Mapping Above-Ground Carbon Stock of Secondary Peat Swamp Forest Using Forest Canopy Density Model Landsat 8 OLI-TIRS: A Case Study in Central Kalimantan Indonesia

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ABSTRACT

Mapping the above-ground carbon potential by using a non-destructive method has been a serious challenge for researchers in the effort to improve the performance of natural forest management in Indonesia, particularly in the ex-Mega Rice Project (MRP) area in Central Kalimantan Province. Nevertheless, the rapid and dynamic changes in secondary peat swamp forests are currently mapped effectively with the remote sensing technology using the Forest Canopy Density (FCD) model. FCD analysis as done by integrating vegetation index, soil index, temperature index and shadow index of Landsat 8 OLI images. The result was an FCD class map. In each class, parameter measurements were established for seedling, sapling, poles and tree stages. Above-ground carbon stock was calculated using three allometric equations. The results revealed that the values of carbon stock in ±16,147.26 ha dense secondary peat swamp forest, ±1,509.66 ha moderately dense scrub swamp forest, and ±632.07 ha sparse scrub swamp forest were, respectively, 79.28-122.96; 74.06-113.06; and 40.48-63.60 ton/ha. These results show that FCD application could be used to classify forest density effectively and in line with the variety of their attributes such us aboveground biomass and carbon stock potential.

1. INTRODUCTION

With a total area of 15,798,359 ha, Central Kalimantan Province has a large proportion of peatland that can be classified into primary peat swamp forest (228,773 ha), secondary peat swamp forest (45,927 ha), shrub swamp (1,979,807 ha), and peat swamp area (549,007 ha) (Wardoyo, 2002). The average degradation rate of peat swamp forests in 1991-2001 is approximately 3.3% (Boehm et al., 2002). The relatively rapid development and changes of swamp forest status have not been accompanied by specific and comprehensive monitoring system activities. Page et al. (2009) reported that peat land clearing for agricultural use has caused a decrease in the level of groundwater 176 cm in the dry season and flooding up to 100 cm above ground level in the rainy season. Rehman et al. (2015) reported that logging activities cause the humid tropical forests to be highly prone to forest fires and desiccation. Therefore, there is an urgency to devise an inventory system that is able to provide information on carbon potential of forest. Since the beginning of 1990, the Japan Overseas Forestry Consultants Association (JOFCA) and the International Timber Trade Organization (ITTO) have succeeded in creating a Forest Canopy Density (FCD) model with an accuracy level above 90% (Rikimaru, 1996). The classification of forest canopy density using the FCD model is in line with the variety of structural and floristic composition of peat swamp forest (Sukarna, 2009; Sukarna and Syahid, 2015). Previous studies using the FCD model have been carried out by Deka et al. (2012) and Banerjee et al. (2014).

The territorial inventory of vast forest areas with dynamic development and limited access requires significant funds, time and energy (Mon et al., 2012; Wannasiri et al., 2013). The research problem entails how to develop an indirect and non-destructive

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method for estimating above-ground carbon stock. It is necessary to standardize the objectives and models that will be developed in mapping the carbon stock. Previous studies of above ground biomass and carbon stock have been carried out by Laurance et al. (1999), Rahayu et al. (2007), Ballhorn et al. (2007), Moder et al. (2008), and Rosalina et al. (2013).

Studies on the estimation of above-ground carbon stock of peat swamp forests by employing Alos Palsar imagery has been conducted by Yuwono et al. (2015). The study claimed the positive coefficient of correlation between backscatter and carbon stock. Furthermore, MOD17 imagery from the Terra/Aqua MODIS satellite has also been the subject in a study carried out by Vetrita and Hirano (2012). Based on the problem and priorities, the objectives of the present study are described as follows: (1) to develop a forest canopy classification model based on Landsat 8 OLI-TIRS images; and (2) to estimate the above-ground carbon stock of the secondary peat swamp forest using allometric equations.

2. METHODOLOGY

2.1 Study area

The study area was conducted in the Block C area of ex-Mega Rice Project (MRP) in Central Kalimantan Province, Indonesia (Figure 1). The ex-MRP is the most important peat swamp ecosystem and also well known for their extreme fragility (Boehm and Siegert, 2004; Fahmi and Radjagukguk, 2013). It has since burned during the annual dry season spewing out a choking haze and large volumes of carbon emissions. It is urgent to study above-ground carbon stock related to the ecosystem condition.

