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The utilization of Depth Invariant Index and Principle Component Analysis for mapping seagrass ecosystem of Kotok Island and Karang Bongkok, Indonesia

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Abstract. Seagrass perform a variety of functions within ecosystems, and have both economic and ecological values, therefore it has to be kept sustainable. One of the stages to preserve seagrass ecosystems is monitoring by utilizing the spatial data accurately. The purpose of the study was to assess and compare the accuracy of DII and PCA transformations for mapping of seagrass ecosystems. Field study was carried out in Karang Bongkok and Kotok Island waters, in August 2014 and in March 2015. A WorldView-2 image acquisition date of 5 October 2013 was used in the study. The transformations for image processing data were Depth Invariant Index (DII) and Principle Component Analysis (PCA) using Support Vector Machine (SVM) classification. The result shows that benthic habitat mapping of Karang Bongkok using DII and PCA transformations were 72% and 81% overall's accuracy respectively, whereas of Kotok Island were 83% and 84% overall's accuracy respectively. There were seven benthic habitat types found in Karang Bongkok waters and in Kotok Island namely seagrass, sand, rubble, coral, lagoon, sand mix seagrass, and sand mix rubble. PCA transformation was effectively to improve mapping accuracy of sea grass mapping in Kotok Island and Karang Bongkok.

1. Introduction

Seagrass beds are highly diverse and productive ecosystems and mostly covered by seagrass as their dominant vegetation [1]. Seagrasses form extensive beds or meadows, which can be either mono-specific (made up of a single species) or in mixed beds where more than one species coexist. According to [2], the seagrass ecosystem of Indonesia is 30,000 km². However, according to the last report it showed that 58% of world's seagrass meadows are currently decreasing, including Indonesia itself lost about 30-40% of its seagrass beds [3]. In Seribu Islands including Kotok Island and Karang Bongkok the coastal resources such seagrass ecosystem has been degraded caused by natural factors and human induced factors such as, unsustainable resource exploitation (destructive fishing) and overfishing [4].

Kotok Island and Karang Bongkok, have high potential of diversity coastal resources, one of which is seagrass ecosystems. Seagrass ecosystems should be preserved because they contribute to the improvement of the fishery and tourism sectors. Thus, seagrass is an important instrument for both ecologically and economically, they sequester large amounts of carbon within plants above and below sea-level as well as within soils [5, 6]. Although they are important, unfortunately, seagrass is seldom



given the attention or protection to they deserves. Improved management and protection of seagrass are required to understand better the dynamic nature of these ecosystems.

Remote sensing data from satellite images had been utilized to generate objective information to monitor large of coastal areas [7]. Ecosystem mapping of shallow waters based on satellite imagery can be done using Depth Invariant Index (DII) transformation [8, 9]. DII transformation has also been utilized for mapping seagrass [10], but the accuration in Karang Bongkok and Kotok Island waters lower than 85% [11]. In addition to DII, Principle Component Analysis (PCA) was applied on satellite imagery hyperspectral for mapping seagrass. Mapping of *Posidonia oceanica* seagrass using PCA had successfully in the Mediterranean with more than 90% accuracy [12]. Accordingly, the authors conducted such study to assess whether high spatial resolution satellite images of PCA transformation can be used effectively for mapping diverse species compositions, cover, and above-ground biomass of seagrass in Kotok Island and Karang Bongkok.

Principle Component Analysis is a mathematical procedure that uses an orthogonal transformation to convert a set of observations of possibly correlated variables into a set of values of uncorrelated variables called principal components. The other main advantage of PCA is that once we have found these patterns in the data and we compress the data i.e. by reducing the number of dimensions without much loss of information [13]. This process is performed for the multispectral image, a particular class of images that require specialized coding transformations. In multispectral images, the same spatial region is captured multiple times using different imaging modalities, so that some objects in the image are hard to recognize [14]. Therefore, PCA is often viewed as an efficient compression technique for information. The purpose of this research was to assess and compare the accuracy of DII and PCA transformations for mapping seagrass ecosystems.

