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Monitoring the Restored Mangrove Condition at Perancak Estuary, Jembrana, Bali, Indonesia from 2001 to 2015

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Abstract. Mangrove is unique vegetation that lives in tidal areas around the tropical and subtropical coasts. It has important physical, biological, and chemical roles for balancing the ecosystem, as well as serving as carbon pool. Therefore, monitoring the mangrove condition is very important step prior to any management and conservation actions in this area. This study aims to map and monitor the condition of restored mangroves in Perancak Estuary, Jembrana, Bali, Indonesia from 2001 to 2015. We used IKONOS-2, WorldView-2 and WorldView-3 image data to map the extent and canopy cover density of mangroves using visual delineation and semi-empirical modelling through Enhanced Vegetation Index (EVI) as a proxy. The results show that there was a significant increase in mangrove extent from 78.08 hectares in 2001 to 122.54 hectares in 2015. In term of mangrove canopy density, the percentage of high and very-high canopy density classes has increased from 32% in 2001 to 57% in 2015. On the other hand, there were slight changes in low and medium canopy density classes during the observation period. Overall, the result figures from both area extent and canopy density indicates the successful implementation of mangrove restoration effort in Perancak Estuary during the last 14 years.

Keywords: Mangroves, Monitoring, Perancak Estuary, SAVI

1. Introduction

Mapping and monitoring mangrove forest is essential to provide a baseline of mangrove status and support for management and conservation policy. Mangroves have been recognized among the most important objects in coastal areas which has many ecological functions. It is a breeding ground for juveniles of aquatic organism, providing habitat and food chain for coastal flora and fauna, protecting the coastline from tsunami and sedimentation, and attracting tourists [1,2]. According to Donatoa et al. [3], mangrove forest has important function as carbon sink in tropical forests and has the higher average of carbon storage compared to other forest type. Despite this ecological importance of mangrove, FAO [4] reported that 36% of the world mangrove forest is damaged. The decreasing mangrove ecosystem either from natural or anthropogenic disturbances cause loss of many ecological functions of mangroves. These including the high intensity of coastal abrasion, higher rate of sea water intrusion, loss of fish habitat, decreasing nutrition supply for aquatic organism, and thus causing imbalance of the ecosystem interface between land and sea ecosystem [5]. These threats of mangrove forest corroborate the need to provide efficient tools for mapping and monitoring the status of mangroves both their extent and conditions.

Remote sensing has been acknowledged as one of the most efficient tools for mapping and monitoring environmental changes such as vegetation and other non-renewable resources [6]. Among of the key advantages in using remote sensing for mangrove monitoring are the provisions of synoptic and repeated coverage of mangrove sites [7]. Remote sensing images provide sources for monitoring mangrove forest through the change detection procedure. The changes between mangrove forest extent and status from one date to the other can be monitored using multi-temporal images. The rapid development of Geographic Information System (GIS) also contributes to the development of monitoring methods for environmental changes. Remote sensing and GIS can be integrated in this context; GIS-based change detection requires multi-temporal images as data source, and overlay analysis in GIS is a powerful tool to perform the change analysis [8].

The Perancak estuary in Jembrana Bali is covered by mangroves that experienced an anthropogenic pressure. Most of mangroves forest in this area were altered to aquaculture for economic purposes, which threatening the ecosystem. The Institute of Marine Research and Observation [9] explained that these changes took place in 1980s and mostly from mangrove forest to shrimp ponds. Since 2000s the restoration efforts have been done to the abandoned shrimp ponds to restore the ecological functions of the ecosystem [10]. Therefore, it is important to monitor the growth rate of Perancak mangrove forest to assess the progression of forest restoration process. One of the key parameters of forest physical characteristics observable from remote sensing images is the forest canopy cover density. It is defined as the percent forest area occupied by the vertical projection of tree crowns [11]. It shows an aggregate of leaves from tree crown at a forest stand which can be used to indicate the health of forest and wild life habitat, predict wood plant composition and measure leaf area index (LAI) [11,12]. This study aims to map and monitor the condition of restored mangroves in Perancak Estuary, Jembrana, Bali, Indonesia from 2001 to 2015 by means of mangrove canopy cover density. Several specific objectives are to (1) use high-spatial resolution remote sensing data to estimate mangrove canopy cover, (2) assess the accuracy of canopy cover estimation result, and (3) monitor the condition of mangroves at Perancak Estuary from 2001 to 2015.

2. Data and Methods

2.1. Study site

Perancak Estuary is a mangrove preservation site located in Jembrana Sub-district, Jembrana Regency, Bali (114°37’11.7” - 114°37’12.2” E and dan 08°24’33.5” - 08°24’36.1” S, Figure 1). The study site approximately 876 ha, consists of more than 390 ha of the area as aquaculture (both active and inactive fishpond) and 78.6 ha as mangrove forest. This area of Perancak Estuary includes six villages, which are Perancak, Pengambengan, Air Kuning, Budeng, Yeh Kuning, and Sangkar Agung [13].