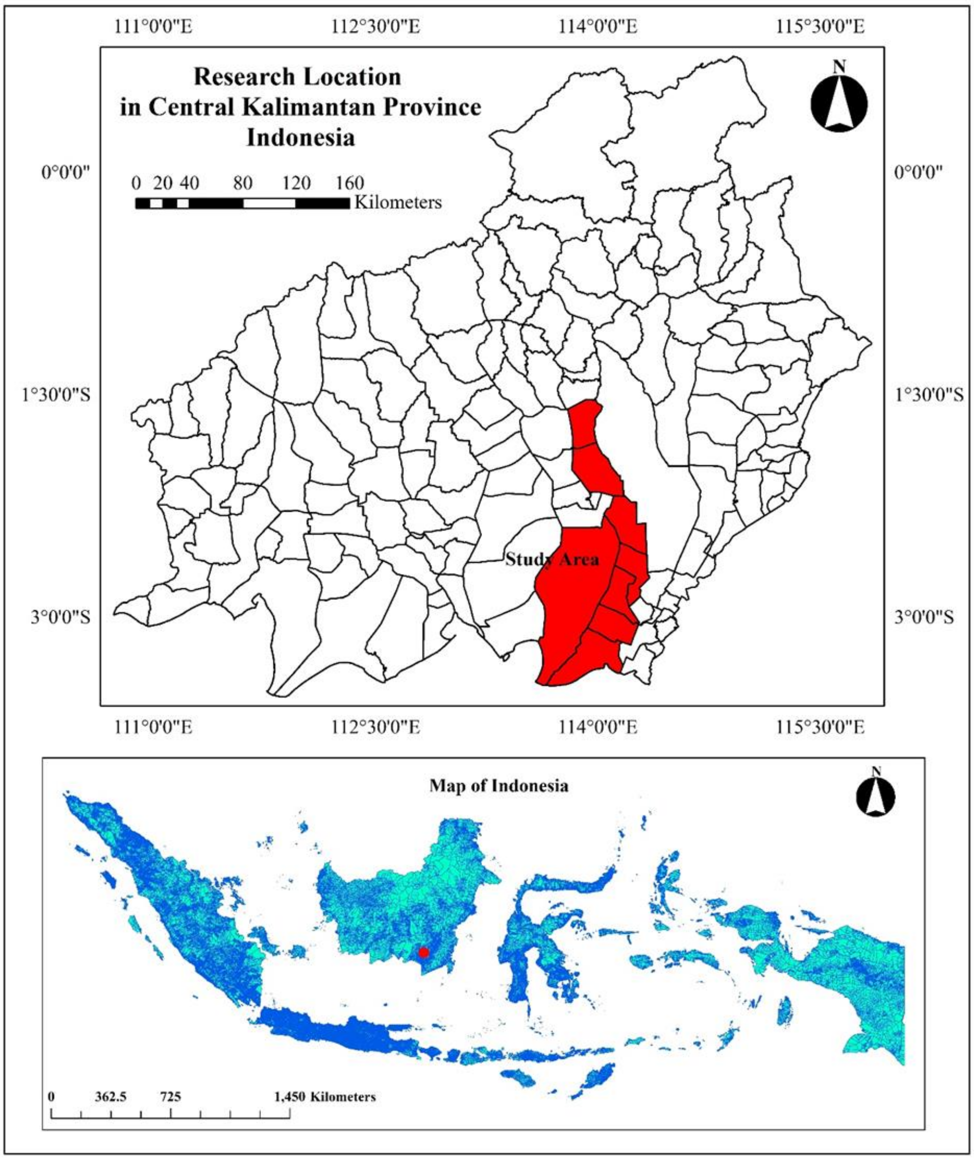

Figure 1. Map of study area

2.2 Data acquisition

The Landsat 8 OLI/TIRS path/row 118/062 on 21 August 2016 were used to cover the study area, then map of Central Kalimantan Province.

2.3 Correction and normalization

The correction of the spectral value of imagery is required due to the cloud and atmospheric disturbances. The histogram matching method and data normalization through contrast stretching technique were carried out by FCD Mapper Version 2.0 to correct the data, resulting in new images with a value between 0 to 255 for all bands. Geometric correction was done using the Indonesia Topographic Map through affine transformation with geographic coordinates and the World Geodetic System datum (WGS 84) in Quantum GIS version 3.14.

2.4 Image processing of FCD

Classification was carried out through a spectral data of Landsat images using the FCD models (Rikimaru, 1996; Rikimaru, 1997; Roy et al., 1997), with formulations as follows:

- Advanced vegetation index: $(\mathrm{AVI}) = \{(\mathrm{NIR}+1) \times (256-\mathrm{Red}) \times (\mathrm{NIR}-\mathrm{Red})\}^{\frac{1}{3}}$
- Bare soil index: $(\mathrm{BI}) = \left\{(\mathrm{SWIR}+\mathrm{Red}) - \frac{(\mathrm{NIR+Blue})}{(\mathrm{SWIR+Red})} + (\mathrm{NIR+Blue})\right\} \times 100 + 100$
- Shadow index: $(\mathrm{SI}) = \{(256-\mathrm{Blue}) \times (256-\mathrm{Green}) \times (256-\mathrm{Red})\}^{1/3}$
- Temperature index: $(\mathrm{TI}) \rightarrow \mathrm{L} = \frac{[\mathrm{L.min}+(\mathrm{L.max}-\mathrm{L.min})]}{255} \times \mathrm{Q}$

With the spectral bands Landsat 8 OLI/TIRS consisting of: Blue Band, Green Band, Red Band, Near Infra Red (NIR) Band, Short Wave Infra Red (SWIR) Band, L (Thermal infrared radiance), and Q is the digital number of the image.

The Advanced Vegetation Index (AVI) is used to measure and analyze green vegetation density changes, the Bare soil Index (BI) is used to analyze open areas, the Shadow Index (SI) is used to analyze forest canopy cover conditions, and the Thermal Index (TI) is used to determine the differences of micro temperature in each land cover unit (Roy et al., 1997).

Based on these 4 (four) indices, the forest canopy density value is estimated using the following equation (Rikimaru, 1996).

