CARBON STOCK ESTIMATION OF MANGROVE VEGETATION USING REMOTE SENSING IN PERANCAK ESTUARY, JEMBRANA DISTRICT, BALI

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Abstract. Mangrove vegetation is one of the forest ecosystems that offers a potential of substantial greenhouse gases (GHG) emission mitigation, due to its ability to sink the amount of CO_2 in the atmosphere through the photosynthesis process. Mangroves have been providing multiple benefits either as the source of food, the habitat of wildlife, the coastline protectors as well as the CO_2 absorber, higher than other forest types. To explore the role of mangrove vegetation in sequestering the carbon stock, the study on the use of remotely sensed data in estimating carbon stock was applied. This paper describes an examination of the use of remote sensing data particularly Landsat-data with the main objective to estimate carbon stock of mangrove vegetation in Perancak Estuary, Jembrana, Bali. The carbon stock was estimated by analyzing the relationship between NDVI, Above Ground Biomass (AGB) and Below Ground Biomass (BGB). The total carbon stock was obtained by multiplying the total biomass with the carbon organic value of 0.47. The study results show that the total accumulated biomass obtained from remote sensing data in Perancak Estuary in 2015 is about 47.20±25.03 ton ha^{-1} with total carbon stock of about 22.18±11.76 tonC $ha^{-1}$and CO_2 sequestration 81.41±43.18 tonC ha^{-1}.

Keywords: *Perancak Estuary, carbon stock estimation, mangrove, CO_2 sequestration, NDVI*

1 INTRODUCTION

Global warming is one of the strategic issues in the world today, as marked by the incidence of rising earth temperatures related to greenhouse gases. Several researchers noted that the major contributors to global warmings, such as carbon dioxide (CO_2), and methane (CH) gases are anthropogenic, mainly produced from the human activities like fossil fuels burning, industry, deforestation, forest degradation and other forest conversion through combustion (Giri and Mandla 2017; Vicharnakorn *et al.* 2014). The accumulation of these gases causes the earth's temperature to rise, triggering climate change on Earth (Manuri *et al.* 2011).

Sutaryo (2009) describes the forest biomass as highly relevant to climate change issues. Forest biomass has an important role in the biogeochemical cycle, especially in the carbon cycle. Of the total forest carbon, about 50% is stored in forest vegetation. As a consequence, if there is forest damage, forest fire, logging and etc., it will increase the possibility to have larger -amount of carbon in the atmosphere. The dynamics of carbon in nature can be explained simply by the carbon cycle. The carbon cycle is a biogeochemical cycle that includes the exchanged/transferred of carbon between the biosphere, the pedosphere, the geosphere, the hydrosphere and the earth's atmosphere. The carbon cycle is actually a complex process and every process related to other processes. The global carbon describes the exchanges of carbon between the Earth's atmosphere, oceans, land and fossil fuels, which are both sources of emissions and sinks that contain carbon. One important function of the carbon cycle is the regulation of earth's climate (Bennington 2009).

Mangrove ecosystems, like other forest ecosystems, have a potential -ability to absorb carbon dioxide better than other forest ecosystems due to its ability to grow faster than any other forest vegetation. It is noted that mangrove forests have an important role in reducing the concentration of carbon dioxide in the air. Mangrove forest is one of the highest carbon-storage forests in the tropics and it is very high compared to the average carbon storages in other kinds of forest in the world (Donato *et al.* 2012). Although mangroves are known to have good assimilation capabilities with environmental components and have a high rate of carbon sequestration, data and information on carbon storage for some components, especially for tree biomass are very limited (Komiyama *et al.* 2008), so it is important to know that biomass information in the mangroves for sustainable forest management. In forest carbon inventories, carbon pools are accounted for by at least 4 carbon bags: surface biomass, subsurface biomass, dead organic matter and soil organic carbon. According to Donato *et al.* (2011), carbon is mostly stored in the sediments, aerial vegetal biomass, and below-ground biomass in the descending order. However recent studies suggest the importance of the carbon stock in the below-ground biomass of mangrove forests (Abohassan *et al.* 2012), there a few estimates regarding this compartment (Komiyama *et al.* 2008).