Perancak Estuary has a strategic functions as a producer of biological natural resources (source of fisheries, agricultural and timber products, germplasm sources), as transportation facilities, as a port location for ships, fishing sites, as aquaculture and recreation or tourism facilities[13]. Mangrove forests in Perancak Estuary with area of about 177.09 ha are the remaining forest after the land conversion to aquaculture in 1980s [9]. According to Susiana [14], the condition of mangrove ecosystem in this site is divided into natural and rehabilitated mangrove areas, and each have similar biodiversity status with tree stand density more than 1,500 tree/ha. There are nine mangrove species found in the area of Perancak and Tuwed with *Sonneratia alba* as the most dominant species. Based on the magnitude of the important vegetative value index, the nine mangrove species are listed respectively from the largest to the smallest; *Sonneratia alba*, *Rhizophora apiculata*, *Avicennia* *marina*, *Bruguiera gymnorrhiza*, *Rhizophora stylosa*, *Rhizophora mucronata*, *Ceriops decandra*, *Ceriops tagal* and *Excoecaria agallocha* [15].

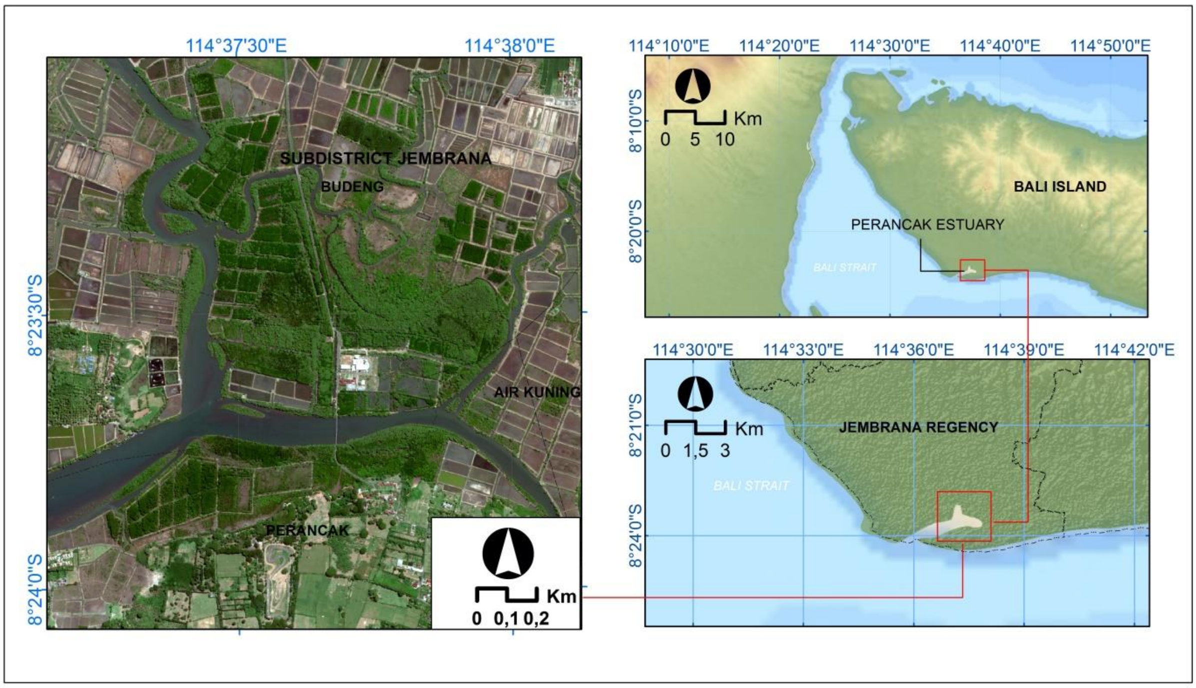

Figure 1. Study Site at Mangroves of Perancak Estuary, Bali, Indonesia

2.2. Image data

The images used in this study are a high resolution satellite imagery possessed by BPOL (Institute for Marine Research and Observation) Jembrana, Bali. The images used in this study are WorldView-3, WorldView-2, and IKONOS-2 (Table 1). The World View images have been orthorectified and radiometrically corrected at standard level. While for IKONOS-2, it has been geometrically corrected at standard level. There are four multispectral bands used in this study, which are red, green, blue and near infrared bands. These four bands are used for vegetation index calculation to estimate the multi-temporal mangrove canopy density and to monitor changes in mangrove condition resulting from restoration efforts in Perancak Estuary.

Table 1. Remote Sensing Image Specification Used in This Study

Images	Acquisition date	Spasial resolution	Spectral attributes (nm)
Worldview-3	16 April 2015	1,31 m (multi) 0,31m (Pan)	Coastal blue (400-450), blue (450-510), green (510-580), yellow (585-625), red (630-690), red edge (705-745), NIR1 (770-895), NIR2 (860-1040), Panchromatic (450-800).
Worldview-2	16 August 2010	1,84 m (multi) 0,48 m (Pan)	Coastal blue (400-450), blue (450-510), green (510-580), yellow (585-625), red (630-690), red edge (705-745), NIR1 (770-895), NIR2 (860-1040), Panchromatic (450-800).
IKONOS-2	2 August 2001	3,2 m (multi) 1 m Pan	Blue (450-520 nm), Green (520-600 nm), red (625-695 nm), NIR (760 – 900 nm), Panchromatic (450-800).