- Forest Canopy Denssity $(\mathrm{FCD}) = (\mathrm{VD} \times \mathrm{SSI}+1)^{1/2} - 1$

Where; VD is the Vegetation Density and SSI is the Scaled Shadow Index.

2.5 Field survey

Field survey was carried out to investigate and measure the conditions at each canopy density of the peat swamp forest. For each unit of forest canopy density, a sample plot was established in a stratified sampling with a size of 10 × 10 m for the tree/pole level, 2 × 2 m for the sapling level, and 1 × 1 m for the seedling level. Totally, there were 60 sample plots, consisting of 20 plots in the secondary peat swamp forest with dense canopies, 20 plots in the secondary peat swamp forest with moderately dense canopies (shrubs), and 20 plots in the forests with sparse canopy (scrub swamp).

2.6 Estimation of above-ground carbon stock potential

In the present study, the calculation of the above-ground carbon stock potential of vegetation was estimated using the allometric equations of biomass/dry weight and subsequently used to calculate the carbon stored in vegetation.

- Allometric equation model proposed by Kettering et al. (2001): $\mathrm{DW} = 0.11\ \rho\ \mathrm{D}^{2.62}$
- Allometric equation model proposed by Murdiyarso et al. (2004): $\mathrm{DW} = 0.19\ \rho\ \mathrm{D}^{2.37}$
- Allometric equation model proposed by Jaya et al. (2007): $\mathrm{DW} = 0.107\ \mathrm{D}^{2.486}$

Where; DW=dry weight/tree biomass (kg/tree); ρ=wood density (gr/cm^3); D=tree diameter at breast height (dbh) (cm); The amount of carbon stored in vegetation using the Brown (1997) equation:

$$\mathrm{C}\left(\frac{\mathrm{kg}}{\mathrm{tree}}\right) = \mathrm{DW} \times 0.50$$

3. RESULTS AND DISCUSSION

3.1 Image analysis of FCC, AVI, BI, SI, and TI

The results of the vegetation density analysis derived from the integration of AVI and BI images obtained highly detailed land cover classes compared to the false color composite image (FCC 654; Figure 2), particularly in distinguishing open area and dense above-ground vegetation. Nevertheless, the Vegetation Density image still had a few shortcomings, including dense grasslands and shrubs revealed a higher percentage value of vegetation density (>80%) than young scrub swamp forests (40-60%), which is an error in interpreting the peat swamp forest vegetation structure.