According to Lu (2006), field or terrestrial measurement is the most accurate way to collect biomass data, but this method is generally very expensive, time-consuming, labor-intensive and difficult to apply into remote and broad areas. Therefore there is another alternative solution in knowing the potential information of biomass that is by using aerial approach through remote sensing technology. The advantage of the remote sensing technology is to provide information needed quickly and completely at a relatively cheaper cost. In addition, the use of remote sensing technology in finding information on potential estimation of mangrove biomass as CO_2 absorber can be monitored effectively and efficiently every year. One of the remote sensing data that can be utilized is Landsat satellite data.

Situmorang *et al.* (2016) found that there was a high correlation (R^2=0.729) between vegetation index resulted from satellite data and carbon stock estimation calculated using allometric equation. This high determination coefficient indicates that the satellite data is feasible to use to estimate carbon stock. Many studies on carbon stocks in mangrove vegetation by using remote sensing techniques have been conducted. In mangrove forest carbon stock (Mariana *et al.* 2015; Alemayehu *et al.* 2014; Sitoe *et al.* 2014; Hamdan *et al.* 2013; Murdiyarso *et al.* 2009) carbon sequestration (e.g. Bouillon *et al.* 2008; Khan *et al.* 2007) and organic carbon dynamics (Kristensen *et al.* 2008; Machiwa and Hallberg 2002) have been studied much. Carbon stock in mangrove ecosystem varies with species (Fu and Wu 2011; Laffoley and Grimsditch 2009), vegetation type (Sahu *et al.* 2016; Cerón-Bretón *et al.* 2011; Mitra *et al.* 2011; Sapit *et al.* 2011) and salinity (Adame *et al.* 2013).

Perancak Estuary is one of the four main mangrove ecosystems in Bali Island besides West Bali National Park, Benoa Bay and Nusa Lembongan. In addition to feeding, spawning and nursery ground, information on the ability of mangrove forest in Perancak Estuary to store carbon utilizing of remote sensing technology is still very low, so this research becomes very important to do. The objective of this research is to identify the biomass and potential carbon stock of mangroves vegetation in Perancak Estuary by using remote sensing approach. This information is very useful for Jembrana district government to support sustainable development planning based on low carbon, especially for the coastal area.

2 MATERIALS AND METHODOLOGY

2.1 Location and Data

The research is located in Perancak Estuary, Jembrana District, Bali as shown in Figure 2-1. Geographically, Perancak Estuary is located between 8°22'30"S to 8°24'18"S and 114°36'18"E to 114°38'31.2"E. Perancak Estuary has an area of 2512.69 ha, with land use in the form of fishponds and mangroves.

Data used in this research is Landsat 8 OLI/TIRS with acquisition date 13 September 2015 and path/ row 117/ 66 which obtained from United States Geological Survey (USGS) through website https://earthexplorer.usgs.gov.

2.2 Data Analysis

2.2.1 Converting digital values into reflectance

The Landsat sensor is converted into reflectance value by using the variable factors that provided in the metadata. Landsat suggests to converting the digital value into Radian using the following formula:

$$\rho\lambda' = M\rho Qcal + A\rho \quad (2\text{-}1)$$

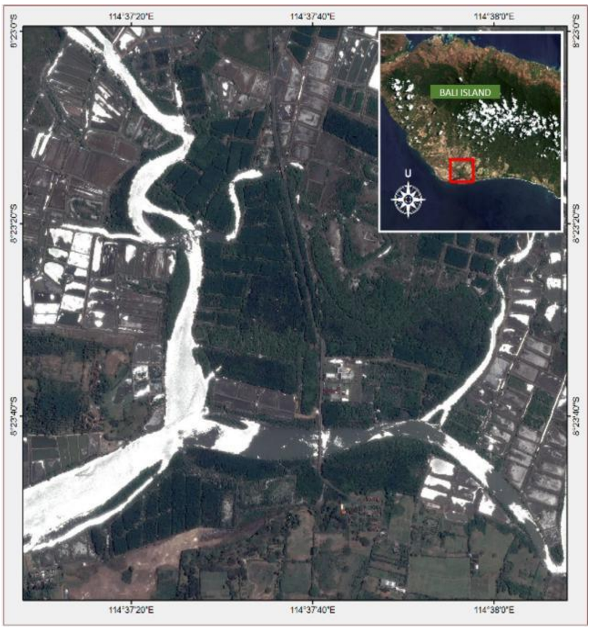

Figure 2-1: Location of the research area

$\rho\lambda'$ = a reflectance value without correction to the sun's elevation, $M\rho$ = band specific multiplicative rescaling factor (where$x$ is *Band* (*REFLECTANCE_MULT_BAND_x*), $A\rho$ = Band-specific additive rescaling factor from the metadata (where x is *Band* (*REFLECTANCE_ADD_BAND_x*,), *Qcal* = quantized and calibrated standard product pixel values(DN).

