample collection was done by using harvest method in seagrass bed of optically-shallow water area. Seagrass leaves of different species were harvested in a healthy and fresh conditions, and were put into non-translucent bottle and were placed inside cool box until spectra measurement was performed. This was done to prevent structural and leaf pigment damages due to the delay between harvesting time and spectra measurement (6 hours differences in average for all species). List of seagrass species collected from the field is listed on Table 2.
Table 2. List of seagrass species collected from Karimunjawa Islands

| No | Species              | Abbreviation |
|----|----------------------|--------------|
| 1  | Enhalus acoroides    | Ea           |
| 2  | Thalassia hemprichii | Th           |
| 3  | Cymodocea rotundata  | Cr           |
| 4  | Cymodocea serrulata  | Cs           |
| 5  | Halophila ovalis     | Ho           |
| 6  | Halophila minor      | Hm           |
| 7  | Halodule uninervis   | Hu           |
| 8  | Halodule pinifolia   | Hp           |
| 9  | Thalassodendron ciliatum<sup>a</sup> | Tc |
| 10 | Syringodium isoetifolium | Si |

<sup>a</sup>Tc was collected from Nusa Lembongan Island as accuracy control

3.2. Spectra Measurement
Spectra measurement was done above water surface on harvested seagrass leaves. Each species leaves stored in bottle were grouped until covering an area with minimum size of 25 mm<sup>2</sup>. The spectra measurement instrument is the field spectrometer Jaz EL-350 VIS/NIR with 350 – 1100 nm wavelength range (effective at 400 – 900 nm). The white and dark reference was calculated by measuring the reflectance of white reference (Spectralon® WS-1-SL) and dark reference (performed by covering the collimating lens with its cap). Spectrometer default field-of-view is 14.25°, hence, to prevent mixing with background spectral responses, the spectra measurement was conducted very close to the seagrass leaves. The setting for spectra measurement, including Boxcar width, Scans-to-average, and Electric dark correction were similar with the setting published in [8] and [15]. We also added the spectra measurement of Tc as a control in the spectral-based classification. Tc spectra were measured from samples collected in Nusa Lembongan Island. Each species was measured several times and the average spectra were calculated. The output of spectra was recorded as .jaz format data and was processed in spreadsheet after being converted to ASCII format.

3.3. Spectra Resampling
The seagrass species spectra were resampled based on the spectral resolution of multispectral images. Resample procedure can be performed in several ways, such as using image containing central wavelength of each band, ASCII format file that contains central wavelength, or pre-defined filter function provided by image processing software. In this research, we used pre-defined filter function for each multispectral image.

3.4. Spectra Analysis (Tukey-Test)
Post-Hoc Analysis Tukey-test commonly used to assess the statistical difference between data groups. Tukey-test represents the differences between groups statistics more explicitly. Therefore, this method can be applied on spectra data to identify if seagrass species can be spectrally distinguished. Tukey-test analysis procedure was divided into three steps, i.e., one-way ANOVA calculation, yardstick of honestly significant difference (HSD) calculation, and pairwise comparisons (Tukey matrix calculation). Each seagrass species spectra data between 400 – 900 nm was treated as individual group. Therefore, there are 10 groups of seagrass species as listed in Table 2.

One-way ANOVA test was performed to gain average value of entire reflectance’s value in each group ($\bar{X}$), number of treatments or groups ($K$), and number of spectral data or wavelength within a group ($N$). $SS_w$ and $df_w$ value were required to calculate the mean square error within groups ($MS_w$) using equation (1).
\[ MS_{wi} = \frac{SS_{wi}}{df_{wi}} \]  

(1)

\( SS_{wi} \) is sum of square within group and \( df_{wi} \) is degree of freedom within groups from compared spectral groups. These two values were generated by one-way ANOVA calculation in spreadsheet.