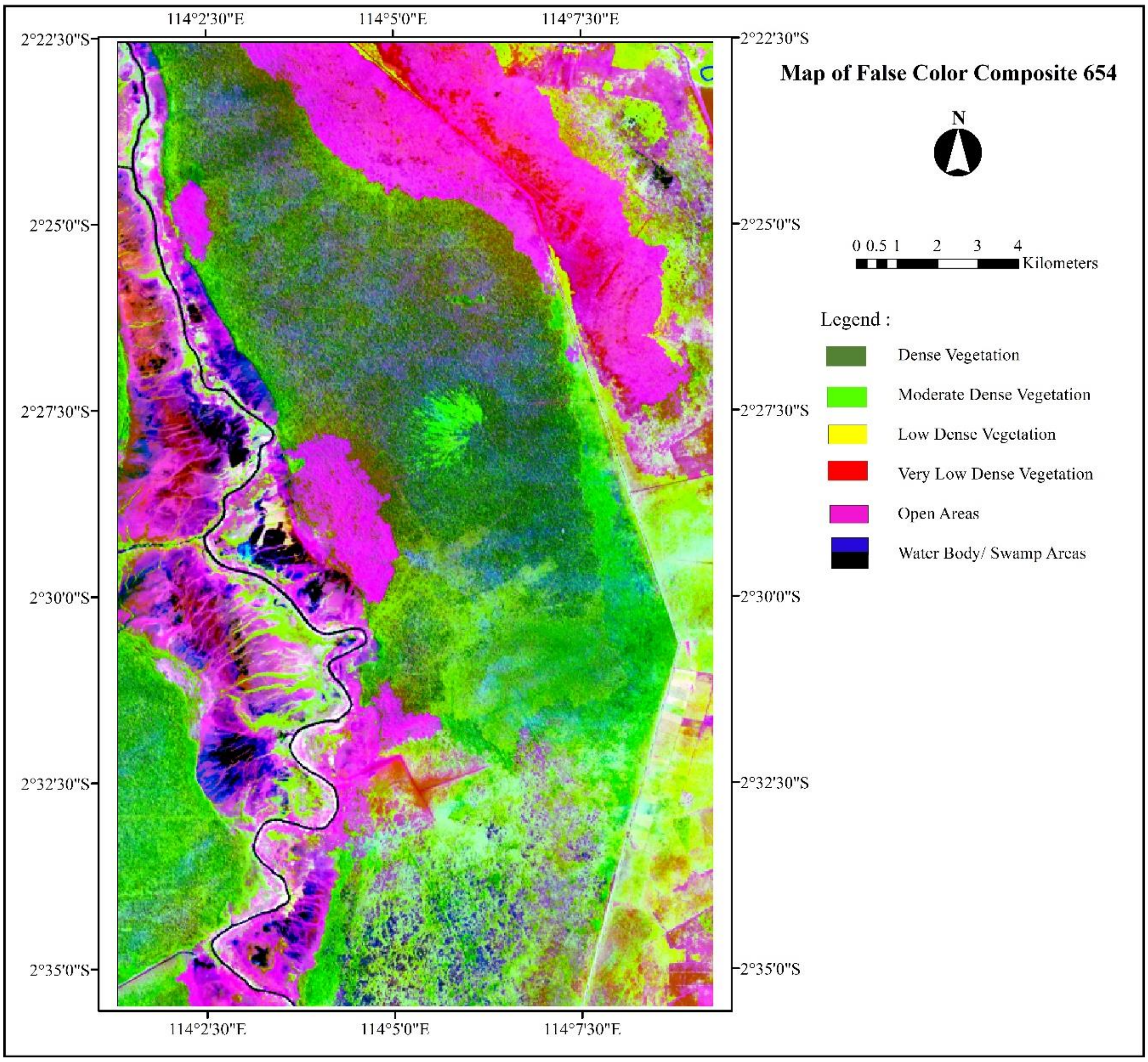

Figure 2. Map of false color composite 654

To evade misidentification and classification of the vegetation structure, a method has been developed by inputting the values of shadow index (SI) and thermal index (TI). Rikimaru (1997) suggested that the maximum value of the vegetation index does not primarily depend on tree or forest density since it is saturated earlier than the shadow index (SI). On the contrary, the SI value is highly dependent on the amount of tall vegetation such as trees with a significant canopy shadow. The higher the tree vegetation density level, the higher the shadow level. Therefore, the higher the SI value, the lower the thermal index (TI) value (Figure 3).

The results of the analysis revealed the negative correlation between SI and TI with a correlation value of -0.684. It explains the phenomenon of the higher the vegetation canopy shadow in the peat swamp forests, the lower the temperature (TI). On the contrary, it also revealed the positive correlation between BI and TI with a correlation value of 0.783. It explains the phenomenon of the higher the open area index value at the study area, the higher the temperature (TI). The combination of AVI, BI, SI and TI as presented in Table 1.

Table 1. Correlation value of AVI, BI, SI, and TI combination

No.	Combination	Landsat 8 OLI-TIRS		
		Correlation	Mean	Deviation
1	AVI-BI	-0.601	101.048	30.833
2	SI-TI	-0.684	133.124	51.171
3	AVI-SI	0.123	101.048	30.833
4	BI-SI	-0.661	123.901	20.660
5	BI-TI	0.783	123.901	20.660

Remark: AVI=Advanced Vegetation Index; BI=Bare Soil Index; SI=Shadow Index; TI=Thermal Index