2. Methods

2.1. Data collections

The study was carried out at two different locations namely Kotok Island and Karang Bongkok, in the Seribu Islands National Park, Jakarta (Indonesia) (figure 1). Field data collections were implemented in two steps, the first step was in August 2014 (represent East Monsoon) and the second step was in March 2015 (represent West Monsoon).

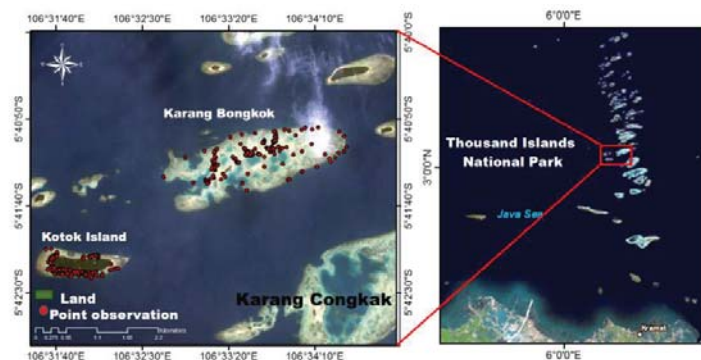


Figure 1. Study area

The tools used in this study were Global Positioning System (GPS) Garmin 76 CSX with 2m precision, transect quadrant, scale meter, stationery, The guidelines for seagrass identifier guideline (Seagrass Watch), underwater camera, snorkel and mask. The material used in this study was the satellite imagery of WorldView-2 with the acquisition date was 5 October 2013. The WorldView-2 satellite imagery have 8 bands with high spatial resolutions, 1.84 m (multispectral) and 0.46 m (panchromatic). WorldView-2 images can register the energy reflected by the shallow water habitat different intervals of the electromagnetic spectrum with wavelengths ranging from the blue region to the mid-infrared (Coastal: 0.40–0.45 μ m; Blue: 0.52–0.51 μ m; Green: 0.51–0.58 μ m; Yellow: 0.585–

0.625 μm ; Red: 0.63–0.69 μm ; Red-edge: 0.705–0.745 μm ; N-IR-1: 0.720–0.895 μm ; N-IR-2: 0.86–1.04 μm).

Line transects and some spot check methods were used for collecting spatially referenced benthic cover of the seagrass beds [15, 16]. This transect was used again to conduct the substrate line transect. Transect lines used to collect the data of seagrass was 30 m perpendicular that parallel the coast. At both locations observations performed 3 times for each station

Quadrant size to collect seagrass is 1m x 1 m and divided into 4 segments which 25 cm size each segments placed along the transect line. Data observations were carried out using Seagrass watch monitoring methods [17].

2.2. Image processing

Image processing was performed with several stages such as geometric correction, radiometric conversion and atmospheric correction, image segmentation and enhancement. Image enhancement was conducted by correction of the water column with using the *DII* transformation. This method is based on the electromagnetic wave that are emitted by the sun will experience the gradual loss in intensity due to absorption and scattering by particles contained in water (attenuation). *DII* derivative of the transformation is as follows [18]:

$$\begin{aligned} DII_{ij} &= \ln(L_i) - \left[(k_i / k_j) \ln(L_j) \right] \\ k_i / k_j &= a + \sqrt{a^2 + 1} \\ a &= \frac{\sigma_{ii} - \sigma_{jj}}{2\sigma_{ij}} \end{aligned} \quad (1)$$

Where, L_i and L_j = the reflectance values of the band all i and j, k_i / k_j = ratio attenuation coefficient of the band all i and j, σ_{ii} = variance of the band i, σ_{jj} = variance of the band j and σ_{ij} = covariance of the band.

PCA transformed value of digital data into the new smaller data. A satellite image can be expressed in matrix format in the following way [18]:

$$(C - \lambda_k I) w_k = 0, \quad (2)$$

Where, n represents the number of the pixels and b the number of bands. Considering each band as a vector, the above matrix can be simplified as follows:

$$X_k = \begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_6 \end{pmatrix} \quad (3)$$

Where, k is the number of bands.