Level 2A of Worldview-2 and Worldview-3 images are standard geometric and radiometric-corrected image that have position shifts at nadir <3.5 meters. Worldview-3 image was recorded on April 16, 2015 at 09:42:20 and has cloud cover of 2.3% with a recording angle of 59.3˚, and Worldview-2 was recorded August 16, 2010 at 09:51:47 with an angle of 57.8˚ and 0.7% of cloud cover. While IKONOS-2 image was recorded on August, 2 2001 at 09:58:00 with cloud cover of 38% and the angle of recording 56.12˚. A cloud cover of 38% caused the IKONOS-2 image condition being slightly darker. It indicates that the image quality of IKONOS-2 is less than the other images which have very little cloud cover of less than 5%. This is because the acquisition time of IKONOS-2 was in the rainy season. In terms of spatial resolution, the Worldview-3 and Worldview-2 pixel sizes have been resample by Digital Globe to 2 meters and for IKONOS-2 to 4 meters.

2.3. Image Preparation

Remote sensing image processing for change detection requires that all images have the same geometry and radiometric characteristics [8]. Image processing was carried out in this study for geometric, radiometric and atmospheric correction between image, and extraction of vegetation index. Geometric correction between images was done using WV-3 as reference image because it is the latest sensor which geometric aspects are stable. The radiometric correction was conducted up to top of atmosphere (TOA) reflectance level, and then continued with relative atmospheric correction using DOS (Dark Object Subtraction).

Vegetation information extraction was done by applying the vegetation index formula on each image. The vegetation index used included Normalized Difference Vegetation Index (NDVI), Soil-adjusted Vegetation Index (SAVI), and Enhanced Vegetation Index (EVI) (Table 2). NDVI is classified as a generic vegetation index because it uses red, green and NIR bands for vegetation index extraction [16]. SAVI is a vegetation index used to reduce the influence of soil backgrounds. Coefficient value of L = 1 is used to reduce soil variance at low vegetation density used, while L = 0.5 and L = 0-0.25 are used for medium and high vegetation density, respectively. The effects of soil almost all disappear with higher vegetation densities that have smaller L factor [17]. While, the EVI is a vegetation index used to reduce atmospheric disturbances and reflections of soil backgrounds all together in vegetated area so that the index results will be more sensitive to biomass and canopy cover density [18].

Table 2. Vegetation Indices Used in This Study.

Vegetation index	Formula		Reference
NDVI	$\frac{\rho NIR-\rho red}{\rho NIR+\rho red}$	(1)	[20]
SAVI	$\frac{\rho NIR-\rho red}{\rho NIR+\rho red+L}\, x\, (1+L)$	(2)	[18]
EVI	$G\frac{\rho NIR-\rho red}{\rho NIR+C1*\rho red-C2*\rho blue+L}$	(3)	[19]

Note: For SAVI, the L value range between 0 (high vegetation density) to 1 (low vegetation density). For EVI, the coefficient used is as follow G= 2.5, C1= 6, C2= 7.5, and L= 1.

2.4. Canopy Density Estimation

Digital photography using hemispherical lenses is a fairly accurate approach in estimating the density of forest canopy cover [19]. The use of fisheye lenses is aimed at obtaining a 180˚ viewing angle, thus being able to see leaf cover more flexibly on each layer [20]. Measurements with hemispherical photographs were performed with upward taking with a shooting height of approximately 1.5 meters from the ground surface and covering an area of approximately 2.3 m^2 [21]. An example of an upward hemispherical photo acquisition is shown in Figure 2a.

The sampling scheme used in this study was purposive sampling which is based on variation of mangrove canopy cover and sample accessibility. The advantage of this approach is its ability to obtain similar samples representing an object at geographically difficult sites from accessible point sampling [22]. The determination of the sample location is done visually from the image by considering the qualitative density of the mangrove forest. Assessment of mangrove conditions in the field was conducted with 10x10 meter plot for tree level (Figure 2b). The selection of this size is because the mangrove area is relatively heterogeneous and mixed for each size, so the size of the stake and seedlings are covered by the tree level when projected from the image. Assessment of the condition is done only at the tree level by considering the tides as the basis for shooting with a height of 1.5 meters sensor/camera on the ground.