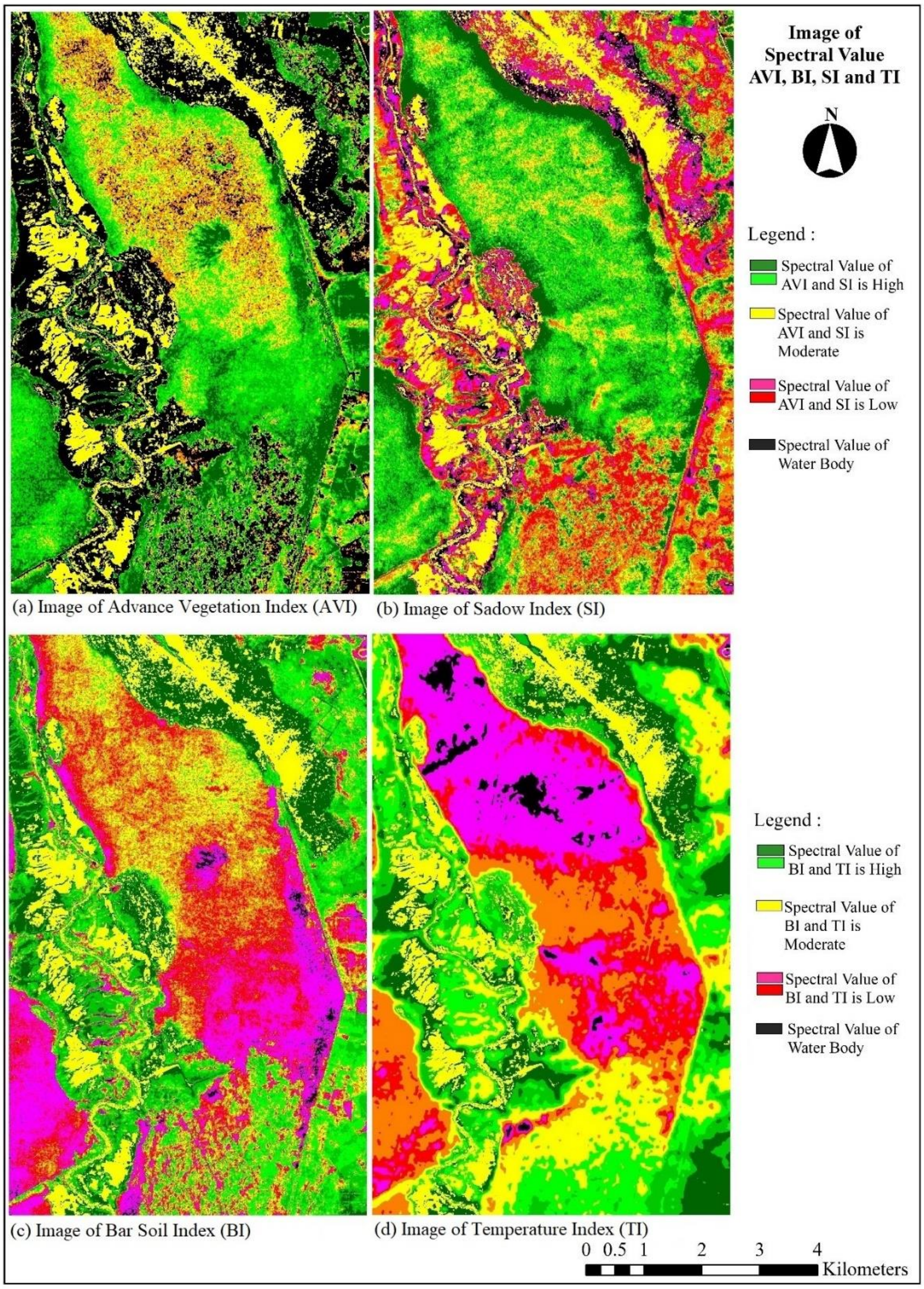

Figure 3. Image of Spectral Value (a) AVI image; (b) SI image; (c) BI image; and (d) TI image

3.2 Image analysis of forest cluster

The integration between the thermal index (TI) and the canopy shadow index (SI) resulted in the Advanced Shadow Index (ASI). The application of ASI is used as a reference for creating a Scaled Shadow Index (SSI) model which serves to determine the detailed structural clusters of peat swamp forests. The results of the analysis revealed that forest areas that were classified in dense canopy structure (SI>60%) had a lower value of TI (<60%). Meanwhile, forest areas with sparse canopy structures (SI<60%) had a higher value of TI (>60%). As a consequence, the SI value of almost all areas with dense canopy shadow is more than 80%, and it certainly became a problem in determining and analyzing forest structure in a factual basis. The analysis of the spectral data clusterization of Landsat 8 OLI-TIRS images generated 8 forest clusters based on the characteristics of the spectral value as presented in Table 2. The results of the analysis of forest clusters generated a new image, namely a scaled shadow index (SSI) image.

Forest clustering derived from the spectral analysis of SSI Image relatively provides information based on the differences in the vertical structure of the forest canopy density (Figure 4). The results of the forest clustering analysis are useful to identify the differences and variations in forest canopy structure based on the conditions of the canopy classes. Moreover, the provisional identification of the forest clustering revealed that forest with dense vegetation canopy had a higher SSI value, while forest with low or sparse vegetation canopy had a lower SSI value. Rikimaru (1996) explained that in areas where the SSI value is zero, this corresponds with forests that have the lowest shadow value (i.e., 0%). In areas were the SSI value is 100, this corresponds with forests that have the highest possible shadow value (i.e., 100%). The SSI can clearly differentiate between vegetation in the canopy and vegetation on the ground. It significantly improves the capability to provide more accurate results from data analysis than was possible in the past

Table 2. The spectral value of forest clusters in SSI landsat 8 OLI-TIRS image

No.	AVI	BI	SI	TI
1	56.8	140.3	12.4	140.1
2	28.9	157.6	59.5	203.5
3	144.9	126.6	131.0	158.0
4	136.6	123.2	163.0	123.2
5	136.6	113.9	175.7	63.0
6	179.3	103.5	179.1	73.5
7	188.6	108.1	172.2	108.3
8	200.3	112.2	162.1	143.8

Remark: AVI=Advanced Vegetation Index; BI=Bare Soil Index; SI=Shadow Index; TI=Thermal Index

3.3 Image analysis of vegetation density

In order to reduce and neutralize possible spectral misinterpretations in analyzing forest clustering through the SSI image model, the present study attempted to develop a vegetation density image model (VD model). The analysis of vegetation density image was intended to enhance the validity of the vegetation density model in accordance with the factual green vegetation density (green biomass) in the field (Figure 5). The results of the visualization of the SSI Image and the VD Image demonstrated opposite results in describing the condition of the vegetation canopy density. It revealed that the dense vegetation with the structure of vegetation on the ground had a higher density index in VD image, and on the contrary, had a lower canopy shadow index in SSI image.

3.4 Image analysis of forest canopy density

Based on the results of the analysis of Vegetation Density (VD) and Scaled Shadow Index (SSI) image, an integration process was carried out to obtain a new image model, namely the Forest Canopy Density (FCD) image which is expected to produce variations in the spectral value of the vertical structure of forest canopy and horizontal density of forest vegetation (Figure 6). Ultimately, the new image would provide a more representative and accurate classification in determining the condition of the canopy structure of peat swamp forest. The results of spatial analysis of the FCD image showed that the total area of the study area was ±28,968.48 ha, which could be classified into 6 categories according to the level of vegetation canopy density (Table 3).