Furthermore, \( MS_{wi} \) value was used to calculate the yardstick HSD value for determining the significantly difference margin. Yardstick calculation require \( MS_{wi} \), \( q \)-value, and \( N \). The \( q \)-value was obtained using table of critical values for studentized range with \( \alpha = 0.05 \) (required \( df_{wi} \) and \( K \) values). In addition, the Tukey-test can be continued if the \( P \)-value is less than 0.05. The yardstick HSD value was calculated using equation (2).

\[ HSD = q \left( \frac{MS_{wi}}{N} \right)^{1/2} \]  

(2)

Pairwise comparisons principle was used to test the mean of each species pair. Average value of each seagrass species obtained from one-way ANOVA was calculated for each absolute difference (e.g., |\(Ea - Th\)|; |\(Ea - Cr\)|; and |\(Th - Cr\)|). A pairwise comparison matrix was created for easier and structured difference calculation. Difference value of each seagrass species pair group was compared with the yardstick HSD value. If the difference value of pair group greater than the yardstick HSD value, then the two seagrass species spectra is honestly significantly different.

3.5. Spectral Angle Mapper (SAM)

SAM classification technique was applied on multispectral images to map seagrass species distribution. This technique is a physical-based spectral classification. SAM algorithm requires resampled spectra as pure endmember to determine spectra similarity between reference spectra and target spectra (pixel) [16]. The difference in the angle of radian between those spectra was used as threshold to classify image pixels to particular seagrass species class. SAM is insensitive to illumination and albedo effect, therefore noise such as atmospheric path radiance does not impact on classification process [9].

The radian angle threshold assigned for each image in SAM classification is 0.1; 0.4; 0.7; and 1.0. The threshold was set from the narrowest to the widest possible angle to identify the trend of seagrass species spatial distribution classified by SAM classification technique. Wider angle of radian threshold gives more opportunities for pixels to be classified, and vice versa.

4. Result and Discussion

4.1. Spectra of Seagrass Species

The spectra of seagrass species are shown in Figure 2. The shape of all seagrass species is relatively similar. There are two minor peaks identified around 600 nm and 635 nm for most seagrass species. \(Ea\) and \(Ho\) have higher reflectance up to 30% and 25% across visible wavelengths, meanwhile the rest are below 18%. \(Ea\) reflectance across the visible wavelengths are almost twice than other species, but \(Ho\) reflectance only higher than another species (except \(Ea\)) in green to red region of wavelengths. \(Cs\) and \(Si\) have the lowest reflectance in almost all visible wavelengths. However, \(Hu\) has the lowest reflectance of all in the red band region.
Figure 2. Spectra of ten seagrass species measured by field spectrometer.

All of these seagrass species spectra are similar to the spectra of healthy vegetation leaf. The major peak at ±550 nm indicates the domination of chlorophyll pigments. Since all species exhibit similar absorption band locations, but different in the strength of absorption, the pigment composition may be similar. However, the concentration of pigments between species is definitely unique.

4.2. Resampling Result of Species Spectra

Resampling result according to multispectral images is shown on Figure 3. The species spectra pattern of each image corresponds to the number and center wavelength of each band. Generally, compared to the field seagrass spectra (Figure 2), all resampled spectra are less precise and more generalized but still retain the same pattern of the original spectra i.e. Ea and Ho have higher reflectance than other species. It is more difficult to differentiate between species based on the resampled shape, which is caused by the limited band number and wider bandwidth. The peak reflectance of resampled spectra is still at 540 – 560 nm (green band) and the lowest reflectance is located between 650 – 670 nm (red band). The absence of blue band in ASTER VNIR image made the species spectra even harder to be differentiated. These resampled spectra were used as pure endmember for SAM classification.
Figure 3. Seagrass species spectra resampled to multispectral images (a) WorldView-2, (b) Quickbird, (c) Sentinel-2A, (d) ASTER VNIR, and (e) Landsat 8 OLI.