To reduce the dimensionality of the original bands the eigenvalues of the covariance matrix must be calculated. This matrix can be calculated as follows:

$$C_{b,b} = \begin{pmatrix} \sigma_{1,1} & \dots & \sigma_{1,6} \\ \vdots & & \vdots \\ \sigma_{6,1} & \dots & \sigma_{6,6} \end{pmatrix} \quad (4)$$

where $\sigma_{i,j}$ is the covariance of each pair of different bands.

$$\sigma_{i,j} = \frac{1}{N-1} \sum_{p=1}^N (DN_{p,i} - \mu_i) (DN_{p,j} - \mu_j) \quad (5)$$

Where, $DN_{p,i}$ is a digital number of a pixel p in the band i, $DN_{p,j}$ is a digital number of a pixel, p in the

band j , μ_i and μ_j are the averages of the DN for the bands i and j , respectively. From the variance-covariance matrix, the eigenvalues (λ) are calculated as the roots of the characteristic equation,

$$\det(C - \lambda I) = 0,$$

Where, C is the covariance matrix of the bands and I is the diagonal identity matrix.

The PCA can be expressed in matrix form:

$$Y_6 = \begin{pmatrix} y_1 \\ y_2 \\ \vdots \\ y_6 \end{pmatrix} = \begin{pmatrix} w_{1,1} \dots w_{1,6} \\ \dots \\ w_{6,1} \dots w_{6,6} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_6 \end{pmatrix} \quad (6)$$

Where, Y is the vector of the principal components, W the transformation matrix, and X the vector of the original data. The eigenvectors can be calculated from the vector - matrix equation for each eigenvalue k ,

$$(C - \lambda_k I)w_k = 0, \quad (7)$$

Where, C is the covariance matrix, k is the k eigenvalues (six in our example), I is the diagonal density matrix, and w_k is the k eigenvectors.

Image classification was performed using the Support Vector Machine (SVM). SVM have their roots in Statistical Learning Theory. SVM is a classification technique to find a vector or line that has functions as the separator between the classes [19] explained that the simple concept of SVM is the classification of the image pixel by finding the best hyperplane. Hyperplane serves as a divider of two classes in the input space. All classification transformations are based on the assumption that the image in question depicts one or more features and each of these features belongs to one of several distinct and exclusive classes. SVM classification is done on the image of the DII and PCA transformations.

The accuracy of satellite image classification was conducted by using the confusion matrix table. The confusion matrix is a rigorous statistical technique where number or value of pixels correctly assigned to each classification class and those missassigned to other classes are arranged in rows and columns relating allotted pixels in the classification image to a ground data. The percentage accuracy of classification is calculated from the ratio of the sample point calculation in the field (ground-truth) with image data classification results (the number of pixels). Test accuracies were calculated including User's Accuracy (UA), Producer's Accuracy (PA) and Overall's Accuracy (OA). User's accuracy occurs when pixels associated with a class are incorrectly identified as other classes, or from improperly separating a single class into two or more classes. Producer's accuracy is obtained by dividing the total pixels not correctly classified for each class in the reference data (column) by the total pixels for that class in the reference data/image (column total). Overall's accuracy is obtained by dividing the total number of correct pixels (diagonal) by the total number of pixels in the error matrix. Calculation accuracies of image classifications were performed with the following equation [20]:

$$\text{Overall's accuracy: } (n_{11} + n_{22} + n_{kk}) * 100\% \quad (8)$$

$$\text{Producer's accuracy: } \frac{n_{ii}}{n_{i+}} * 100\% \quad (9)$$

$$\text{User's accuracy: } \frac{n_{ii}}{n_{+i}} * 100\% \quad (10)$$

		j = Columns (Reference)			Row Total
		1	2	k	n_{i+}
i = Rows (Classification)	1	n_{11}	n_{12}	n_{1k}	n_{1+}
	2	n_{21}	n_{22}	n_{2k}	n_{2+}
	k	n_{k1}	n_{k2}	n_{kk}	n_{k+}
Column Total n_{+j}		n_{+1}	n_{+2}	n_{+k}	n

3. Result and discussion

3.1. Seagrass distribution

Field observations revealed three types of seagrass in Kotok Island, namely *Thalassia hemprichii*, *Enhalus acroides*, *Halophila minor*, and two types in Karang Bongkok waters, namely *Halodule uninervis* and *Cymodocea rotundata* (table 1). The differences in the seagrass composition in Karang Bongkok and Kotok Island waters are due to their adaptability to changing environmental conditions [21]

Thalassia hemprichii species was distributed in both locations due to the facts that *Thalassia hemprichii* was a wide spread and common species. The population appears to be stable, despite considerable threats. This species grow in various types of substrates such as muddy sand, medium-sized and coarse sand, rubble until death [22].

