*Original Research Article*

# Evaluation of Water Column Correction Methods in Mapping Seagrass Bed Using Remote Sensing Data in Khanh Hoa Province, Vietnam

.

## ABSTRACT

The use of remote sensing images for the interpretation of underwater substrate objects depends on their reflectance spectrum of different water depths. Thus, the water column correction step is important in the interpretation. Two commonly used water column correction methods are Lyzenga's depth invariant index (DII) method and Sagawa's bottom reflectance index (BRI) method. To evaluate the role of each method in Khanh Hoa waters, Tuan Le water, with a high seagrass coverage and moderate turbidity, and Thuy Trieu Lagoon, with high biodiversity of seagrass species and turbidity water, were selected as representatives. 70% of the survey data was used for ground training data of seagrass (dense and patchy), muddy-sand and sand features and the interpretation of both methods, whereas the remaining 30% of the survey data was used for validation of the mapping results. The maximum likelihood classification approach was used to extract the seagrass map and evaluated by overall accuracy as well as the Kappa coefficient. The processing results show that, in Tuan Le water, using the DII method gives an accuracy of 82.1% and the BRI of 80.1%; and in Thuy Trieu Lagoon, the DII method has an accuracy of 80.67% and the BRI of 80.0%. These results demonstrate that both methods have high accuracy results in both areas, but the method of BRI gives better results.

*Keywords: Seagrass bed, water column correction, DII method, BRI method.*



## 1. INTRODUCTION

The use of remote sensing images for mapping in general, particularly for the mapping of seagrass distribution has become popular [1]. In recent years, applications of remote sensing technology combined with GIS techniques have been widely used for many coastal ecosystems studies such as coral reefs, seagrass beds, and mangroves not only in coastal waters but also in small islands with several sensors [1,2,3,4,5].

Several methods have been used to interpret remote sensing images for mapping coral reefs and seagrasses [2,6], including the Principal Component Analysis (PCA) method applied to Landsat-TM and SPOT images [7,8]; the Normalized Difference Vegetation Index (NDVI) [9]; Leaf Area Index (LAI) combined with field optical properties measurement data [10,11]; and Object-based Classification method [12]. However, after analyzing and classification based on these indexes, it turns out that most of the above methods have not considered water depth, whereas the light intensity is absorbed and reduced exponentially when passing through the water column [13]. As a result, for example, the reflectance spectrum of the same sand type at a water depth of 2m is very different from that at a water depth of 20m. On the other hand, the reflectance spectrum of the sand object at a water depth of 20m might be similar to the seagrass object at a water depth of 4m [14]. Hence, it is very difficult to distinguish between sand and seagrass, and the image classification directly has certain limitations. In addition, the signals of underwater objectives obtained by the satellite sensors depend not only on the different types but also on their depth [14]. This would lead to errors in interpretation resulting in the supervised and unsupervised classification of multispectral images. Thus, it is necessary to achieve water column correction or converts image signals to distinguish these objects from each other. To deal with these problems, two well-known methods, Lyzenga's depth invariant index (DII) method [15,16] and Sagawa's bottom reflectance index method (BRI) [17] have commonly been used in underwater classification in remote sensing. The DII method uses the water column suppression technique based on the invariance of the linearized function between pairs of bands with different wavelengths of the image, whereas the BRI method uses the water-depth data to calculate the attenuation coefficient for water column correction. According to Sagawa et al. [17], the BRI method could significantly increase the accuracy from 54% to 90% in case I water and from 61.7% to 83.3% in case II water.

In Vietnam, in the term of seagrass mapping by using remote sensing application, Nguyen et al. [18] gave a detailed update and evaluation of the distribution of seagrass beds from Quang Ngai to Kien Giang of Vietnam. Remote sensing was also applied to evaluate multi-year seagrass bed changes in Van Phong Bay [19]. The evaluation of changes in seagrass beds in Cam Ranh Bay over the years was done by Chen et al. [20] . Lau et al. [21] also applied the remote sensing technique for Landsat images to evaluate the distribution of coral reefs and seagrass beds in Ninh Hai waters. Specifically, in Khanh Hoa waters, seagrasses are distributed in Van Phong Bay, Nha Phu Lagoon, Nha Trang Bay, Thuy Trieu Lagoon and Cam Ranh Bay with different substrate objects [18,19,20] and were detected by in-situ observation and remote sensed mapping. According to Nguyen et al. [18], the water quality in Thuy Trieu Lagoon is relatively turbidity due to mainly bottom sandy and muddy, whereas the water in Xuan Tu and My Giang, parts of Van Phong Bay, is relatively clear due to mixed sand and reefs. The seagrass bed distributed in these regions is relatively narrow and slopes, the morphology is not the same as the region in Sagawa et al. [17]. Contrary, the Tuan Le Region is moderate turbidity, but the seagrass is relatively large and applies appropriate interpretation methods.