Conversion of reflectance value to the sun elevation follows equation (2-2).

$$P\lambda' = \frac{\rho\lambda'}{\cos(\theta SZ)} = \frac{\rho\lambda'}{\sin(\theta SE)} \quad (2\text{-}2)$$

$P\lambda'$ = reflectance, θSE = a local sun elevation. The scene center sun elevation in degrees (SUN_ELEVATION); θSZ = local solar zenith angle, $\theta SZ=90°-\theta SE$.

2.2.2 Vegetation index

Calculation of land covers vegetation index using Normalized Difference Vegetation Index (NDVI). NDVI is a calculation of visible light and near infrared which is reflected by vegetation. The classification of pixel values for NDVI ranges from -1 to 1. The low (negative) NDVI values identify areas of water bodies, rocks, sand, and snow. High NDVI values (positive) identify areas of vegetation in the form of savanna, bush, and forests, whereas the NDVI value near 0 generally identifies bare land (Saputra 2007). This value of NDVI can be calculated using the equation 2-3.

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (2\text{-}3)$$

where *NIR* = near infrared band, *RED* = red band.

The NIR reflectance is affected by leaf internal structure and leaf dry matter content. RED is the reflectance or radiance in a visible wavelength channel (0.63 - 0.69 µm) and corresponds to band 3 for ETM+ images.

In this paper, NDVI images were generated to enhance mangrove forest that has higher NIR reflectance, and lower red light reflectance. Also, NDVI images were produced to eliminate water bodies, those of low red light reflectance, and those of very low NIR reflectance.

2.2.3 Image classification of mangrove land

Image classification is performed to separate the spectral values contained in the pixel image unit. The unit of the pixel value is explained into several classes of land cover. The method of satellite image classification guided using imagery classification method to distinguish between mangrove area and non-mangrove area. Guided classification uses the maximum likelihood method which assumes that the class statistics in each band are normally distributed. The manual visual analysis classification is performed when the data is cloud-covered and the absence of other data available as the closing or graph fill data so that the edge of limitation digit to classify using the 563 composite band approach with mangrove-looking conditions as seen in Figure 2-2.

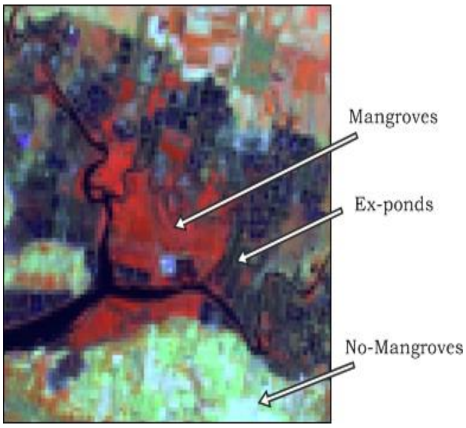

Figure 2-2: The mangrove vegetation shown in the composite image of 5-6-3 (NIR-WSIR 1-Green)

The pixel class is determined by the highest probability level. The results of guided data and manual visual analysis can then be converted to measure the area of land cover.

2.2.4 Above Ground Biomass (AGB) estimation

Estimation of above the ground surface biomass value was done using the approach of NDVI result of equation correlation with Above Ground Biomass (AGB) of mangrove that is equal to 0.787 by Jha *et al.* (2015) as follows:

$$AGB = 305.9 * NDVI^{4.864} \quad (2\text{-}4)$$

NDVI = the value of Vegetation Index,
AGB = the Above Ground Biomass Value (ton ha^{-1}).

2.2.5 Below Ground Biomass (BGB) estimation

The estimated value of Below Ground Biomass (BGB) is obtained from the estimation of AGB which is formulated using the equation compiled by Cairns, *et al* (1997) as follows:

$$BGB = \exp(-1.0587 + 0.8836 * Ln(AGB)) \quad (2\text{-}5)$$

AGB = the value of Above Ground Biomass (ton ha^{-1}), *BGB* = the Below Ground Biomass value (ton ha^{-1}).