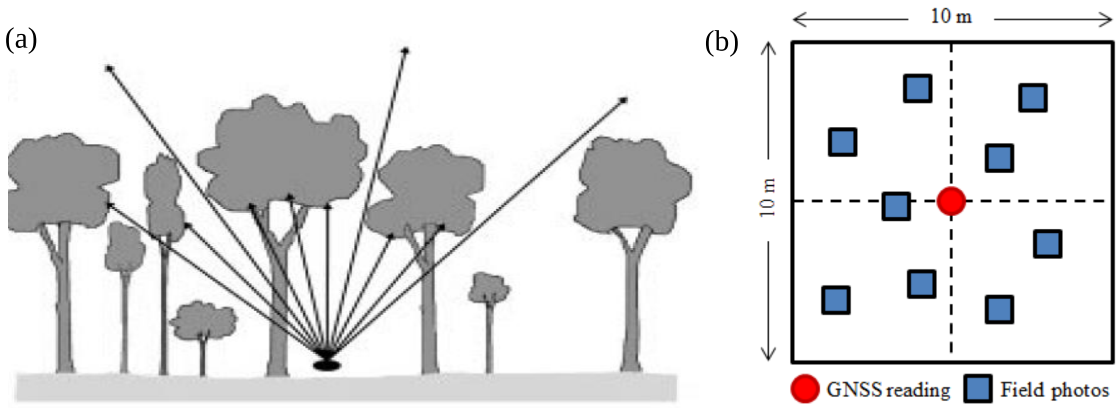

Figure 2. Hemispherical field photos: (a) upward projection of the sensor field of view [23], and (b) field plot and measurement points.

The field sampling was conducted between 1 and 9 May 2016, and was collecting 70 field samples which consist of 36 samples for model development and 34 samples for model validation. On each sampling plot, we recorded the position of the centre of sampling plot using Global Navigation Satellite System (GNSS) receiver and nine random upward facing field photos of the mangrove canopy using a hemispherical camera system. The canopy cover values were then calculated by the CAN-EYE software (http://www6.paca.inra.fr/can-eye) based on the samples collected in the field. The development of canopy cover density map was conducted by correlating field canopy density value with of the corresponding pixels of NDVI, SAVI, and EVI vegetation index values using linear regression analysis. In this case, the relationship analysis was done between vegetation index images as predictor (independent variable (x)) and field data as the response (dependent variable (y)). From the regression analysis, vegetation index that has the highest coefficient of determination (R^2) will be used as the basis for estimating and monitoring of mangrove canopy cover density in the research area.

2.5. Accuracy assessment

The canopy density accuracy assessment was performed using a 1:1 plot of goodness of fit. The aim of this accuracy method is to evaluate the accuracy of the mangrove canopy density estimation from the image (y-axis) based on the ideal value plot (1:1 diagonal line) with the reference value, in this case was the validation field sample (x-axis). From the relationship result, if the data position is above the 1:1 diagonal line, the estimate is over-estimated, and *vice versa* [24]. To obtain a numerical accuracy value, in additoin to the plot of goodness of fit 1: 1, we also performed an accuracy test with Standard Error (SE) (Equation 4) as the following:

$$\textbf{SE}\ (\textit{Standard Error}) = \sqrt{\frac{\Sigma(Y-Y')}{n-2}} \quad (4)$$

where Y = reference value, Y' = estimation value, n = number of sample. The smaller the value of SE, the smaller the error and the more accurate the result of the canopy cover density model.

3. Results and Discussion

3.1. Canopy cover density modelling

The development of canopy cover density map was done by modelling the relationship between field canopy density and vegetation indices value (NDVI, SAVI, and EVI). This is a type of parametric inferential statistics because the data type used has ratio scale (i.e. it has absolute 0 values). The statistical process used to draw conclusions requires the data to be normally distributed. From data analysis, the result of data normality calculation using Kolmogorov-Smirnov method shows that field canopy cover density data is normally distributed with value 0.06 (has significance value > 0.05). The result of the model relationship from 36 field samples is shown in Figure 3a. The three selected indices have a positive correlation with field data with Pearson correlation close to 0.7, or have moderate strength of correlation.

Based on Figure 3a, EVI is able to explain a better data relationship because it considers the atmosphere factor and the background of the soil affecting the reflected value of the image. SAVI has a better coefficient of determination than NDVI, because SAVI considers the soil background aspect, where in the study area with low canopy density conditions tend to have soil background that is not very wet but has an effect on over-estimation at low tide and under-estimation at high tide. By looking at the coefficient of determination, the EVI has the highest value (R^2 = 0.557), therefore we use this index for further processing. We applied the EVI regression model to estimate the mangrove canopy cover density, where Field Canopy Density = 1.6052 EVI – 0.3604, and the mapping result is presented in Figure 3b. There is no specific pattern found from the canopy density map. However, most of the high canopy density values are located at the abandoned fishponds and within the nature mangrove forest. While the low canopy density values are scattered across the study site.