This research aims to test the difference in interpretation results through two methods, DII and BRI water column correction for the Tuan Le Region and Thuy Trieu Lagoon in Khanh Hoa.

## 2. MATERIAL AND METHODS

### 2.1 Study area

Tuan Le area is located to the north of Khanh Hoa Province, Vietnam (Fig. 1), where seagrass is high. A total of 4 seagrass species were recorded, dominated by *Enhalus acoroides*. However, under economic development, from 1998 to 2019, 14.8% of the seagrass area in Tuan Le was lost [19]. Seagrass in Thuy Trieu Lagoon, located in the south of Khanh Hoa, was also a high coverage and species diversity, including 8 species of *Enhalus acoroides*, *Halophila beccarii*, *H. ovalis*, *H. minor*, *Thalassia hemprichii*, *Halodule pinifolia*, *H. uninervis* and *Ruppia maritime*. *H. ovalis* dominates in the upper regions of the Lagoon, whereas *E. acoroides* is distributed mainly in many areas along the coasts of the Lagoon [22,23,24].

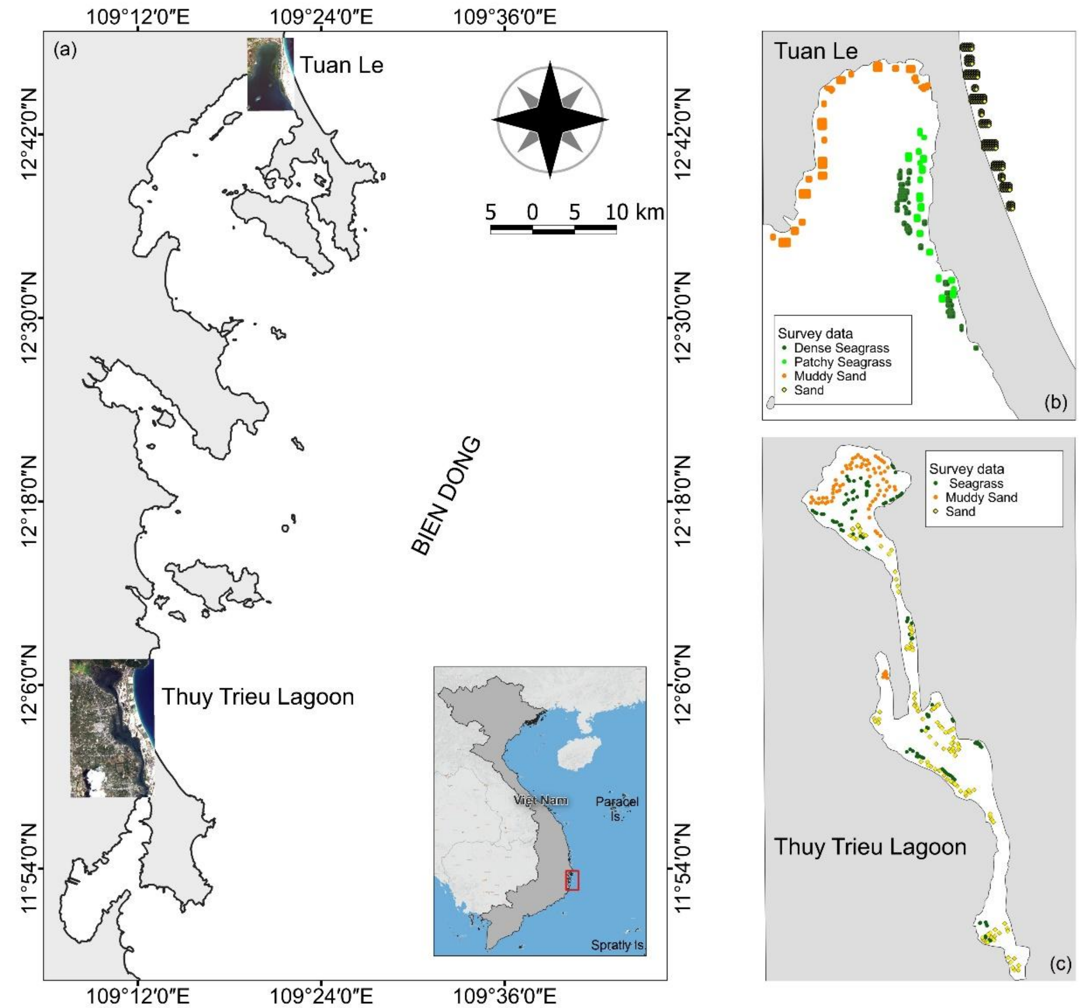


**Fig. 1. Study areas in coastal waters of Khanh Hoa Province. (a) location of Tuan Le Region and Thuy Trieu Lagoon; (b) Ground truthing points in Tuan Le Region; (c) Ground truthing points in Thuy Trieu Lagoon.**