Table 1. Composition of seagrass in Kotok Island and Karang Bongkok

Locations	Species				
	<i>Thalassia hemprichii</i>	<i>Cymodocea rotundata</i>	<i>Enhalus acroides</i>	<i>Halophila minor</i>	<i>Halodule uninervis</i>
Kotok Island	+	-	+	+	+
Karang Bongkok	+	+	-	-	-

Description: + = Found, - =unfound

3.2. Classification of benthic habitat

DII transformation uses a combination of band for the correction of the water column as coastal-blue bands (bands 1-2). The combinations of these three bands were used for the calculation attenuation coefficients (k_i/k_j). The k_i/k_j ranged between 0.59-0.89 (table 2) were the range of k_i/k_j values marine waters [8]. The attenuation coefficient varies depending on the specific type of waters or waters optical properties. The higher attenuation coefficient values in Karang Bongkok shows that Karang Bongkok was shallower than Kotok Island and the existence of mixed pixel between sand and sea grass patchy [23].

Table 2. Attenuation coefficients (k_j/k_i) determinant (r^2) on Karang Bongkok and Kotok Island

Pair bands	k_i/k_j		r^2	
	Karang Bongkok	Island Kotok	Karang Bongkok	Island Kotok
Coastal-Blue (1-2)	0.89	0.59	0.81	0.82

PCA transformation technique was conducted for bands-1, 2, 3, 4, 5 and 6 of WorldView-2 imagery. The sixth bands have important interconnected information [24], so the transformation of the PCA provided more complete informations. PCA transformations were generated new bands, namely PC-1, PC-2 and PC-3, contains nearly all image information.

PC-1 constructed from band-1 up to band-6 contains 90% of the information on the image transformation [25, 26]. From band-1 up to band-4 provided more information on aquatic habitat, because the band 1 to band 4 penetrated the water column. PC-2 contains about 7% of the information, whereas the PC-3 contains about 2% the information from the transformation images [25]. PC-2 was constructed from band-1 up to band-4, while PC-3, the band-3 up to band-6.

DII and PCA transformations were performed on the World-View2 satellite imagery. There were seven benthic habitat types in Karang Bongkok waters and in Kotok Island namely seagrass, sand, rubble, coral, lagoon, sand mix seagrass and sand mix rubble (figure 2). In general, the total area of each class object generated by PCA and DII transformations were relatively equal except for seagrass. The area of seagrass using PCA was larger than DII transformations (table 3). The use of PCA transformation could generated information completely from satellite imagery [13]. Meanwhile, DII transformation could lead to the loss of some information recorded satellite sensors [25].

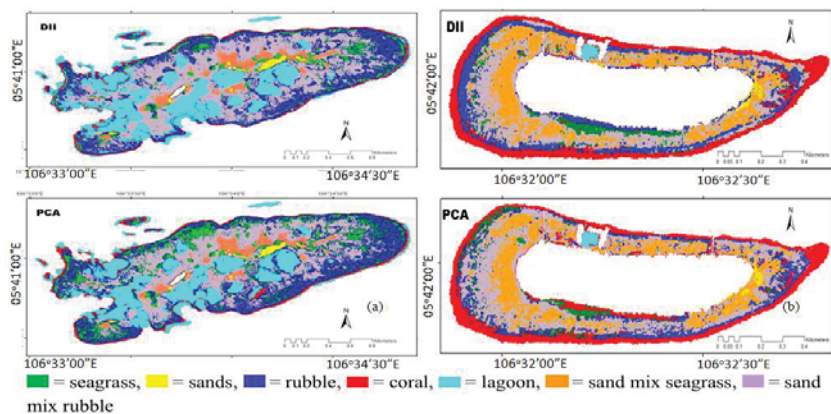


Figure 2. Map of benthic habitat using classification SVM transformation on the DII and PCA image transformation of (a) Karang Bongkok and (b) Kotok Island.