2.2.6 Total Accumulated Biomass (TAC) Calculation

Total Accumulation Biomass (TAB) is formulated by using:

$$TAB = AGB + BGB \quad (2\text{-}6)$$

TAB = Total Accumulated Biomass (ton ha^{-1}).

2.2.7 Total Carbon Stock (TCS) calculation

Calculation of total carbon stock based on Westlake (1963) using the following formula:

$$TCS = TAB * \%\,C\,organic \quad (2\text{-}7)$$

TCS = the value of Total Carbon Stock (ton C ha^{-1}), *TAB* = the value of Total Accumulated Biomass (ton ha^{-1}), *%C organic* = the percentage value of carbon stock (0.47) or using the value of carbon emitted from the measurement results in the laboratory.

2.2.8 Amount of CO_2 Sequestration (ACS) calculation

IPCC (2001) suggests converting carbon stock from biomass to carbon dioxide uptake using the following conversion:

$$ACS = 3.67 * TCS \quad (2\text{-}8)$$

ACS = the Amount of CO_2 Sequestration (ton C ha^{-1}), *TCS* = the value of Total Carbon Stock (ton C ha^{-1}).

The biomass or carbon stock unit can be converted from unit ton ha^{-1} into kg/Landsat Pixel (kg/900m^2) by using the equation (9).

$$Data\left(\frac{kg}{Landsat\ Pixel}\right) = Data\left(\frac{ton}{ha}\right) * 90 \quad (2\text{-}9)$$

2.2.9 Estimation of biomass, carbon stock and CO_2sequestration

The biomass, carbon stocks, and carbon sequestration are calculated by constructing the equation above using ArcGIS Geoprocessing toolbox application for Landsat Image 7 and 8.

3 RESULTS AND DISCUSSION

From the image analysis, we found that the extent of mangrove vegetation within the research area is approximately 101.16 ha. Green, *et al* (1998) did the assessment of mangrove area using NDVI to estimate of percent canopy, the accuracy of the percent canopy closure image was 80%. High accuracy to assess mangrove using NDVI also reported by Otero, *et al* (2016) with the overall accuracy of 87% ± 2%. The ability of the NDVI method to detect mangrove vegetation conducted by Guha (2016) has an overall accuracy of 88.75% for 1989 image and 86.25% for 2010 images, and the overall Kappa coefficient of 0.81 and 0.76.

Based on the area of mangrove forest, the range of mangrove vegetation index in Perancak Estuary is 0.0025 – 0.78 (Table 3-1). This range of NDVI values differs from Prameswari *et al.* (2015), where the minimum value of NDVI obtained from the measurement using ALOS AVNIR-2 image data is -0.723 and maximum of 0.530 with the standard deviation 0.127.

A variety of vegetation index has been developed by retrieving vegetation density from optical remote sensing. Li *et al.* (2007) are used the most common one method is NDVI to predict the biomass of trees. NDVI is based on the characteristics that vegetation has noticeable absorption in the near read infrared spectrum.

In addition to NDVI, there are also several image data processing methods for determining vegetation index such as Simple Ratio (SR), Triangular Vegetation Index (TVI), Enhanced Vegetation Index (EVI), Ratio Vegetation Index (RVI), and Soil Adjusted Vegetation Index (SAVI) (Frananda *et al.* 2015). Furthermore, the vegetation index values were used for the determination value of AGB, BGB, TAB, TCS and ACS using equation (4) to (9) above.

Based on Table 3-1, it can be seen that the AGB value is 38.60±20.79 ton ha^{-1} and the value of BGB is 8.60±4.24 ton ha^{-1}. Based on the value of AGB and BGB it can be said that the AGB is bigger than BGB. This is consistent with the results of a study conducted by (BPOL 2015) which states that by conducting field measurements in Perancak Estuary, the average value of AGB is higher than the BGB's.

The value of AGB and BGB on this research still representative with the research about assessment of mangrove forest carbon stock monitoring in Indonesia conducted by Yenni, *et al* (2014), which the average of AGB in Subang, West Jawa 1.65 ton ha^{-1}; Cilacap, Central Java 4.62 ton ha^{-1}; Badung, Bali 12.87 ton ha^{-1}; and Merauke, Papua 3.97 ton ha^{-1}.