## 2.2 Data

### 2.2.1 Remote sensing images

The Landsat 8 satellite consists of two sensors, an Operational Land Imager sensor (OLI) that collects spectral bands in the visible and near-infrared wavelength ranges and a Thermal Infrared Sensor (TIRS) that collects two spectral bands in the infrared heat band. The Landsat OLI image consists of 9 bands from 443nm to 1390nm with a spatial resolution of 30m, of which band 8 is a panchromatic band with a resolution of 15m. For this study, the Landsat 8 OLI images were freely downloaded from the USGS (U.S. Geological Survey) website (https://earthexplorer.usgs.gov/), for Tuan Le Region and Thuy Trieu Lagoon.

### 2.2.2 Water-depth data

Water-depth data was extracted from the Van Phong Bay topographic map of the 1:25,000 scale, updated in 2018. This topographic map was used to select control points with a limitation of the -16m contours. The map was also used to mask waters within -15m contours.

Water-depth data in Thuy Trieu Lagoon were collected by Lawrance VP 1000 single-beam echo sounder. More than 4000 depth points were obtained for interpolating by the natural neighbor method, resulting in the creation of the deep gird corresponded to the Landsat image.

## 2.3 Methodology

### 2.3.1 Remote sensing analysis for seagrass

The image processing framework is explained in Fig. 2. The Landsat 8 OLI imageries were checked for atmospheric correction in the ACOLITE tool [25]. The blue band B2 (λ = 488 nm), the green band – B3 (λ = 565 nm) and the red band – B4 (λ = 655 nm) of Landsat images were applied water column with the DII method [15,16] and the BRI method [17]. The surveys were done in Tuan Le Region and Thuy Trieu Lagoon. Survey data were divided into two parts. About 70% of the data were used to calculate the indexes and/or coefficients through the DII method and the BRI method and also used as ground control points for the classification by the Maximum Likelihood method. Then, the remaining 30% of the data set was applied to evaluate the validation of the classification. As a result, the value of the water column correction method (DII and BRI) was selected for these studied areas.

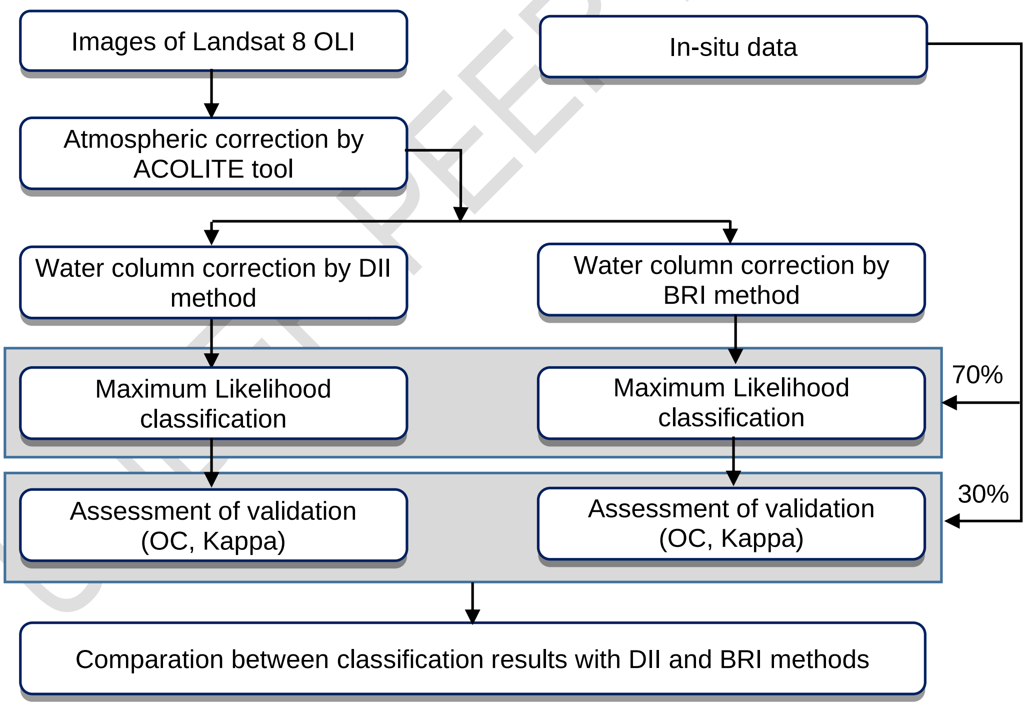


**Fig. 2. Flow chart for seagrass classification with different methods of water column correction in coastal waters of Khanh Hoa Province**