Table 3. The areal of seabed habitat classification

Class	Karang Bongkok (ha)		Island Kotok (ha)	
	DII	PCA	DII	PCA
Coral reefs	335.23	337.70	86.72	87.06
Seagrass	19.51	37.01	2.57	2.63
Lagoon	73.72	62.46	0.40	0.41
Sand	2.44	2.43	0.44	0.43
Rubble	66.94	75.80	7.90	5.96
Sand mix Seagrass	13.80	13.21	10.02	9.86
Sand mix Rubble	99.76	82.92	13.50	15.19

3.3. Classification accuracy of benthic habitat

Overall's accuracy values of the benthic habitat objects classification in Karang Bongkok and Kotok Island more than 70% have a high accuracy values (table 4). The OA value of objects classification in Karang Bongkok using images DII and PCA transformations were 72.38% and 81.00% respectively. Meanwhile, in Kotok Island were 83.00% and 84.29% respectively. An accuracy value of 65-70% can be considered good enough for the coastal habitat mapping using remote sensing [27]. PCA

transformation for objects classification both of Karang Bongkok and Kotok Island was more accurate than DII transformation.

In general, the classification accuracy of each object benthic habitat with higher PCA transformation than DII transformation either in Karang Bongkok and Kotok Island (table 4). This means that the object classification of benthic habitat of the image of the PCA transformation is more accurate than the DII. Based on the type of object the object classification sand, and sand mixed seagrass, logoon have the highest accuracy values. In other words that the object is more easily distinguished class than other objects from satellite images. Rubble class is a class of objects most low-value accuracy it can happen because the object rubble covered with algae that can be classified into seagrass. Accuracy object class coral at Karang Bongkok was smaller than Kotok Island. One of the causes is because Karang Bongkok waters deeper than Kotok Island.

Table 4. Accuracy of benthic habitat classifications in Karang Bongkok and Kotok Island

Location	PA		UA		OA	
	DII	PCA	DII	PCA	DII	PCA
Karang Bongkok						
Coral reef	17%	50%	100%	100%		
Lagoon	100%	100%	63%	83%		
Seagrass	73%	82%	96%	96%	72.38%	81%
Sand	80%	80%	100%	100%		
Sand mix Seagrass	100%	100%	100%	83%		
Sand mix Rubble	100%	100%	50%	50%		
Rubble	57%	64%	35%	53%		
Island Kotok						
Coral reef	87%	80%	81%	80%		
Lagoon	100%	100%	100%	100%		
Segrass	72%	82%	100%	98%		
Sand	100%	100%	100%	100%	83%	84.29%
Sand mix Seagrass	95%	95%	66%	100%		
Sand mix Rubble	100%	88%	50%	44%		
Rubble	100%	83%	64%	75%		

3.4. Mapping of seagrass distribution

Seagrass distribution at Karang Bongkok and Kotok Island was sensed by satellite imagery with PCA transformation wider than the DII transformation (figure 3). Procedure accuracy test of seagrass classification has been carried out on 62 samples in Karang Bongkok and 76 samples in Kotok Island. The test results showed that of the 62 samples of DII classification of image transformation in Karang Bongkok, as many as 45 samples in accordance with field data, the other 5 samples are rubble and sand mix rubble. The test results showed accuracy in Kotok Island of 76 samples, 55 samples in accordance with field data, but samples are objects rubble, rubble and sand mix. Thus the value of procedure accuracy seagrass classification of the image in Karang Bongkok and Kotok was 72 % and 73 % respectively.