AGB will give the best estimation using diameter breast height (DBH) as a parameter (Alemayehu *et al.* 2014). The determination of the AGB value is an important step in the planning of the protection and utilization of natural mangrove resources (Meideros and Sampaio 2008). The differences in AGB and BGB valuescan also be seen among mangrove species, depending on geographical location, tree density and ecology (Sahu *et al.* 2016; Alongi 2012).

Total accumulated biomass (TAB) is the total amount of biomass on above and below the soil surface. The value TAB in Perancak Estuary is 18.67 ton ha^{-1}. If the ratio between BGB and AGB is bigger, then the plant undergoes substantial root growth (below ground) which is quite dominant rather than trunk growth (above ground). Plant biomass is closely related to photosynthesis, biomass increases as plants absorb CO_2 from the air and convert it into organic compounds through photosynthesis. Biomass in each part of the plant increases proportionately with the larger diameter of the tree. The high ability of trees to store carbon free from air depends on the diameter of trees (Imani *et al.* 2017) and tree height (Fu and Wu 2011).

Table 3-1: Average values of AGB, BGB, TAB, ACS and ACS in Perancak Estuary

Average Values	**Statistics (t ha^{-1})**		
	Mean±SD	**Max**	**Min**
NDVI	0.63±0.11	0.78	0.0025
AGB	38.60±20.79	93.43	0
BGB	8.60±4.24	19.11	0
TAB	47.20±25.03	112.54	0
TCS	22.18±11.76	52.89	0
ACS	81.41±43.18	194.12	0

The estimated of total carbon stock value in the Perancak Estuary is 22.18±11.76 tonC ha^{-1} and the amount of CO_2 sequestration estimation is 81.41±43.18 tonC ha^{-1}. The estimated total carbon stock value obtained from the remote sensing measurements is much higher than the field measurements conducted by (Sidik *et al.* 2014) in Perancak Estuary.

Regarding of (Sidik *et al.* 2014), there is a difference in carbon stock value between natural mangrove forest and re-plantation mangroves in ex-ponds. Carbon stock produced by natural mangroves is higher than re-plantation mangroves in ex-ponds. The carbon stock value in natural mangrove forest is 171±43 MgC ha^{-1} while the carbon stock from mangrove that grows in ex-pond is 52±15 MgC ha^{-1}.

The estimated value of carbon stocks in Perancak Estuary can be done by remote sensing approach with a good result, even the value is still low compared with other studies (Table 3-2). The average biomass of live trees found from (Sitoe *et al.* 2014) is below the lower limit 58.38±19.1Mg ha^{-1} and the average carbon 28.02±9.2 Mg ha^{-1}.

Table 3-2 shows, the estimation of carbon stock using remote sensing data at Perancak estuary is still reasonable. Existing mangrove forest is usually producing a higher value of carbon stock comparing to the replanted mangrove.

Table 3-2: Carbon stock estimation of mangrove vegetation found in the literature

Reference	**Carbon Stock (tonC ha^{-1})**
This study	22.18±11.76
Estrada and Soares (2016)	78.0±64.5
Hutchinson *et al.* (2014)	74.5±54.6
Hamdan *et al.* (2013)	1.01 – 259.68
Komiyama *et al.* (2008)	78.3±51.0

Variations of carbon stock value depend on several physical factors of environmental chemistry, the diversity and density of existing plants, soil types and how they are managed. Besides on those factors, mangroves in Perancak Estuary are from rehabilitated mangroves in 2001 and 2009. The dominant mangroves found in Perancak Estuary are *Rhizopora mucronata*, *Rhizopora apiculata*, *Sonneratia alba*, *Avicennia alba* and *Avicennia marina* (Proisy *et al.* 2015).

Mangroves in Perancak Estuary area grow on the mud-soil type substrate mixed with organic material (Kartikasari and Sukojo 2015). The size of the carbon stored in vegetation depends on the amount of biomass contained in the tree, soil fertility and the absorption of the vegetation (Ati *et al.* 2014).