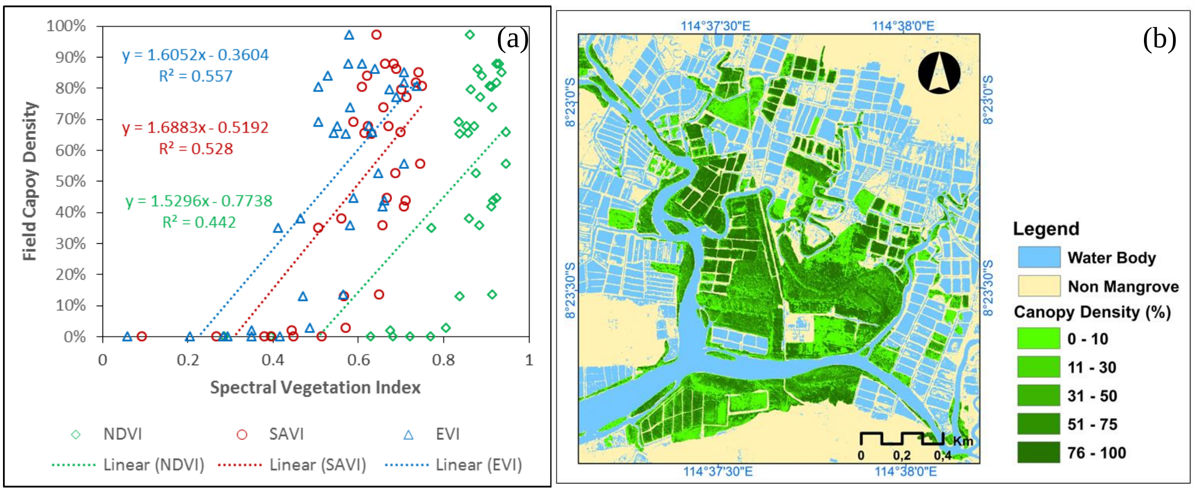

Figure 3. Canopy cover density model: (a) scatter graph between field data and vegetation indices, and (b) canopy density map from EVI model

3.2. Accuracy assessment results

The accuracy assessment used in this research is the plot of goodness of fit 1: 1 and SE. The results in Figure 4 show the distribution of the estimated value of canopy density mangrove value to the corresponding field canopy density value. The linear regression line indicates that there is under-estimation at low canopy density, and over-estimation at high canopy density value. This indicates that the background soil has significant influence on the estimation of the density of the canopy from the image. Because the soil that exists at low densities is not very wet, thus contributing a high reflection due to understory covers. The low accuracy is affected by several factors such as low GNSS accuracy due to positioning problem caused the incompatibility between the sampling positions in the field with the image. In addition, higher image spatial resolution result in more variation within a single object on the image and thus decrease the estimation accuracy [21].

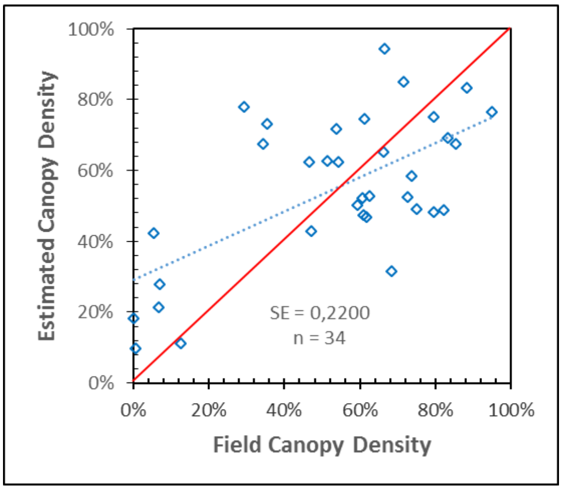

Figure 4. Plot Goodness of Fit 1:1 of EVI

The over-estimation at low density (0-10%) tends to occur due to the reflectance of seedlings, stakes or shrubs on the mangrove understorey. The low density mangrove forest makes understorey vegetation observable from remote sensing images. On the other hand, there is an under-estimation result at 50-80% canopy density, where the field measurements were conducted at the tree level at 1.5 meters above the soil surface. Hence, the density of shrubs and mangrove seedlings is not recorded, but these features are identifiable from the image and increase the value of the canopy cover density.

3.3. Multi-temporal analysis

This research is aimed to monitor the condition of canopy density by using vegetation index as a proxy. The canopy density condition in 2015 was developed from the relationship between field data and vegetation index data using linear regression. EVI was used because it has the best coefficient of determination value. The distribution of mangrove canopy cover density in 2010 and 2001 were developed using field samples collected in 2016. We selected samples where the forest condition did not change much from 2001-2015. Regression functions generated each year of observation is presented in Table 3. In 2001 the coefficient of determination only reached 0.527, meaning the image data was only able to explain about 53% of the field canopy density distribution. While, in the year 2010 the coefficient of determination is 0,816 or about 82% of image data able to explain the field data. The low coefficient of determination in 2001 was mainly attributed to the low quality of IKONOS-2 image mentioned in section 2.2. Other reason might be related to the time difference between image acquisition and field campaign.