### 2.3.2 Depth invariant index (DII) method

To remove the effect of depth, Lyzenga [15] recommended the bottom reflectance equation following equation (1).

$$L_\lambda = a.r.e^{-K_\lambda gZ} \qquad (1)$$

where, $L_\lambda$ is atmospheric corrected reflectance at wavelength $\lambda$; a is a constant which includes the solar irradiance, the transmittance of the atmosphere and the water surface, and the reduction of the radiance due to refraction at the water surface (mW $cm^{-2}$ $sr^{-1}$); r is the bottom surface reflectance, $K_\lambda$ is the effective attenuation coefficient of the water ($m^{-1}$), g is a geometric factor to account for the path length through the water, and z is the water depth (m).

The water column correction with the DII method given by Lyzenga [15,16] follows a step-by-step guide:

Step 1: Linearize the reflectance by depth for each band in the natural logarithm following equation (2).

$$X_i = \text{Ln}(L_i) \qquad (2)$$

where, $L_i$ atmospheric corrected reflectance value of band i; $X_i$ linearized reflectance of band i, in which band i was one of the visible bands, such as bands 2, 3 and 4 in Landsat 8 OLI images.

Step 2: based on reflectance values at one region, the slope coefficient of reflectance between two bands i and j ($k_i/k_j$) is calculated according to Lyzenga [16] following equation (3).

$$\mathrm{k}_i/\mathrm{k}_j = \mathrm{a} + \sqrt{(a^2+1)} \qquad (3)$$

where, $\mathrm{a} = \frac{\sigma_i - \sigma_j}{\sigma_{ij}}$; $\sigma_i$, $\sigma_j$, $\sigma_{ij}$ are the variance and covariance of bands i and j.

Step 3: The index $DII_{ij}$ is calculated by equation (4).

$$\text{DII}_{ij} = \text{Ln}(L_i) - \frac{k_i}{k_j}\text{Ln}(L_j) \qquad (4)$$

where $DII_{ij}$ is called the bottom invariant index between bands i and j.

**2.3.3 The bottom invariant index (BRI) method**

Unlike the DII method, the BRI method does not use a ratio between 2 bands to remove water effects on light intensity through the water column. The water correction is the corresponding depth data. Sagawa [17] proposed the BRI index as follows equation (5).

$$\text{BRI}_i = \frac{(L_i - L_{si})}{\exp(-K_i gZ)} \qquad (5)$$

where, $L_i$ is the atmospheric corrected reflectance of the band i from the image, $L_{si}$ is the reflectance recorded over deep water of band i, z, K and g are the same as equation (1).
In equation (5), the ($L_i$ – $L_{si}$) is replaced by $a_i.r_i.e^{-K_i gZ}$ in equation (1). The $BRI_i$ indexes become the following equation (6).

$BRI_i = a_i.r_i$ (6)

where $a_i$ and $r_i$ are the same as in equation (1) for a band i. The $BRI_i$ is called the bottom reflectance index of band i.

In this study, we assumed that the hypothesis of the light attenuation coefficient is the same as in one study area as well as on bottom objects. From equation (1), Sagawa [17] uses logarithmic regression to obtain coefficients K and g. Then, BRI could be easily calculated by equation (5).

## 3. RESULTS AND DISCUSSION

The ratio of attenuation coefficients for band-by-band ($k_i/k_j$) in the DII method is shown in Table 1 and the attenuation coefficients ($k_l$ g) in the BRI method are shown in Table 2. According to surveys, the bottom objects of the Tuan Le Region included dense seagrass, mixed seagrass, sand and muddy sand, whereas the ones of Thuy Trieu Lagoon were seagrass, sand and muddy sand.