Figure 3-1 shows the location of natural and rehabilitation (re-plantation) mangroves in Perancak Estuary. In the natural mangroves dominated by *Avicennia* sp. and *Sonneratia alba.* While the dominant mangrove grown in the former location of ponds (rehabilitation mangroves) estimated to be around 8-10 years old is *Rhizopora* sp. (BPOL 2015). Based on the result of this research, the variation values of carbon stock in Perancak Estuary due to the age of the relatively young mangrove trees. Almost 70% of carbon stock variability is explained by age (Estrada and Soares 2017), species, management regime, as well as the climate (Kairo *et al.* 2008). It has been reported that the highest carbon stock for > 80-year-old *R. apiculata* - dominated mangrove forest was 230.0 t C ha^{-1} (Putz and Chan 1986) while those of 20- and 28-year-old *Rhizopora* forests were 114 and 105.9 t C ha^{-1} respectively (Ong *et al.* 1995). The standing biomass for the 12-year-old *Rhizopora mucronata* plantation was 106.7±24.0 t/ ha, giving a biomass accumulation rate of 8.9 t/(ha year) (Kairo *et al.* 2008). The condition of mangrove vegetation in Perancak Estuary shown in Figure 3-2**.**

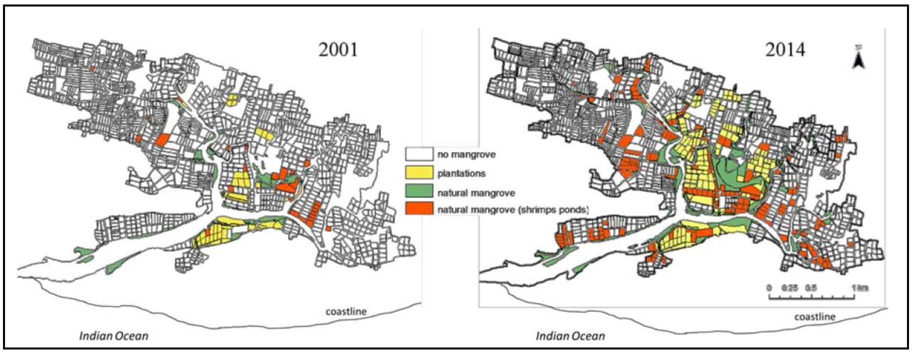

Figure 3-1: Fine-scale maps of changes in mangrove cover between 2001 (left) and 2014 (right) over the whole Perancak Estuary (Rahmania *et al.* 2014)

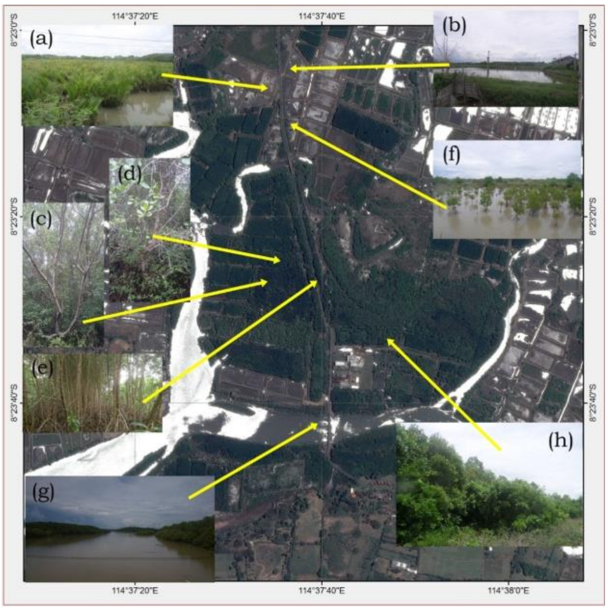

Figure 3-2: Mangrove vegetation condition in Perancak Estuary which surrounded by river and ponds (a) *nypa* sp. which grow in ex-ponds (b) active ponds (c) *avicennia* sp. (d) *sonneratia* sp. (e) *rhizopora* sp. (f) *rhizopora* sp. re-plantation in the ex-ponds (g) natural mangrove vegetation that grows along the river (h) natural mangrove vegetation