Table 3. Regression Functions at Different Years

r	R^2	Regression function	Year
0.746	0.557	Y = 1.605 x – 0.3604	2015
0.903	0.816	Y = 1,419 x – 0.1216	2010
0.726	0.527	Y = 0.980 x – 0.4713	2001

The results of mangrove canopy cover density mapping in 2001, 2010 and 2015 are presented in Figure 5a-c. Overall, we can see the change pattern of Perancak Estuary mangroves; the canopy density of is increasing throughout the observation years. It is indicated by an increase of area extent of dark green features on the maps. From change detection point of view, there are two major changes happen in this area. First, there were land cover changes of non-mangrove area to mangrove area. This pattern is observable from the 2001 – 2015 canopy density maps, especially in the fish ponds area. This pattern indicates that the efforts of restoring mangroves by replanting in abandoned fish pond were successful. We can also see this pattern form the graph in Figure 5d and Table 4, where the total area extent of mangroves increased from 2001 to 2015. Second, there were significant canopy cover density increases during the fourteen years period. This type of change is identified in the natural mangrove forest patch in the middle of the research site, and within some abandoned fish ponds. This pattern indicated a significant growth of mangrove forest in this area. Figure 5d also confirms this pattern; the dark green bar (very high canopy density class) is increasing from 2001 to 2015. This finding is supported by Rahmania et al. [25] where they also found a significant canopy cover increase in this area from 2001 to 2014.

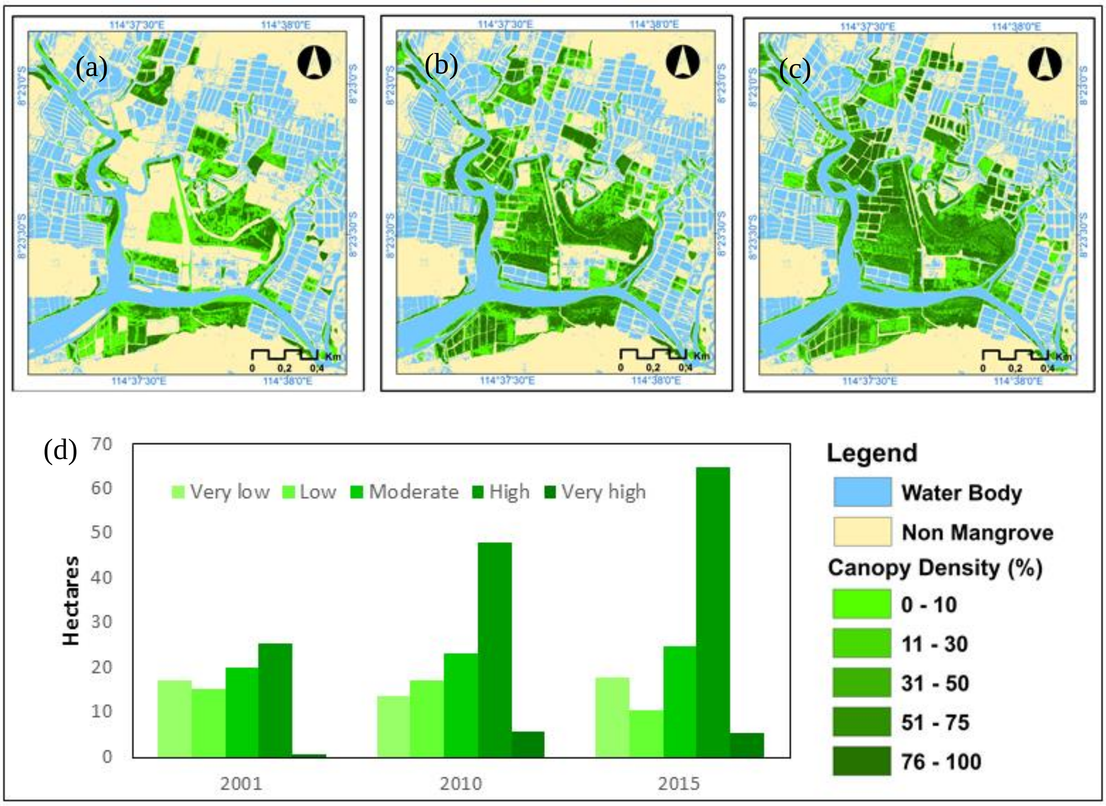

Figure 5. Mangrove canopy cover density in (a) 2001, (b) 2010, (c) 2015, and (d) the canopy density area comparison between years

Tabel 4. Area extent of mangrove canopy cover (in hectares).