**Table 1. Ratios of band pairs of attenuation coefficients according to the DII method**

| Coefficient | Tuan Le area | Thuy Trieu Lagoon |
|---|---|---|
| $k_2/k_3$ | 0.87 | 0.63 |
| $k_2/k_4$ | 0.50 | 0.48 |
| $k_3/k_4$ | 0.52 | 0.76 |

**Table 2. Attenuation coefficients of bands according to the BRI method**

| Coefficient | Tuan Le area | Thuy Trieu Lagoon |
|---|---|---|
| $k_2$ g | 0.106 | 0.024 |
| $k_3$ g | 0.196 | 0.062 |
| $k_4$ g | 0.144 | 0.072 |

The results of seagrass classification using the water column correction by the DII method in the Tuan Le Region showed that the seagrass covered an area of 232.65 ha (Fig. 3a) with an accuracy of 82.1% as well as a kappa coefficient of 0.76 (Table 3), whereas by the BRI method the area of seagrass was about 231.75ha (Figure 3b) with an accuracy of 80.1% and a kappa coefficient of 0.73 (Table 3). Thus, the results of seagrass classification in the two methods DII and BRI were not significantly different in terms of area. In terms of spatial distribution, both methods also give relatively similar results, but in the north of the Tuan Le Region, the distribution of seagrass was different. This area has a depth of 1-2m and muddy sand, so the value from the DII method was similar to that of the sparse-density seagrass, and the result was classified as seagrass. In contrast, the BRI method using depth to calculate the bottom reflectance values produced a different value of muddy sand compared to the sparse grass, so the classification results showed this area was not seagrass.

**Table 3. Results of accuracy assessment after classification by DII and BRI methods**

| Factor | Tuan Le Region | | Thuy Trieu Lagoon | |
|---|---|---|---|---|
| | DII | BRI | DII | BRI |
| *Overall accuracy* | 82.10% | 80.10% | 80.77% | 80.00% |
| *Kappa coefficient* | 0.76 | 0.73 | 0.71 | 0.69 |
| *Producer accuracy* | 81.00% | 74.65% | 58.5% | 56.00% |
| *User accuracy* | 77.84% | 79.50% | 80.00% | 76.60% |