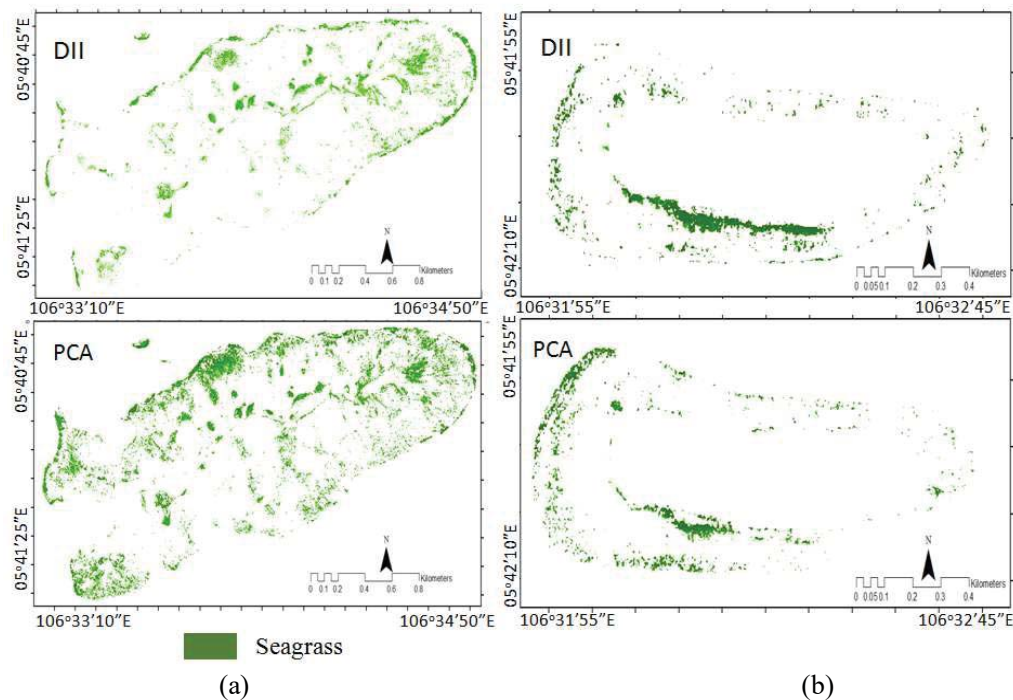


Figure 3. Classification of seagrass utilizing SVM transformation by enhancement technique of DII and PCA in (a) Karang Bongkok and, (b) Kotok Island.

The test results obtained on the different accuracy classes of seagrass of image transformation and PCA in Karang Bongkok and Kotok Island. Of the 62 samples of seagrass object classification results of 51 samples in accordance with field data and 11 other samples are objects rubble and sand mixed rubble. From 76 samples of seagrass class in Kotok Island, 62 samples in accordance with field data, while 14 samples is the object of rubble and sand mixed rubble. Thus both the value of the procedure's accuracy of the classification seagrass PCA transformation in Karang Bongkok and Kotok Island were 82% (table 2). Value procedure's accuracy of the image classification seagrass PCA transformation is higher than DII eventhough in Karang Bongkok and Island Kotok (table 2).

The results of this study indicate that both the PCA and the DII transform a portion of the object classification seagrass in the field is the object rubble, sand mixed rubble. Bottom waters where covered by rubble generally overgrown by algae so that the spectral values similar to seagrass. Likewise, the sandy sea floor covered with sea grass and seaweed that is similar to the spectral values of seagrass.

User's accuracy values of seagrass both of in Kotok Island and Karang Bongkok were a range between 96-100%. These results were similar to previous studies using satellites SPOT with PCA transformation in Morenton Bay, Australia [12].

4. Conclusion

Utilization of satellite imagery Word-view-2 using PCA transformation for mapping benthic habitat of Kotok Island and Karang Bongkok was more accurate than DII transformation. There were seven benthic habitat types in Karang Bongkok waters and in Kotok Island namely seagrass, sand, rubble, coral, lagoon, sand mix seagrass, and sand mix rubble.

Both of PCA and DII transformations were applicable for mapping seagrass ecosystems in Kotok Island and Karang Bongkok with very high accuracy. However, PCA has been applied effectively to improve mapping accuracy of sea grass mapping in Kotok Island and Karang Bongkok.

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