Category	Canopy cover (%)	2001	2010	2015
Very low	0-10	29.68	27.02	30.59
Low	11-30	10.52	12.10	9.54
Moderate	31-50	11.31	15.10	17.56
High	51-75	16.17	27.98	34.94
Very high	76-100	10.42	25.00	29.91
Total (ha)		78.08	107.19	122.54

3.4. Mangrove Change at Perancak Estuary

Mangrove monitoring in this study conducted from 2001, 2010 and 2015 to observe changes in the area of mangrove forest and its canopy density conditions. The result of visual interpretation indicates that mangrove at Perancak Estuary shows improvement from year to year, in terms of area extent and density of the canopy. In 2010, mangroves expanded by 29.1 ha from 2001 (Table 5). However, there were about 6.51 ha mangrove areas disappeared in some locations; hence, the area extent of mangroves in 2010 was 107.19 ha. From the maps, there was an increase in mangrove extent in 2015 at about 15.35 ha, and the total mangrove extent was 122.54 ha. However, in 2015 there was an area reduction of 1.37 ha. During the period of 14 years there were 70.19 ha of mangrove forest that remains stable. This result shows that in terms of extent of mangrove Perancak from 2001-2015 is improved significantly as seen from Figure 6a. In terms of mangrove canopy density value, there was a significant increase from 2001 to 2010, which amounted to 70.07 ha. Then from 2010 to 2015 there was an increase in mangrove canopy density as much as 48.78 ha. This shows improvement in the quality of mangrove canopy cover in the study area (Figure 6b).

Table 5. Mangrove changes recorded in 2001, 2010 and 2015.

Changes	Mangrove extent			Mangrove canopy cover		
	2001	2010	2015	2001	2010	2015
Increase	-	29.1	15.35	-	70.07	48.78
Decrease	-	6.51	1.37	78.08	24.83	25.44
No change	78.08	71.57	70.19	-	18.82	49.71
Total (ha)	78.08	107.19	122.54	78.08	113.71	123.92

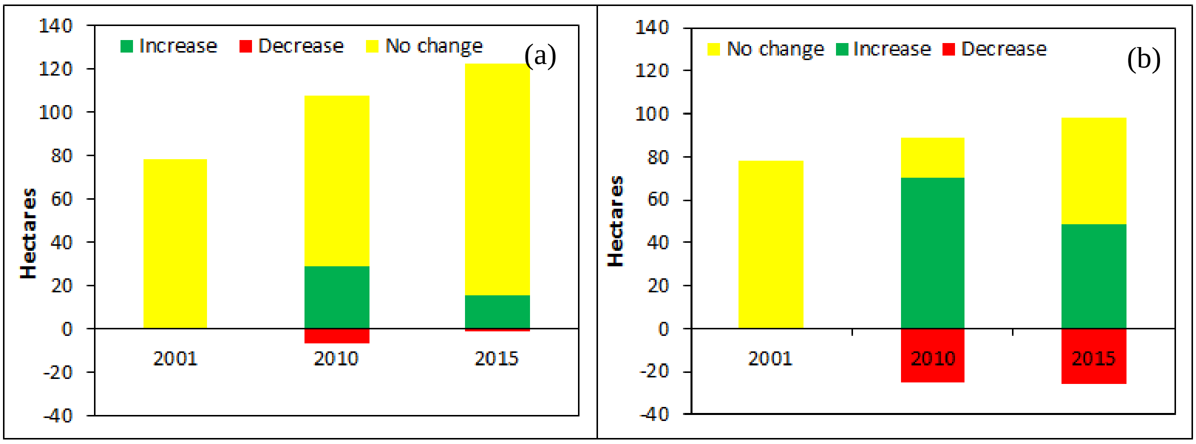

Figure 6. Changes in Perancak Estuary mangroves; (a) mangrove extent, and (b) mangrove canopy cover density.

The pattern of canopy density development from 2001-2010 and 2010-2015 has changes as shown in Figure 7a and b. The pattern of density development with green colour indicates mangrove area that has increased the density of the canopy, with the dominant distribution being in the planting area. Mangroves basically have a slow development [26], but the pattern does not apply to mangrove planting. Distance of mangrove planting was arranged about 1-2 meters, so within 1-2 years it canopy covers the mangrove gaps. The natural mangrove area tends to decrease. This pattern is in line with the research of Rahmania et al. [25] at Perancak, which monitor open and closed canopy cover. Their result shows that open canopy was increasing in the natural mangrove area in 2014, while for the closed canopy area did have a significant increase in the area of planting.