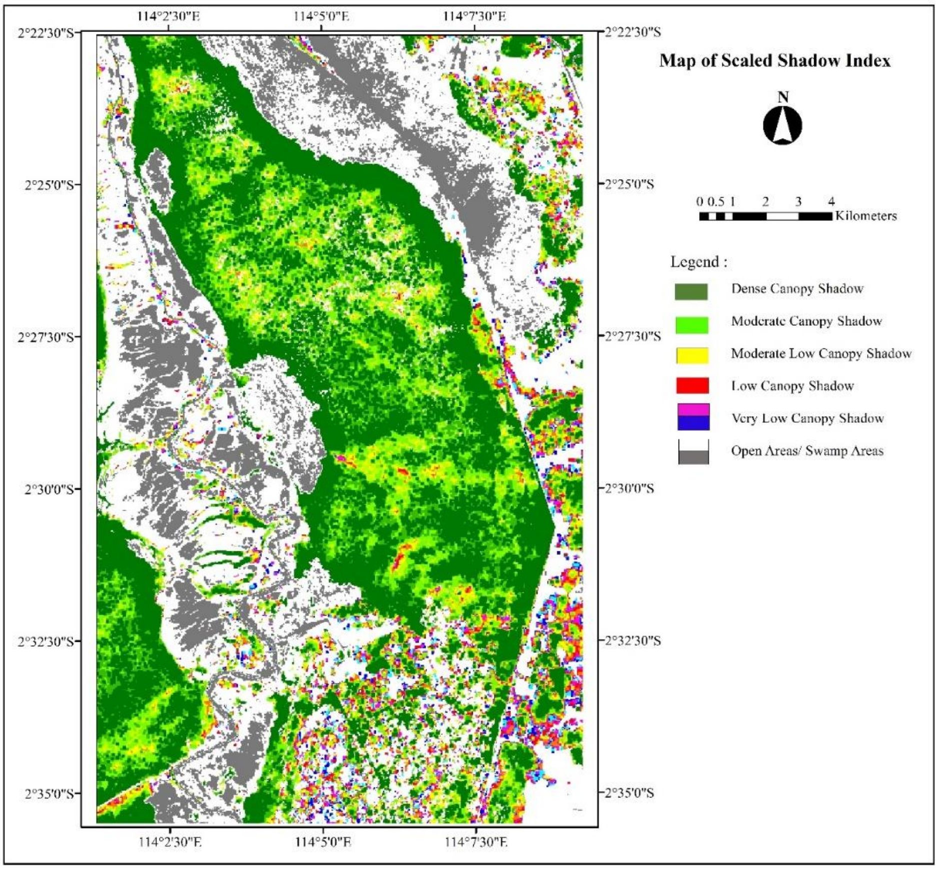

Figure 4. Map of forest cluster based on SSI.