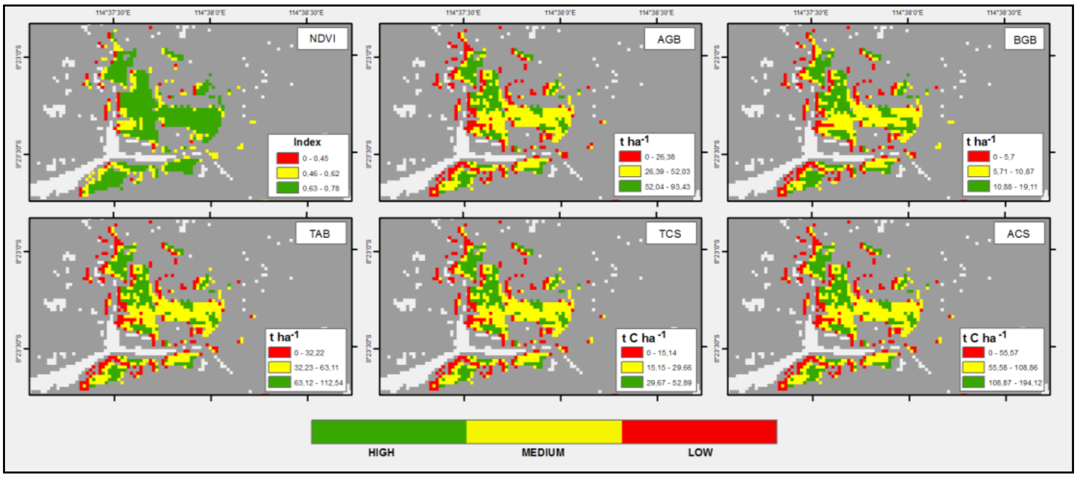

Figure 3-3: Map of value and distribution of NDVI, AGB, BGB, TAB, TCS and (ACS) in Perancak Estuary in 2015

Figure 3-3 shows the values and distributions of NDVI, AGB, BGB, TAB, TCD and ACS in the Perancak Estuary. Spatially viewed of the distribution of NDVI value, the range value of AGB, BGB, TAB, TCD and ACS are different. Variations of the distribution of these values are speculated because of the different types of mangroves, namely mangroves that grow naturally and rehabilitated mangroves. Value of NDVI, the average value of AGB, BGB, TAB, TCD and ACS in natural mangroves is higher than mangroves that grow in the former location of ex-fishponds and rehabilitation mangrove (Figure 3-3).

NDVI value generated for each pixel on the images was converted to carbon stock will give a different result. The higher NDVI will produce a high biomass value as well. The relationship between NDVI and biomass is also reported (Hamdan *et al.* 2013), which states that there are different relationships between AGB and NDVI. Linear regression produced higher correlation coefficients but not represent the real distribution, especially when the NDVI value approaches 0.

Optic data approach commonly used vegetation indices for mangrove biomass estimation (Sahu *et al.* 2016; Hamdan *et al.* 2013; Wicaksono *et al.* 2011; Li *et al.* 2007) and for the common forest (Laurin *et al.* 2016; Jha *et al.* 2015). Vegetation indices are highly related to net primary productivity (Li *et al.* 2007).

Given that optical imagery cannot obtain tree height as a crucial parameter in biomass estimation, detailed and accurate estimation of mangrove forest AGB still presents a challenge when parameters derived from optical imagery are applied to biomass estimation. Studies of plant allometry indicated that biomass is determined not only by canopy parameters but also by other factors such as wood density, trunk taper and tree height (Komiyama 2008; Chave *et al.* 2006; Niklas 1995) which are closely relevant to the floristic characteristics of the species.

The results of research on estimation of carbon stock by using remote sensing method still require the accuracy and field test to mangrove type and density. The NDVI method is not the best method for estimation of carbon stocks, but the method has relatively consistent accuracy at various levels of radiometric correction (Wicaksono *et al.* 2011). According to Frananda (2015), measuring the vegetation index using TVI has the best accuracy. In addition, the use of high-resolution image data is necessary to be applied in assessing the condition and dynamics of mangroves properly (Rodriguez and Feller 2004), classification of tree species based on their reflectance value (Wang *et al.* 2004; Dahdouh-Guebas *et al.* 2005) and the other necessities.

4 CONCLUSION

Estimated carbon stocks in Perancak Estuary can be done using remote sensing data with the good enough result, which is 22.18±11.76 tonC ha^{-1}. The use of NDVI is still relevant for biomass and carbon stock estimation in a mangrove ecosystem. Moreover, the difficulty of distinguishing mangrove vegetation is due to relatively small research areas. Field measurement and high-resolution satellite data in carbon stock estimation, especially in Perancak Estuary still need further study to improve the accuracy of carbon stock estimation results.

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