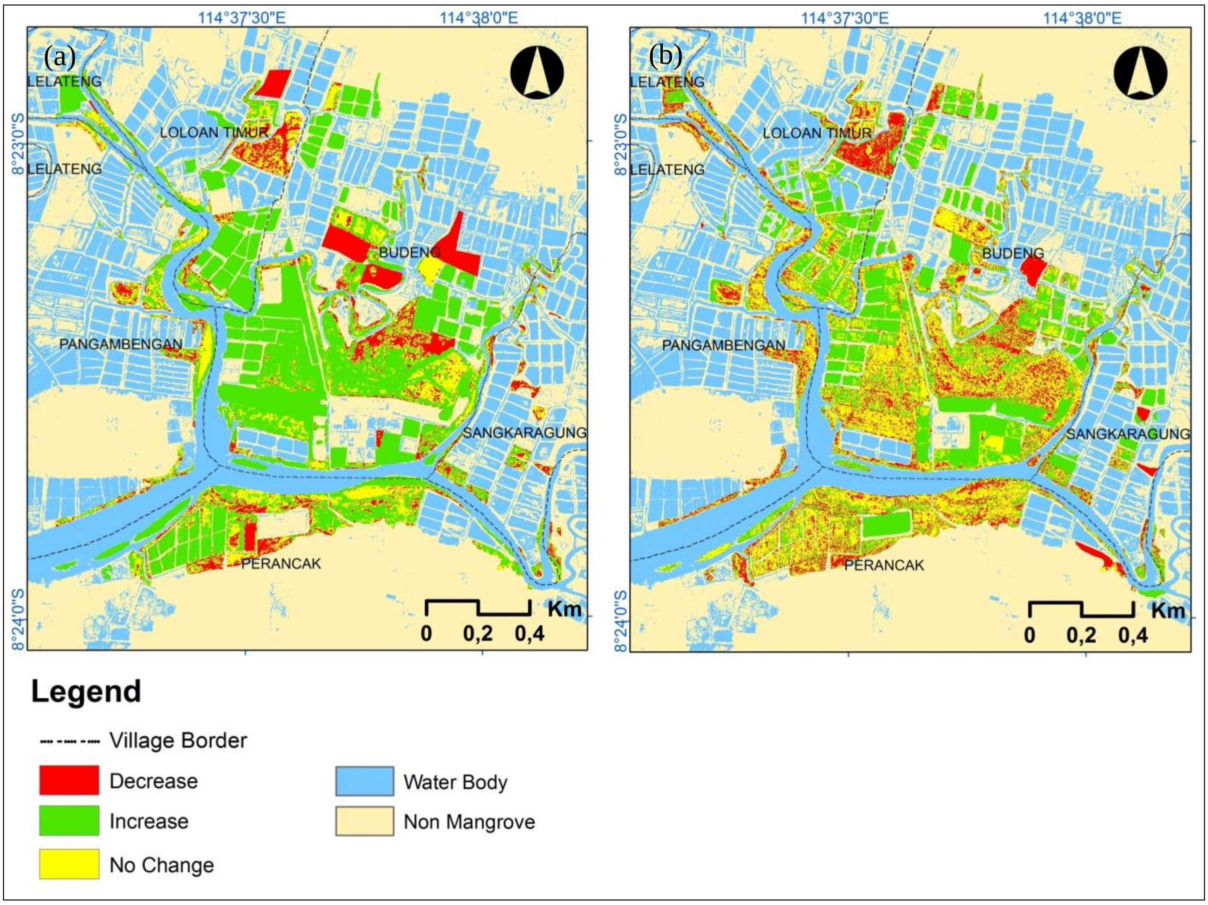

Figure 7. Changes in Perancak Estuary mangroves; (a) from 2001 to 2010, and (b) from 2010 to 2015

Planting activities produce new mangroves plants with relatively rapid vegetation growth. In addition, the pattern of adjacent planting triggers the closure of the canopy and almost all areas of planting have areas that meet closely. According to Rahmania et al. [25], planting in the fish pond area made mangrove propagules locked in the pond and prevent it to spread across the site. It is also one of the new individual developments that led to the growth of the relatively fast growing mangrove area. However, some mangrove planting experiencing leaf decay and dieback, especially *Rhizophora sp*. This condition was due to the competition of photosynthesis among individual mangrove which grows close to each other. Decreased mangrove areas are more affected by the human factor, for example the opening of mangrove areas for shrimp ponds since the 1980s has triggered the changes in mangrove conditions in Perancak Estuary [10]. However, organic litter in mangrove canopies with very high density (75-100%) are more affected by natural factors such as sea level rise or human disturbance.

4. Conclusion and Future Work

This study employed remote sensing data to estimate and monitor mangrove canopy cover density at Perancak Estuary in 2001, 2010 and 2015. Several vegetation indices were used as proxy to estimate this information from semi-empirical relationship between the indices and field data. Overall, remote sensing data are successfully map mangrove extent and canopy cover density in the study site. From the estimation result, the density of the canopy in Perancak Estuary in 2015 is dominated by high density (50-75%). The resulting accuracy assessment of the estimation is moderate, but enough to distinguish the density level of mangrove canopy. From the statistical analysis we found that the best vegetation index is EVI with SE value of 0.220. 2. The extent of Perancak Estuary mangroves was increased from 78.08 ha in 2001, to 107.13 and 122.54 ha in 2010 and 2015, respectively. Similar pattern also found in mangrove canopy density where the condition was tend to improve at planting area marked by increasing of canopy density of about 48.78 ha of mangrove. However, we also noticed some canopy density decrease of about 25.44 ha in natural mangrove. Some future directions proposed as the follow up of this study are (1) to use real time image or image that is obtained not too far from field campaign, (2) to use similar image dataset throughout the year of observation, and (3) to evaluate the mangrove changes using at a shorter period of observation (i.e. yearly or each six months).

5. Acknowledgement

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