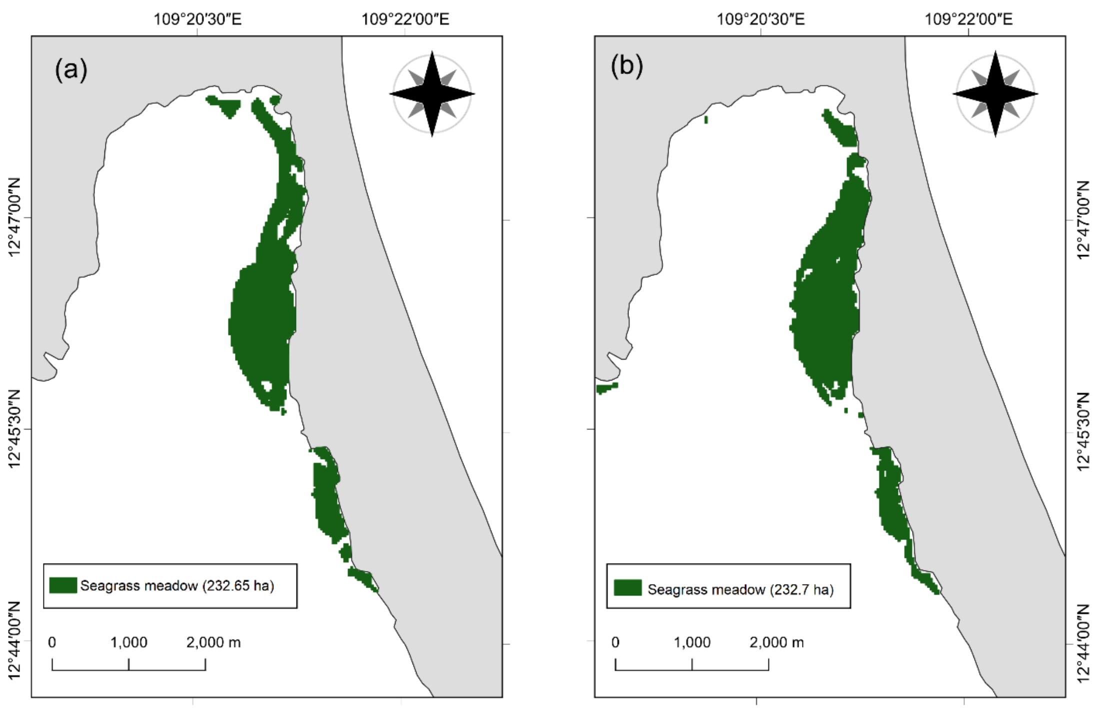


**Fig. 3. The distribution of seagrass beds in the Tuan Le Region. (a) Using the DII method; (b) Using the BRI method**

The results of seagrass classification in the Thuy Trieu lagoon show there are significant differences in terms of area and spatial distribution of seagrasses by two methods DII and BRI. Seagrass area was 333 ha by the DII method (Fig. 4a), and less than 472.5 ha by the BRI method (Fig. 4b). In terms of spatial distribution, seagrasses distributed in the western area of the upper region of Thuy Trieu Lagoon are similar in both methods, whereas, in other areas, seagrasses classified by DII method were less distributed than by BRI method. According to Hoa et al. [23], seagrass in Thuy Trieu Lagoon has a large distribution area, but the density, biomass and coverage degree are very low. In addition, this area was turbid water, high phytoplankton [26,27] and sandy bottom, which critically affects the interpretation results. As a result, the *Producer accuracy* value of classification was only 58.5% by the DII method and 56% by the BRI method (Table 3). Therefore, the results need validation in more detail. However, seagrass coverage in this study (in 2021) was similar to the classified result in 2014 [28], and the seagrass area decreased by about 135 hectares on both DII and BRI methods.

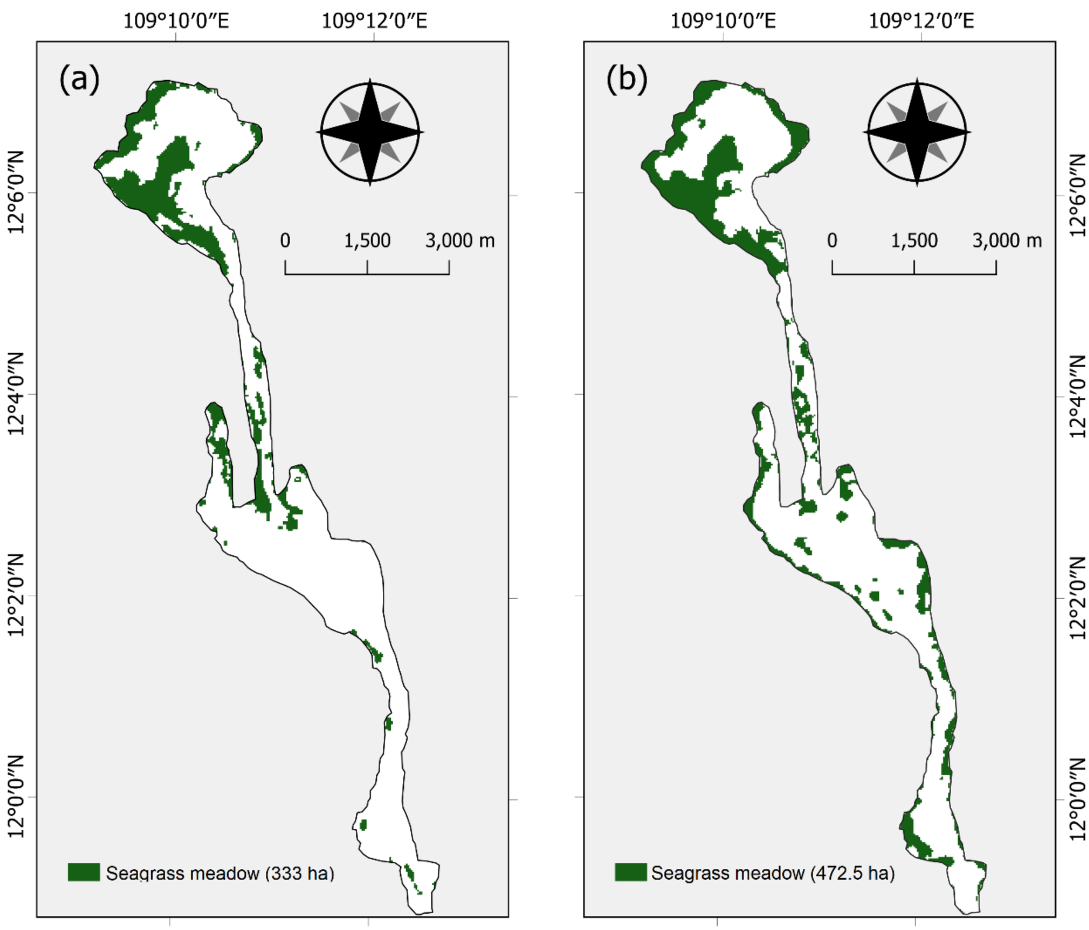


**Fig. 4. The distribution of seagrass beds in Thuy Trieu Lagoon. (a) Using the DII method; (b) Using the BRI method**

## 4. CONCLUSION

The Landsat 8 OLI images are freely available with a temporal resolution of 16 days as an appropriate image source for seagrass classification. With the accuracy of classification results over 80%, both DII and BRI methods are suitable for the interpretation of Khanh Hoa waters. However, the DII method has the advantage as it does not require water deep data for the interpretation area. The DII method gives better results than BRI one in terms of seagrass classification. It is recommended to use the DII method for Khanh Hoa waters. However, in turbidity water (case II water) as well as shallow water conditions, such as Thuy Trieu Lagoon, the classification of seagrass using remote sensing data should be had more in-situ data for improving the accuracy value.