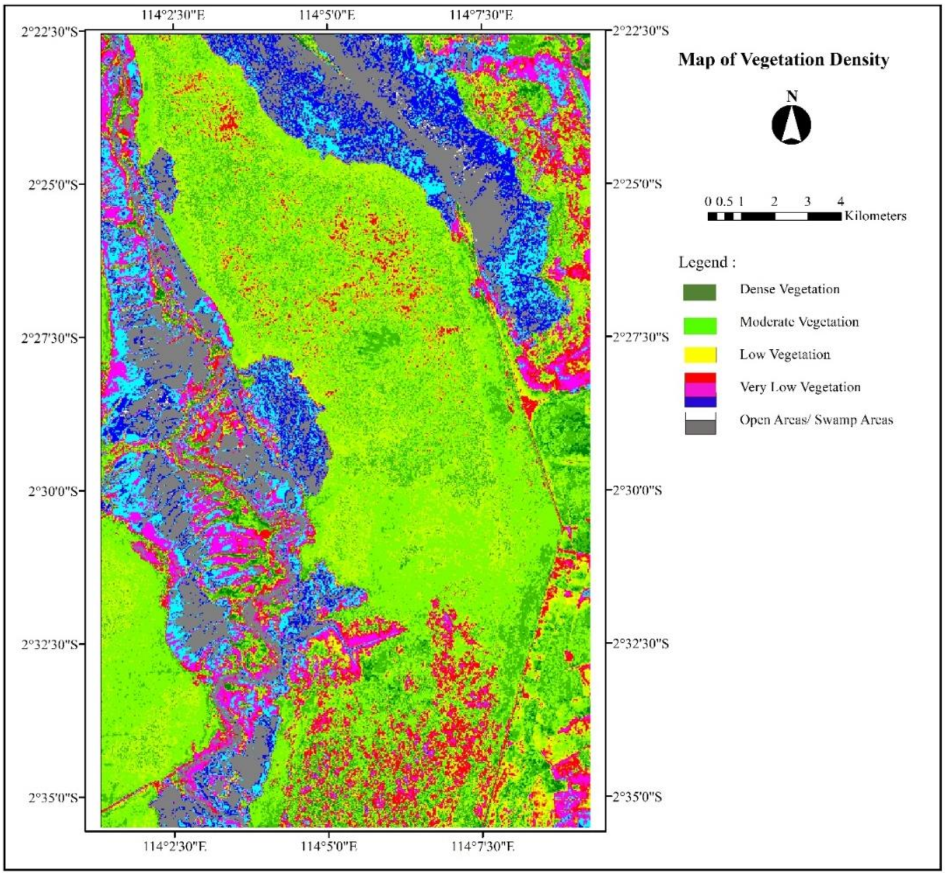

Figure 5. Map of vegetation density

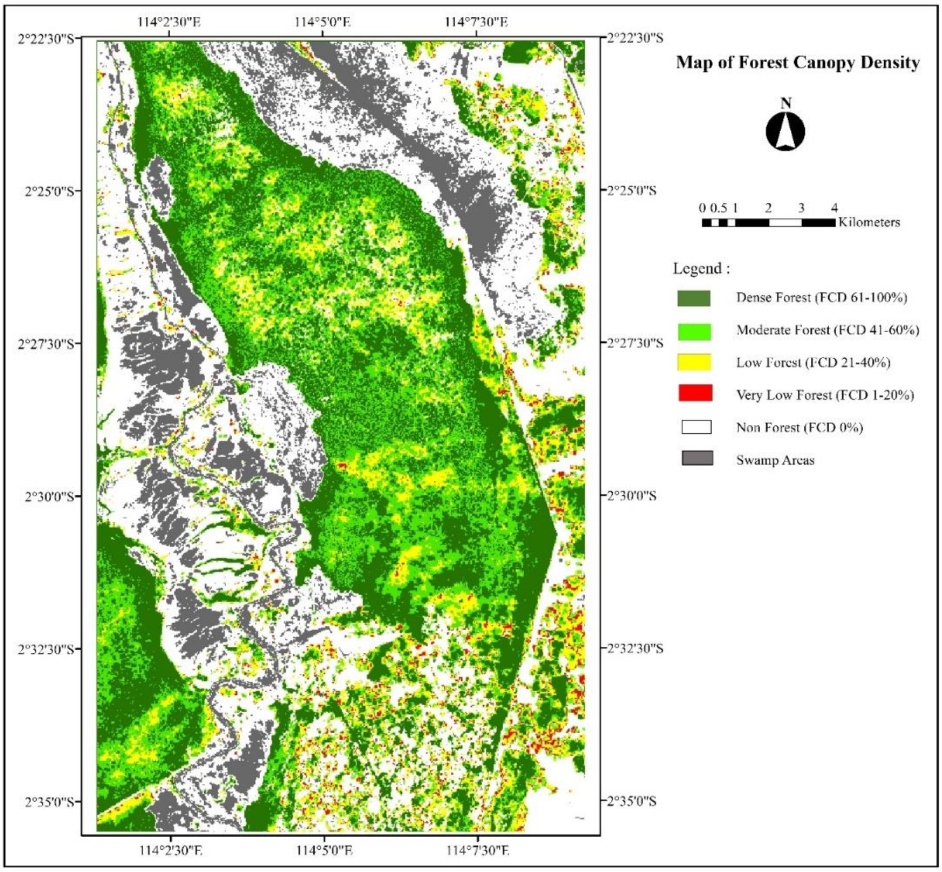

Figure 6. Map of forest canopy density

Table 3. Result of FCD image analysis, identification and interpretation of object in secondary swamp forest, Central Kalimantan

No.	Interval of FCD (%)	Area (ha)	Identification and interpretation
1	0	10,508.13	Open area, grasslands, ferns, and shrubs
2	1-20	130.77	Grasslands, ferns, and small trees with very low dense trees/ forest
4	21-40	632.07	Scrub swamp, sparse trees with shrubs with low dense trees/ forest
5	41-60	1,509.66	Scrub swamp with moderately dense trees
6	61-100	16,147.26	Secondary peat swamp forest with dense trees
Total area (ha)		28,968.48	

3.5 Above-ground carbon stock potential

In the present study, the calculation of the estimated above-ground carbon stock potential included trees and tree regeneration. The carbon stock potential is calculated using allometric equations according to Kettering et al. (2001); Murdiyarso et al. (2004); and Jaya et al. (2007). The classification of forest cover classes was obtained from FCD image analysis, namely: dense secondary peat swamp forest, moderately dense forest, and low dense forest. The data gained from the calculation of the above-ground carbon stock potential using 3 (three) allometric equations in each forest cover class are presented in Table 4.

The calculation using three allometric equations models for each class of peat swamp forest cover demonstrated a variety of value distribution. The dense secondary peat swamp forest had the highest distribution value of total above-ground carbon stock potential (92.59 to 122.96 ton/ha), followed by moderately dense forest (74.06 to 113.06 ton/ha), while the lowest was dense forest (40.48 to 63.60 ton/ha). The high distribution of the carbon stock potential in the dense secondary peat swamp forest is possibly influenced by its vegetation density level. In fact, it has a higher vegetation density (93,075 tree individual/ha) than moderate dense swamp forest (45,173 tree individual/ha) or low dense swamp forest

(6,840 tree individual/ha). Vegetation density is one of the parameters that affect the value of vegetation biomass and carbon stock potential in an ecosystem (Kusmana et al., 1992; Dharmawan and Siregar, 2008; Rachmawati et al., 2014; Chairul et al., 2016). We found that a dense forest is not a forest with larger trees than a sparse forest. The difference between dense forest and sparse forest is the number of trees per hectare. In addition, the study area is a secondary peat swamp forest for a long-time disturbance such us hydrological cycle, logging and forest fire (Boehm et al., 2002; Boehm and Siegert, 2004).