4.3. Tukey-test Result
Tukey-test analysis showed that most of seagrass species were spectrally-different. From 45 pairs of seagrass species, 34 pairs clearly different and the rest 11 pairs are similar. These results refer to the calculation of species pair difference and yardstick HSD value. Through one-way ANOVA calculation, $MS_{wi}$ value of 384.305 was obtained. Then, based on the original field spectra, the $N$ value between 400 – 900 nm is 1,457 for each group. Table of critical values gave $q$-value at 4.47 ($\alpha = 0.05$). Since the $P$-value is less than 0.05, yardstick HSD can be calculated and the value of 2.29 was obtained. This yardstick value was used as margin in pairwise comparison of Tukey-test calculation (Table 3).

Table 3 is a 2-dimensional Tukey-test matrix of seagrass species pairwise comparisons. Spectral average value was used to assess the absolute difference. Green boxes on Tukey-test matrix show the honestly significant different of seagrass species pair. For example, $Ea - Th$ pair difference is 15.25, which is clearly higher than the yardstick. Oppositely, $Hu - Cs$ pair difference is 0.94, far lower the yardstick value. $Ea$, $Ho$, and $Tc$ are completely different from other species spectrally. Thereafter, followed by $Th$ and $Cr$ that which is similar to each other. $Cs$, $Hu$, $Hm$, $Hp$, and $Si$ could not be differentiated due to the very low value of pair difference, which is between 0.5 – 1.0. Hence, these species are not spectrally-distinguishable.
Analyzing all SAM results, there are much of inconsistency in the seagrass species spatial distribution between images. Different images classified different species with different spatial distribution. This indicates that multispectral images with limited number of bands do not provide sufficient spectral information for the spectral-based classification of seagrass species. Interestingly, image with four bands had less confusion in classifying seagrass species based on their spectra. Although may not be fully accurate, the spatial distribution of seagrass species is consistent between image and is more acceptable than from WorldView-2 that has more bands, for instance, in the distribution of *Ea* and *Cr*. ASTER VNIR produced the least reliable result, which is understandable as

| Species | Spectral average (\(\bar{X}\)) | Difference |
|---------|-------------------------------|------------|
| *Ea*    | 41.27                         |            |
| *Th*    | 26.01                         | 15.25      |
| *Cr*    | 24.85                         | 16.41, 1.16|
| *Cs*    | 20.12                         | 21.14, 5.89, 4.72 |
| *Ho*    | 38.12                         | 3.14, 12.10, 13.27, 17.99 |
| *Hu*    | 21.06                         | 20.20, 4.94, 3.78, 0.94, 17.05 |
| *Hm*    | 19.58                         | 21.68, 6.43, 5.27, 0.54, 18.54, 1.48 |
| *Hp*    | 19.46                         | 21.80, 6.55, 5.38, 0.66, 18.66, 1.60, 0.11 |
| *Tc*    | 28.48                         | 12.78, 2.47, 3.63, 8.36, 9.63, 7.42, 8.90, 9.02 |
| *Si*    | 20.69                         | 20.57, 5.32, 4.15, 0.57, 17.42, 0.37, 1.11, 1.23, 7.79 |

*Green box indicates the difference between two species greater than the yardstick HSD value = 2.29

### 4.4. SAM Result

The application of SAM classification on each image produced different result. Generally, almost all pixels were misclassified (Figure 4). In the classified image, several species such as *Ea*, *Cr*, *Hp*, and even the unlikely *Tc* dominate the seagrass area. All images, especially WorldView-2 and ASTER VNIR images failed to classify any seagrass species using smaller angle thresholds (<0.7). SAM threshold of 0.1 produced high number of unclassified pixels due to the wide angle between reference spectra and target spectra. Pixels started to be classified at 0.4 and 0.7 angle threshold, except for WorldView-2 image. Landsat 8 OLI pixels near the shoreline stay unclassified despite the threshold, which is suspected due to the mixing between seagrass and both emerged and submerged substrates.