## REFERENCES

1. Green, E.P., Mumby, P.J., Edwards, A.J. & Clark, C.D. Remote Sensing Handbook for Tropical Coastal Management. UNESCO. 2000.

2. Komatsu, T., Hashim, M., Nurdin, N., Noiraksar, T., Prathep, A., Stankovic, M., Son, T.P.H., Thu, P.M., Luong, C.V., Wouthyzen, S., Phauk, S., Muslim, A.M., Yahya, N.N., Terauchi, G., Sagawa, T. & Hayashizaki, K.-i. Practical mapping methods of seagrass beds by satellite remote sensing and ground truthing. Coastal Marine Science. 2020; 43: 1-25.
3. Lazuardi, W., Wicaksono, P. & Marfai, M.A. Remote sensing for coral reef and seagrass cover mapping to support coastal management of small islands. IOP Conference Series: Earth and Environmental Science. 2021; 686: 012031.
4. Kovacs, E., Roelfsema, C., Lyons, M., Zhao, S. & Phinn, S. Seagrass habitat mapping: how do Landsat 8 OLI, Sentinel-2, ZY-3A, and Worldview-3 perform? Remote Sensing Letters. 2018; 9: 686-695.
5. Hossain, M.S., Bujang, J.S., Zakaria, M.H. & Hashim, M. The application of remote sensing to seagrass ecosystems: an overview and future research prospects. International Journal of Remote Sensing. 2015; 36: 61-114.
6. Veettil, B.K., Ward, R.D., Lima, M.D.A.C., Stankovic, M., Hoai, P.N. & Quang, N.X. Opportunities for seagrass research derived from remote sensing: A review of current methods. Ecological Indicators. 2020; 117: 106560.
7. Ferguson, R.L. & Korfmacher, K. Remote sensing and GIS analysis of seagrass meadows in North Carolina, USA. Aquatic Botany. 1997; 58: 241-258.
8. Pasqualini, V., Pergent-Martini, C., Pergent, G., Agreil, M., Skoufas, G., Sourbes, L. & Tsirika, A. Use of SPOT 5 for mapping seagrasses: An application to Posidonia oceanica. Remote Sensing of Environment. 2005; 94: 39-45.
9. Barillé, L., Robin, M., Harin, N., Bargain, A. & Launeau, P. Increase in seagrass distribution at Bourgneuf Bay (France) detected by spatial remote sensing. Aquatic Botany. 2010; 92: 185-194.
10. Yang, D., Yang, Y., Yang, C., Zhao, J. & Sun, Z. Detection of seagrass in optical shallow water with quickbird in the Xincun Bay, Hainan province, China. IET Image Processing. 2011; 5: 363-368.
11. Hedley, J.D., Russell, B.J., Randolph, K., Pérez-Castro, M.Á., Vásquez-Elizondo, R.M., Enríquez, S. & Dierssen, H.M. Remote Sensing of Seagrass Leaf Area Index and Species: The Capability of a Model Inversion Method Assessed by Sensitivity Analysis and Hyperspectral Data of Florida Bay. Frontiers in Marine Science. 2017; 4:
12. Roelfsema, C.M., Lyons, M., Kovacs, E.M., Maxwell, P., Saunders, M.I., Samper-Villarreal, J. & Phinn, S.R. Multi-temporal mapping of seagrass cover, species and biomass: A semi-automated object based image analysis approach. Remote Sensing of Environment. 2014; 150: 172-187.
13. Wozniak, B. & Dera, J. Light Absorption in Sea Water. Springer. 2007.
14. Louchard, E.M., Reid, R. Pamela, Stephens, F.C., Davis, Curtiss O., Leathers, R.A. & T. Valerie, D. Optical remote sensing of benthic habitats and bathymetry in coastal environments at Lee Stocking Island, Bahamas: A comparative spectral classification approach. Limnology and Oceanography. 2003; 48: 511-521.
15. Lyzenga, D.R. Passive remote sensing techniques for mapping water depth and bottom features. Applied Optics. 1978; 17: 379-383.
16. Lyzenga, D.R. Remote sensing of bottom reflectance and water attenuation parameters in shallow water using aircraft and Landsat data. International Journal of Remote Sensing. 1981; 2: 71-82.
17. Sagawa, T., Boisnier, E., Komatsu, T., Mustapha, K.B., Hattour, A., Kosaka, N. & Miyazaki, S. Using bottom surface reflectance to map coastal marine areas: a new application method for Lyzenga's model. International Journal of Remote Sensing. 2010; 31: 3051-3064.
18. Nguyen, X.-V., Lau, V.-K., Nguyen-Nhat, N.-T., Nguyen, T.-H., Phan, K.-H., Dao, V.-H., Ho-Dinh, D., Hayashizaki, K.-i., Fortes, M.D. & Papenbrock, J. Update of seagrass