Table 4. Above-ground carbon stock potential (trees and regeneration) of different allometric equation models and forest cover classes in secoundary swamp forest

Stage of tree	Allometric equation	Carbon stock potential (ton/ha) of peat swamp forest based on cover classes					
		Dense forest	%	Moderately dense forest	%	Low dense forest	%
Seedling	Kettering et al. (2001)	1.16	1.25	0.47	0.57	0.94	1.95
	Murdiyarso et al. (2004)	1.97	2.48	0.79	1.07	1.31	3.24
	Jaya et al. (2007)	2.24	1.82	0.91	0.80	1.63	2.56
Sapling	Kettering et al. (2001)	23.99	25.91	52.94	63.65	7.56	15.65
	Murdiyarso et al. (2004)	25.89	32.66	49.45	66.77	7.76	19.17
	Jaya et al. (2007)	36.22	29.46	73.86	65.33	11.12	17.48
Pole and tree	Kettering et al. (2001)	67.44	72.84	29.76	35.78	39.80	82.40
	Murdiyarso et al. (2004)	51.42	64.86	23.82	32.16	31.41	77.59
	Jaya et. al. (2007)	84.50	68.72	38.29	33.87	50.85	79.96
Total	Kettering et al. (2001)	92.59	100	83.17	100	48.30	100
	Murdiyarso et al. (2004)	79.28	100	74.06	100	40.48	100
	Jaya et al. (2007)	122.96	100	113.06	100	63.60	100

In general, the distribution of the above-ground carbon stock potential in each class of peat swamp forest cover as revealed in the present study was relatively higher than those of the peat swamp forests of South Sumatra (Heriyanto et al., 2020) and Riau (Suwarna et al., 2012). Nevertheless, compared to the results reported by Ludang and Jaya (2007) on the distribution of carbon stock potential in Central Kalimantan, the value was lower. The distributions value of above-ground (trees and regeneration) carbon stock potential in several classes of peat swamp forest cover in Indonesia are presented in Table 5.

Based on Table 5, the distribution value of above-ground carbon stock in the dense secondary peat swamp forest as generated in this study was higher than that in the secondary peat swamp forests in Riau (Suwarna et al., 2012) and South Sumatra (Heriyanto et al., 2020). It indicates that the secondary succession process of vegetation in this study area was faster than the process in the secondary peat swamp forest in Riau and Sumatra. Similarly, in the dense and sparse scrub peat swamp forest, the results of the present study were higher than those in the old scrub peat swamp in South Sumatra (Heriyanto et al., 2020) and in open area or barren peatland with the estimated carbon stock between 4 to 7 ton/ha (Moore et al., 2002).

The contribution of carbon stock at each stage of tree growth to the total carbon stock in each class of peat swamp forest cover was diverse. The stage of tree and poles had the highest contribution to the total above-ground carbon stock potential in the dense secondary peat swamp forest and sparse scrub peat swamp. Meanwhile, the highest contribution of carbon stock to total above-ground carbon stock in the moderately dense scrub peat swamp was found in the sapling stage. The lowest contribution was in the seedling phase. The contribution percentage of carbon stock in the seedling stage as generated in the present study was higher than that in dry-land primary forests as reported by Junaedi (2007). The other reseach using a destructive method reported that the carbon stock potential of burned peat swamp forest in South Sumatra Indonesia was 11.82 ton/ha (Widyasari et al., 2010). In the same way, Perdhana (2009) reported that carbon stock potential of virgin peat swamp forest in Riau Indonesia was 172.16 ton/ha.

Table 5. Distribution value of above-ground carbon stock potential in several peat swamp forest cover classes in Indonesia

Class of forest cover	Estimated carbon (ton/ha)	Study area	Source of data
Old secondary peat swamp forest	90.79	South Sumatera	Heriyanto et al. (2020)
Young secondary peat swamp forest	58.51		
Old scrub swamp	0.66		
Logged-over peat swamp forest	97.19	Riau	Suwarna et al. (2012)
Burnt peat swamp forest	2.96		
Secondary peat swamp forest	86.43		
Primary peat swamp forest	351.33	Central Kalimantan	Ludang and Jaya (2007)
Logged-over peat swamp forest	173.33		
Burned peat swamp forest	143.33		
Dense secondary peat swamp forest	92.59*	Central Kalimantan	Present study
	79.28**		
	122.96***		
Moderately dense scrub swamp	83.17*		
	74.06**		
	113.06***		
Sparse scrub swamp	48.30*		
	40.48**		
	63.40***		

*Calculation using allometric model in Kettering et al. (2001); **Calculation using allometric model in Murdiyarso et al. (2004); *** Calculation using allometric model in Ludang and Jaya (2007).

4. CONCLUSION

Usage FCD model Landsat 8 OLI/TIRS in this study is accurate and capable to identify forest structure and its attributes effectively and with less information of ground validation. The results show that FCD model are able to provide an accurate classification of above ground carbon stock of peat swamp forest. It means that assessment of FCD is a prerequisite for various forest planning activities especially at large areas. Results based on FCD found that on average the above-ground carbon stock in ex-MRP is relatively lower compared to previous studies carried out in different sites. This shows that the low of above ground carbon stock is related to ecosystem stability. These facts illustrate that peat swamp forest in this area is decreasing in terms of its environment. We can consider to manage peat swamp forest ecosystem using forest canopy density model that is in line with the variety of their attributes such us aboveground biomass and carbon stock potential.

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