WorldView-2 image only classified *Hp* and *Hm* species, but only on some pixels near the shoreline. WorldView-2 result is surprisingly poor as *Hp* and *Hm* in fact is the most difficult species to be found in the study area. Quickbird image only classified *Cr* species, yet other species were unclassified. Sentinel-2A image produced better seagrass species distribution and the only one to map *Ea* correctly along water near the shoreline. Other classified species are *Cr* and small area of *Tc*. *Cr* distribution may be overestimated but still acceptable as *Th* and *Cr* are mixing strongly in the study area and their spectra based on Tukey-test is similar. Similar to WorldView-2 classified image, ASTER VNIR image was unable to classify seagrass species at 0.1, 0.4, and 0.7 thresholds, and at 1.0 threshold most pixels were classified as *Hp*, which is highly unlikely. Other species were also classified, this includes *Cr*, *Cs*, *Hm*, and *Ea*. Landsat 8 OLI image produced consistent result at the 0.1, 0.4, 0.7, or 1.0 angle thresholds and produced similar results to Sentinel-2A but failed to classify *Ea* near the shoreline and produced more misclassification of *Tc* in the seaward margin of seagrass habitat. Quickbird and Landsat 8 OLI results are almost similar, where *Cr* and *Tc* dominates the classified image. In the actual condition, *Cr* may dominate some places in the eastern coast, but *Tc* was not found across the study area.

Analyzing all SAM results, there are much of inconsistency in the seagrass species spatial distribution between images. Different images classified different species with different spatial distribution. This indicates that multispectral images with limited number of bands do not provide sufficient spectral information for the spectral-based classification of seagrass species. Interestingly, image with four bands had less confusion in classifying seagrass species based on their spectra. Although may not be fully accurate, the spatial distribution of seagrass species is consistent between image and is more acceptable than from WorldView-2 that has more bands, for instance, in the distribution of *Ea* and *Cr*. ASTER VNIR produced the least reliable result, which is understandable as
it has the smallest number of bands. Nevertheless, this needs to be confirmed in other areas whether the pattern of result is consistent. In addition, this highlight the importance of tuning the threshold for SAM classification algorithm to produce more accurate classification result, by not only using the default value (0.1) or similar value for all class (set the threshold value similarly for all class), but using unique value for different seagrass species based on the abundance and probability of each species encounter in the study area.

Seagrass species spectra (Figure 2 and Figure 3) and Tukey-test result (Table 3) have opposite characteristics. The Tukey-test shows that seagrass species are spectrally-different. However, the classification of field spectra and the resampled spectra using SAM indicated otherwise. Future research should investigate more appropriate classification technique needed for better classification result, considering the SAM classification technique could not differentiate spectra with similar shape. Furthermore, hyperspectral image should also be tested, with the expectation that its narrow wavelength and more number of water penetration bands may improve the classification result.
Figure 4. SAM classification of (a) WorldView-2 with angle 0.1; 0.4; 0.7; and 1.0, (b) Quickbird with angle 0.1; 0.4; 0.7; and 1.0, (c) Sentinel-2A with angle 0.1; 0.4; 0.7; and 1.0, (d) ASTER VNIR with angle 0.1; 0.4; 0.7; and 1.0, and (e) Landsat 8 OLI with angle 0.1; 0.4; 0.7; and 1.0.

5. Conclusions
Multispectral resampling of seagrass species spectra shows that the resampled spectra exhibit similar shape and pattern with the original spectra, but less precise and lose the unique absorption feature of seagrass species. Although spectrally-different based on spectra measurement, the difference in seagrass species spectra is not in the shape but in the absolute reflectance value. As a consequence, using seagrass species spectra as pure endmember for SAM classification is unrealistic, as the algorithm normalizes the variation in absolute value and only sensitive to the shape of spectra. The classification results between images are inconsistent, and as a consequence, no agreement between results, which indicates the ineffective use of SAM algorithm.

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