cover and species diversity in Southern Viet Nam using remote sensing data and molecular analyses. Regional Studies in Marine Science. 2021; 44: 101803.
19. Vo, T.-T., Lau, K., Liao, L.M. & Nguyen, X.-V. Satellite image analysis reveals changes in seagrass beds at Van Phong Bay, Vietnam during the last 30 years. Aquatic Living Resources. 2020; 33:
20. Chen, C.-F., Lau, V.-K., Chang, N.-B., Son, N.-T., Tong, P.-H.-S. & Chiang, S.-H. Multi-temporal change detection of seagrass beds using integrated Landsat TM/ETM+/OLI imageries in Cam Ranh Bay, Vietnam. Ecological Informatics. 2016; 35: 43-54.
21. Lau, V.-K., Chen, C.-F. & Tong-Phuoc, H.-S. Mapping seagrass beds and coral reefs in the coastal of Ninh Hai District, Ninh Thuan province of Vietnam using Landsat 8 OLI image. The 36th Asian Conference on Remote Sensing (ACRS). Manila, Philippines, 2015:
22. Dai, N.H., Tri, P.H., Linh, N.T. & Vy, N.X. The degradation of seagrass beds in Khanh Hoa province and the ability of restoration of these medows (in Vietnamese). Scientific Conference of "BIEN DONG - 2002". Nha Trang, Vietnam, Agriculture Publishing House. 2002: 359-368.
23. Hoa, N.X., Thuy, N.T.T. & Thuy, N.N.N. The current status of mangrove and seagrass ecosystems at Thuy Trieu Lagoon, Khanh Hoa Province. Proceedings of the 5th National Scientific Conference on Ecology and Biological Resources. Ha Noi, Vietnam, 18 October 2013, 2013: 488-496 (in Vietnamese).
24. Hoa, N.X. Điều tra, thống kê diện tích, thành phần loài, đánh giá hiện trạng phân bố hệ sinh thái rừng ngập mặn, thảm cỏ biển và vai trò của chúng đối với kinh tế - xã hội, môi trường ở vùng biển ven bờ Khánh Hòa - Đề xuất giải pháp quản lý và sử dụng bền vững (Investigate and statistics on the area and species, assessment of the current status of distribution of mangrove and seagrass beds ecosystems, and their role in socio-economy and environment in waters of Khanh Hoa province. - Proposing solutions for sustainable uses and management). Báo cáo Đề án môi trường tỉnh Khánh Hòa (Report on Environmental Project in Khanh Hoa Province). Viện Hải Dương Học (Institute of Oceanography). 2009: 121 (in Vietnamese).
25. Vanhellemont, Q. & Ruddick, K. Atmospheric correction of metre-scale optical satellite data for inland and coastal water applications. Remote Sensing of Environment. 2018; 216: 586-597.
26. Minh-Thu, P. & Nga, T.N.M. Capacity of physical-biological self-purification of seawaters in Thuy Trieu lagoon, Khanh Hoa. Journal of Fishery Science and Technology. 2015; 1/2015: 57-62.
27. Minh-Thu, P., Du, H.T., Huan, N.H., Dung, L.T., Dung, L.T., Thi, V.H. & Hue, T.T.M. Environmental assessment of Thuy Trieu Lagoon in dry season of 2012 and impacted by socio-economic activities Collection of Marine Research Works, Institute of Oceanography. 2013; 19: 80-90.
28. Lau, V.-K., Chen, C.-F., Tong-Phuoc, H.-S. & Nguyen, X.-V. Mapping seagrass beds in Thuy Trieu Lagoon (Vietnam) by usiing Landsat 8 Image. The 35th Asian Conference on Remote Sensing (ACRS). Nay Pyi Taw, Myanmar, 2014: