Mapping Degraded Area for Tropical Peatland Revegetation Using Forest Canopy Density Model Landsat 8 OLI-TIRS in Central Kalimantan, Indonesia

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ABSTRACT

Peatland rehabilitation in Indonesia has been massively carried out since 2016 following a huge fire event in 2015. Rehabilitation efforts have so far focused only on burned areas, although non-forested areas and areas with a limited number of juveniles must also be considered for natural regeneration. Spatial mapping can identify areas that need revegetation so that resources can be used more effectively and efficiently. This study aims to map potential areas for peatland rehabilitation by determining the distribution of tree canopy cover using the Forest Canopy Density (FCD) model from Landsat 8 OLI. The area selected for study was Ex-Mega Rice Project (MRP) area in Pulang Pisau district and Palangka Raya city, which burns almost every year. The study identifies eight areas with different levels of Forest Cover Density (FCD). Our field observation confirms that the eight different areas have different levels of natural revegetation. When forest cover is 1-30% of the FCD model, natural regeneration is insufficient and revegetation is required. This study found that 34,543.3 ha or 22.1% of the area of the MRP needs to be rehabilitated. This result provides information on which areas can be naturally revegetated and which areas need to be rehabilitated. This information is important to develop a peat restoration strategy and increase the likelihood of success.

1. INTRODUCTION

Despite covering a relatively small portion of the global land area (Andriesse, 1988; Page et al., 2011; Xu et al., 2018), peatland provides numerous benefits both for the global and local community (Usup et al., 2021). About 3.1% or 13.43 million ha of the world's peatlands are in Indonesia (Anda et al., 2021), and especially widespread on the three largest islands, namely Sumatra (5.8-7.2 million ha), Kalimantan (4.5-5.6 million ha) and Papua (about 3.8 million ha) (Anda et al., 2021; Ministry of Agriculture, 2011; Page et al., 2011; Wahyunto et al., 2005). In Kalimantan region, peatlands in Central Kalimantan Province accounted for 2,659,234 ha or 55.6% of the total peat in the island (Ministry of Agriculture, 2011).

Peatlands are a unique and fragile ecosystem. This ecosystem habitat consists of peat with depths that vary from 25 cm to more than 15 m. This ecosystem also has a distinctive richness of flora and fauna and has a high economic value. The peat swamp ecosystem also plays an important role in maintaining the climate and environmental balance, both as a reservoir of water and as a carbon storage (Daryono, 2009).

Peat forests in Central Kalimantan have been degrading as a result of logging activities, agricultural land extensification, and forest fires. In the 1980s, there were approximately 200 forest concession units (HPH) in peatland areas, with a total area reaching 13 million ha. These concession companies have the right to cut down various woods in the peat swamp forests,

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and the destruction of the peat forests had begun at this time (Cattau et al., 2016). In the 1990s, there were more than 50 forest concessions exploiting peat swamp forests in Central Kalimantan. The exploitation and degradation of peat swamp areas was further exacerbated by the Mega Rice Project (MRP), which was implemented under Presidential Decree No. 82 of 1995. This project was intended to support food production by using one million hectares of peat forest in Central Kalimantan to create agricultural land (Government of Indonesia, 1995; Surahman et al., 2018). The project (PLG) then built approximately 4,533 km of drainage canals as necessary infrastructure for agriculture in the peat swamp area. The combination of forest clearing and canal construction resulted in the peatland being over-drained and prone to fire. As a result, the 2015 fire was one of the worst fires in the history of forest and land fires in Indonesia in the last 18 years. More than 2.6 million ha of forest and land burned from June to November 2015. These fires triggered dense smog and caused a national problem. Economic losses from these fires were estimated at $16.1 billion (Glauber et al., 2016). This fire event also released an estimated 800 megatons to 1.6 giga tons of carbon dioxide equivalent (Peat Restoration Agency, 2016; Glauber et al., 2016). The Indonesian government stated that 33% of the burned area in 2015 was peatland (Peat Restoration Agency, 2016).

Degraded peatlands need to be rehabilitated to restore their functions and benefits. The rehabilitation of peatlands is also critical to ensure the sustainability of ecosystem services. From an ecological perspective, peatlands provide habitat for enormous endemic species, maintain hydrological balance, and contribute to climate change mitigation. In addition to their ecological importance, peatlands also support the livelihoods and basic needs of local communities. Peatlands provide fresh water, food, medicinal plants, building materials, fuelwood, and are also a source of their culture (Cheyne and Macdonald, 2011; Wich et al., 2008). In order to restore and maintain the function of peatlands, degraded peatlands must be revegetated. Revegetation of degraded peatlands is intended to complement natural revegetation. Revegetation of degraded peatlands generally uses endemic species that adapt well to flooding and high acidity (Graham et al., 2017).

The Peat Restoration Agency (Badan Restorasi Gambut or BRG) is one of the Indonesian government agencies that has implemented revegetation programs such as (a) planting endemic and adaptive seeds on open peatlands, (b) enriching plantings in degraded peat forest areas, and (c) improving and implementing seed dispersal techniques to promote peat vegetation regeneration. The revegetation activities focused on the areas burned in 2015. The target revegetation areas were classified into three forest classes: dense, medium, and sparse. This classification was based on the 2017 land cover map, which was re-verified with Landsat and the spot image using the on-screen digitizing method.

The main obstacles to the re-vegetation of peatlands include the large area to be worked and the difficulty of access. Therefore, revegetation of degraded peatlands should be well planned to increase the probability of success, use resources efficiently, and reduce costs. Spatial mapping can help identify areas that need revegetation. In this way, allocation of resources (e.g., time, effort, and cost) can be more effective and efficient. This study aims to map degraded peatland by using the distribution of tree canopy cover from the Forest Canopy Density (FCD) model of Landsat 8 OLI to identify areas that need revegetation. This spatial mapping is further able to provide recommendations for areas that need to be revegetated, existing natural regeneration, and vegetation structure and composition in the study area.

2. METHODOLOGY

2.1 Study area

This study is located in the Ex-Mega Rice Project (MRP) area in Pulang Pisau regency and Palangka Raya city (Figure 1). The Ex-MRP area is tropical peatland that has been degraded due to deforestation, and the construction of canals that over-drain the peat and make it susceptible to fires. The study area, which is part of Pulang Pisau administration, covers an area of approximately 131,200 ha and is inhabited by communities in seven villages: Henda, Jabiren, Pilang, Sakakajang, Simpur, Tanjung Taruna, and Tumbang Nusa. On the other hand, the study area in Palangka Raya administrative area covers an area of approximately 24,500 ha, which includes eight villages: Langkai, Panarung, Bereng Bengkel, Kalampangan, Kameloh Baru, Kereng Bangkirai and Sabaru.

The research site reflects a tropical peat swamp area that is severely threatened by land conversion for agricultural purposes, construction of canals and roads, fires, and pressure from population growth. Agricultural land converted from peatlands usually causes fires during the dry season, the effects of which are also felt in neighboring countries such as Singapore and Malaysia. The research site is a peat dome that is prone to fires. The success of revegetation at this site will have a major impact on reducing carbon emissions from agriculture, forestry, and other land use (AFOLU).

The local communities in the study area are predominantly subsistence communities that are highly dependent on natural resources and forests. Their main sources of livelihood are rubber cultivation, fishing, artisanal mining, and collection of non-timber forest products. The peat swamp forests provide latex, building materials, honey, and livestock to meet the basic needs of the local people (Suwito et al., 2020).

2.2 Data acquisition

The basic canopy cover map was obtained from Landsat 8 OLI imagery from the United States Geological Survey (USGS) with the January 2020 Path/Row 118/62 acquisition.

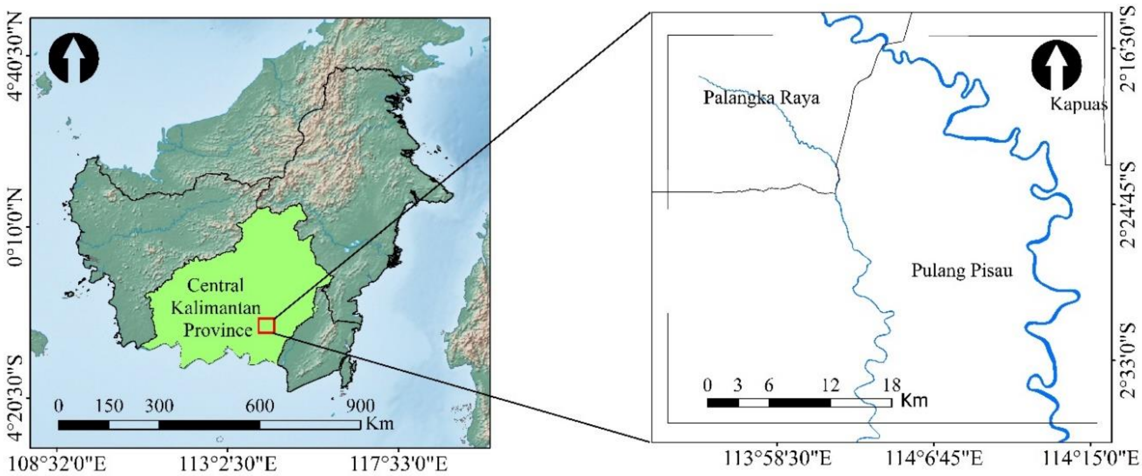

Figure 1. Map of research site in Palangka Raya City and Pulang Pisau Regency

2.3 Correction and normalization image

To obtain a better image of tree canopy cover, the basemap is then corrected to reduce spectral disturbances such as thin clouds, water, shadows, and atmospheric disturbances. The correction was performed using Forest Canopy Density Mapper V.2 software. The generated image was then processed with the Digital Earth Map of Indonesia with datum World Geodetic System (WGS) 1984 using Quantum GIS 3.16 software to improve the geometry.

2.4 Image processing in FCD

The tree canopy cover map was then analysed to differentiate the spectral data from the Landsat image using FCD models (Rikimaru, 1996; Rikimaru and Miyatake, 1997; Chandrashekhar et al., 2005; Roy et al., 1997; Sukarna et al., 2021), with the following descriptions:

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

Landsat's spectral bands consist of 8 OLI/TIRS band colors comprising 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 images.

The analysis included four indices of analysis. The advanced vegetation index (AVI) was used to calculate and evaluate changes in green vegetation density. The bare soil index (BI) was used to examine open areas. The shadow index (SI) was used to analyse forest cover conditions, and the thermal index (TI) was used to determine the differences in micro temperature in each land cover unit. Based on these four indices, the value of forest canopy density is estimated using the following equation (Rikimaru and Miyatake, 1997):

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

2.5 Field survey in tropical peatland

The field survey was conducted to validate the result of the FCD analysis and to calculate the number of natural regeneration of seedlings, saplings, poles, and trees on each hectare. The field survey was conducted using the purposive sampling method. Field survey sampling was conducted for each canopy cover class generated from the Forest Canopy Density (FCD) model (8 classes). Each FCD class consisted of four graded plots with two replicates replications. A 2×2 m^2 plot was used for seedling regeneration observations, a 5×5 m^2 plot was used for sapling regeneration observations, a 10×10 m^2 plot was used for pole regeneration observations, and a 20×20 m^2 plot was used for tree regeneration observations (reference). A total of 64 plots were observed in this study, evenly distributed among eight classes of tree canopy cover in the FCD model.

2.6. Assessment of sufficiency of natural re-generation

Data obtained from field observation were analysed by calculating density (stem/hectare). Whether an area is vegetated or not is determined by assessing the sufficiency of natural regeneration. The assessment of sufficient natural regeneration was based on the standards issued by Ministry of Forestry (1994) and Wyatt-Smith and Panton (1995). The criteria for adequate natural regeneration from the two standards are 1,000 seedlings/ha, 240 saplings/ha, 75 poles/ha and 25 young trees/ha.

2.7. Classification result test

The classification results are tested for accuracy using the confusion matrix method. Classification results are compared to existing field conditions. The confusion matrix provides data on the accuracy of the classification results in terms of overall accuracy (%), producer accuracy (%) and user accuracy (%).

3. RESULTS AND DISCUSSION

3.1 Forest Canopy Density (FCD) processing

The first process is the elimination of water disturbances and the reduction of cloud disturbances. The result of this process is images that are free of water disturbances and thin clouds. Standing water, light clouds, and thin clouds must be removed to obtain the optimal coverage class of the Landsat 8 OLI. To eliminate water and thin clouds, the threshold value is inserted into the curve. The larger the value, the more water will be removed by the software. A similar method is then used in image normalization for cloud and shadow noise. The vegetation index (RVI) and bare soil index (BI) were calculated after the process of reducing cloud, water, and shadow disturbances was complete (Figure 2). Next, the thermal index (TI) and shadow index (SI) are calculated using the FCD mapper (Figure 3).

(a) (b)

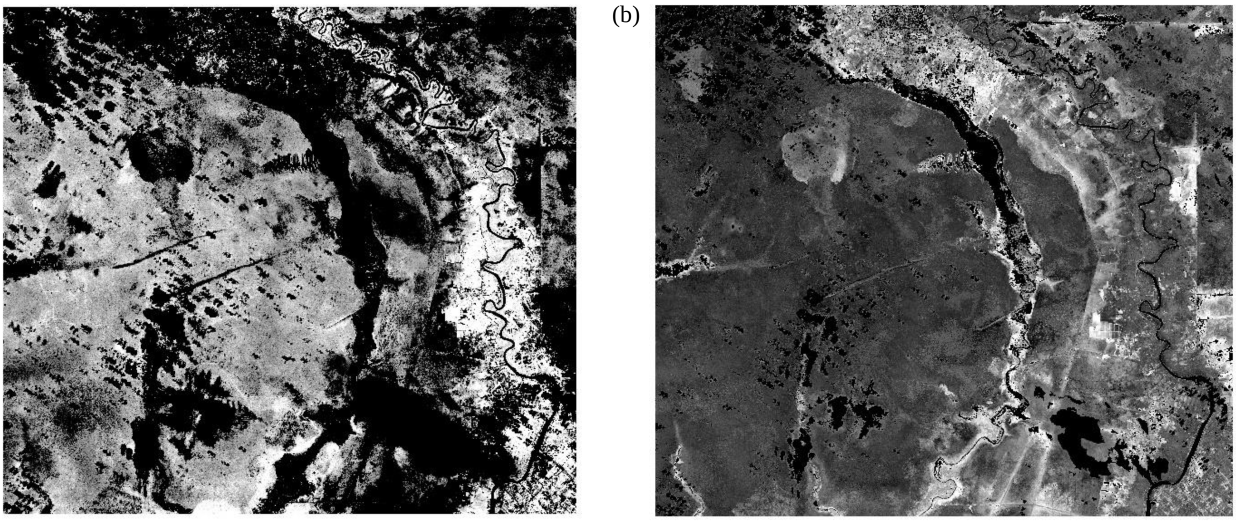

Figure 2. The results of the calculation of the vegetation index (a) and the bare soil index (b) in the Forest Canopy Density (FCD) mapper software

(a) (b)

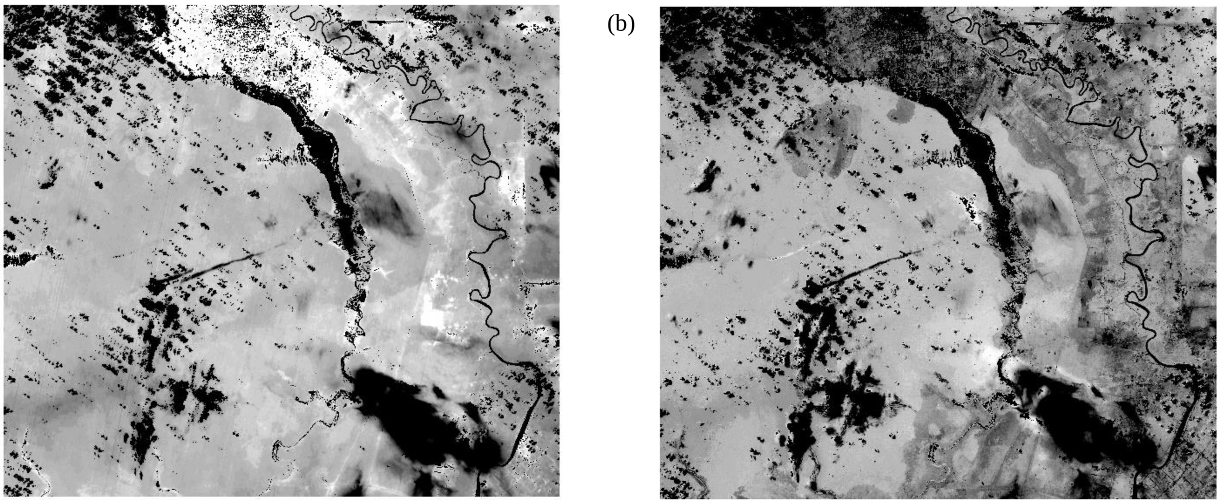

Figure 3. The results of the calculation of the thermal index (a) and the shadow index (b) in the Forest Canopy Density (FCD) mapper software

The next important process in creating canopy cover from the Forest Canopy Density (FCD) model is index integration. The first index combination is the combination of vegetation index (VI) and bare soil index (BI). The result of combining these two indices is vegetation density index (VD) (Figure 4(a)). The second index is a combination of shadow index (SI) and thermal index (TI). The combination of these two indices results in the scaled shadow index (SSI) (Figure 4(b)).

The final process in the series of creating tree canopy coverage in the Forest Canopy Density (FCD) mapper is the combination of the vegetation density index (VD) with the shadow scale index (SSI). The result of combining this index is new data called the Forest Canopy Density model/FCD model, as shown in Figure 5.

(a) (b)

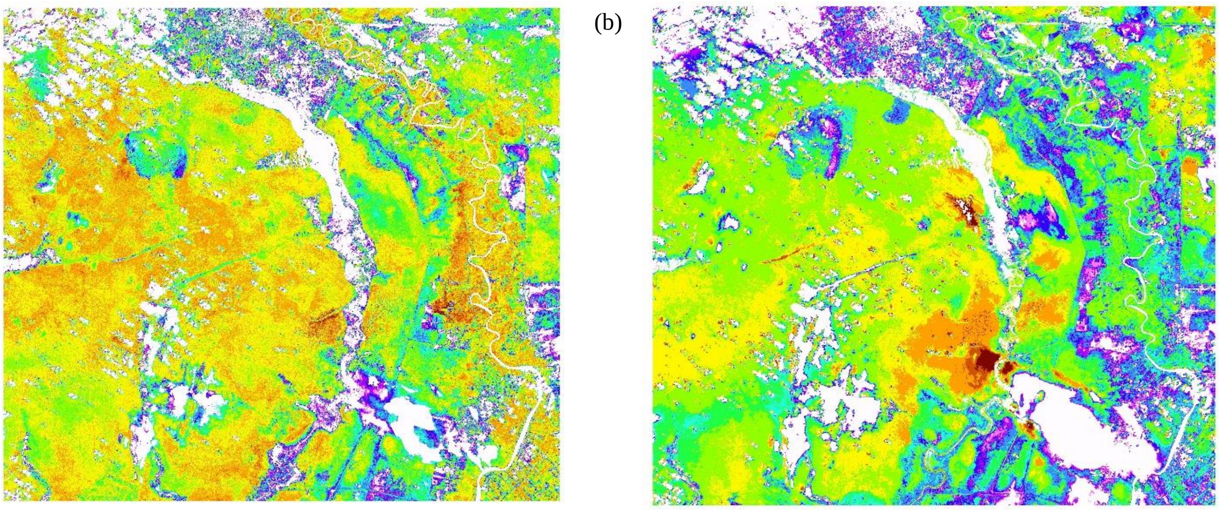

Figure 4. The vegetation density index (VD) is the result of the combination of the vegetation index (VI) and bare soil index (BI) (a) and the shadow scale index (SSI) as a result of the shadow index (SI) and thermal index (TI) (b) in Forest Canopy Density (FCD) mapper

3.2. Classification test results and field survey

The test of classification results was performed by comparing the classification results of the FCD model with the field data. The test results using the confusion matrix give an overall accuracy (89.7%), a producer accuracy (89.8%), and a user accuracy (89.9%). The FCD accuracy rate exceeds the value of 85%, which is the most acceptable standard in remote sensing research (Foody, 2008).

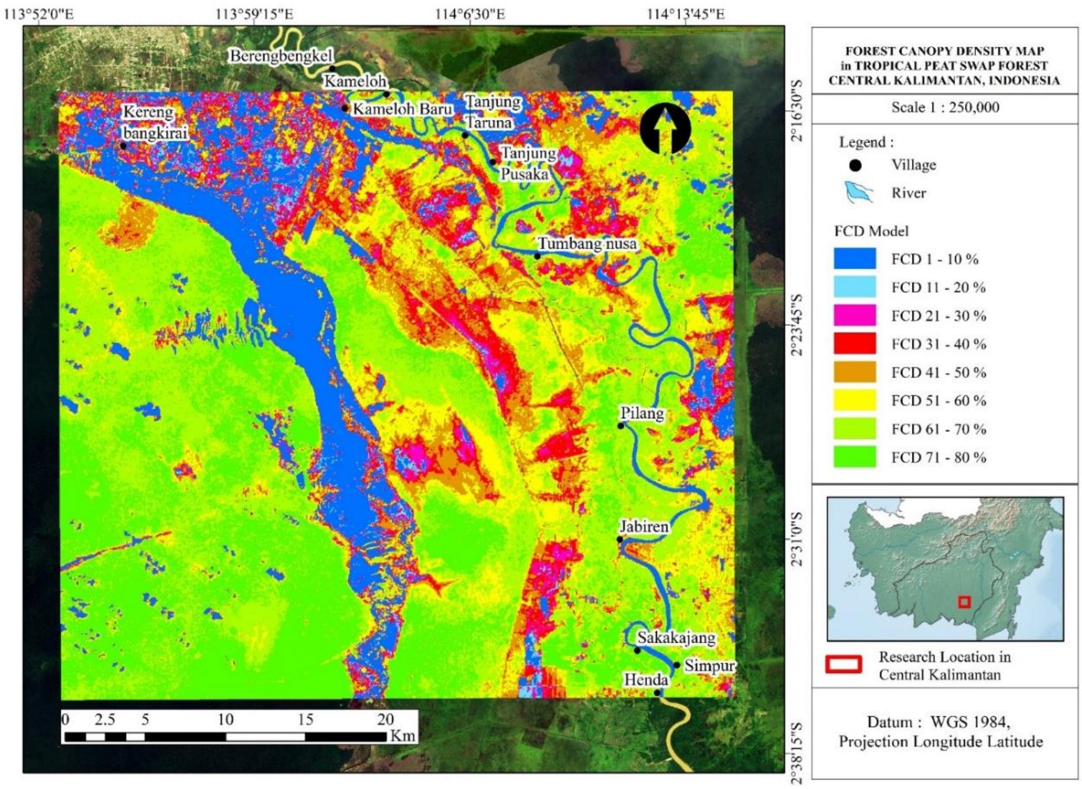

Figure 5. Forest Cover Density (FCD) class

This is consistent with Azadeh et al. (2017), Himayah et al. (2017), Mann et al. (2019), Rikimaru (1996), and Rikimaru and Miyatake (1997) who found that the Forest Canopy Density (FCD) model is very good at differentiating forest cover. FCD is also appropriate when applied with Landsat imagery and in tropical countries. The application of the revegetation space model in tropical peat swamp areas using the FCD model has only been applied to this study.

The results of the confusion matrix analysis show that the software has weaknesses in mapping forest structures in tropical peat swamps. The weakness is that whenever there is still a large puddle of peat swamp water, the software shows higher values than the facts on the ground (overestimation).

3.3. Field survey results in tropical peatland

The results of the field study on eight classes of canopy revealed three main landscapes: (a) Degraded tropical peat swamp forest; (b) Semi-degraded tropical peat swamp forest; and (c) Non-degraded tropical peat swamp forest. In general, the area is classified as non-degraded tropical peat swamp forest with an area of 68,477 ha or 44% of the study area. The field study also shows the area of degraded tropical peat swamp forest with an area of 34,543.3 ha or 22.2% of the study area (Table 1).

Degraded tropical peat swamp forests (FCD 1-30%) show that most of the areas that require revegetation are burned areas with FCD below 30%. This is consistent with the 2015 spatial study by the Ministry of Environment and Forestry (KLHK) for spatial study in 2017, 2019, and 2020, which shows that a large number of burned peat swamp areas in the study area need rehabilitation. The study area is severely degraded due to over-drainage and deforestation. Dianti et al. (2018) stated that excessive drainage is the cause of peatland water mass loss. Hirano et al. (2009) stated that loss of peat moisture in the surface layer is also a factor that can trigger fires. The loss of water in the peat due to drainage that divides the "hummock" makes the peat swamp area susceptible to fires (Hirano et al., 2009; Susilo et al., 2013).

The results of the study also show that the area required for rehabilitation spread at the area accessible by both roads and rivers/canals. This result is consistent with the findings of Rachmanadi et al. (2017) which stated that the closer the accessibility, the fewer species and vegetation density. The loss of tree species diversity is also due to logging as a result of easy accessibility to the field. The vegetation found in the study area such as Purun (*Lepironia articulata*) and Patanak (*Elaeocarpus* sp.) and various species of young trees such as Tumeh (*Combretocarpus* *rotundatus*) and Geronggang (*Cratoxylon arborescens*). Dohong et al. (2017), Tonks et al. (2017), and Cattau et al. (2016) noted that degradation of peatlands in Southeast Asia occurs through deforestation, conversion to industrial plantations, drainage, and repeated fires.

Table 1. Forest canopy class based on FCD Model in study area

Symbol	FCD model	Field appearance	Landscape description	Hectare	%
	FCD 1-10%		Degraded tropical peat swamp forest Most of this area consists of a new burn scar area. Natural revegetation from all classes (seedling, sapling, pole, and tree) is rare. Located at the area with high access such as river bank, near the village road and the canal.	24,430.7	15.7
	FCD 11-20%			3,221.9	2.1
	FCD 21-30%			6,890.7	4.4
	FCD 31-40 %		Semi degraded tropical peat swamp forest. In general, this area includes the relatively old burn scar area. Natural regeneration occurs at an early stage, so seedlings and saplings dominate. The area is easily accessible by small rivers, unused canals, or small trails.	11,628.7	7.5
	FCD 41-50%			16,517.6	10.6

Table 1. Forest canopy class based on FCD Model in study area (cont.)

Symbol	FCD model	Field appearance	Landscape description	Hectare	%
	FCD 51-60 %			24,581.2	15.8
	FCD 61-70 %		Non degraded tropical peat swamp forest the majority of this area consists of ex-logging areas. The succession process in this area almost reaches the natural state. There are no signs of burned areas. The vegetation in this area exhibits all stages of growth (seedling, sapling, pole, and tree). Natural regeneration in the form of trees and poles is abundant in this area. This type of area is located in a remote area, far from accesses or has no access.	49,182.4	31.6
	FCD 71-80 %			19,294.6	12.4
Total				155,747.8	100.0

3.4. Assessment of sufficiency of natural re-generation

The results of the field survey on 64 field measurement plots show that the FCD has insufficient natural regeneration at canopy cover levels of 1-30%. The lack of natural regeneration at the 1-30% canopy cover level of the FCD model can be seen in the regeneration of seedlings, saplings, pole and trees (Figures 6, 7, 8, and 9).

Figure 6 shows that it is difficult to find seedlings when canopy cover is 0-30%. Canopy cover 0-30% is a burned area in 2015 and 2019. Forest and bog fires eliminate almost all seeds in the study area. In the regions with canopy cover 31-40%, the number of seeds increased sharply, reaching about 12,500 stems/ha. The field survey showed that canopy cover of 41-50% was the most common canopy cover that had a sufficient number of seedlings.

Figure 7 shows that the amount of saplings in the remaining burned areas of the 2015 and 2019 fires is relatively low. Sapling density is estimated to be between 11-13 stems/ha at 0-30% of canopy cover. This sapling density is still far from the sufficient level, which is 240 stems/ha. The field survey found that stem density is highest at 41-50% canopy cover.

The absence of poles in FCD 0-30% indicates that no tree survived the large wildfire in 2015 and 2019. Tree density begins to reach sufficient level at 31-80% FCD. The field survey indicated that the most abundant tree natural regeneration is found at 51-60% FCD, which equates to 25 stems/ha. The trees in this area are more diverse compared to the other FCD level.

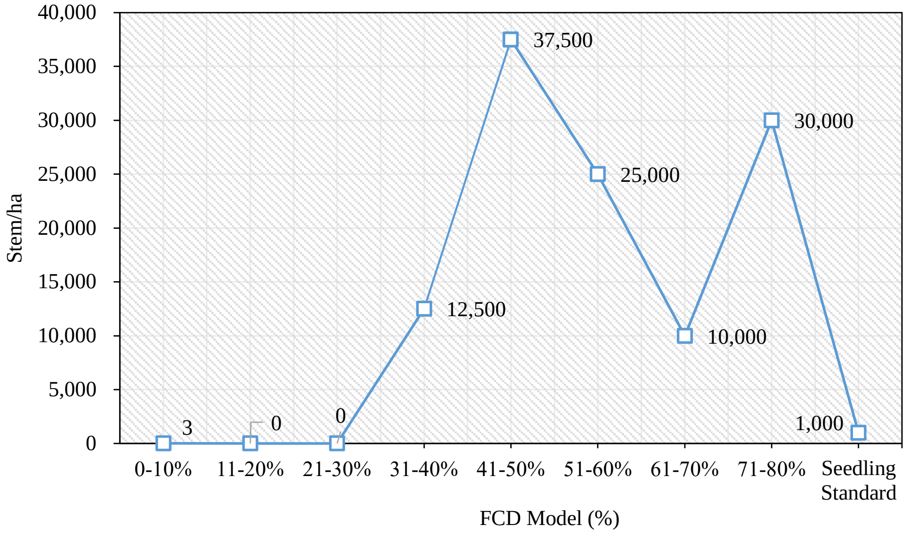

Figure 6. Sufficiency of natural regeneration at the seedling level at the tropical peat swamp research sit

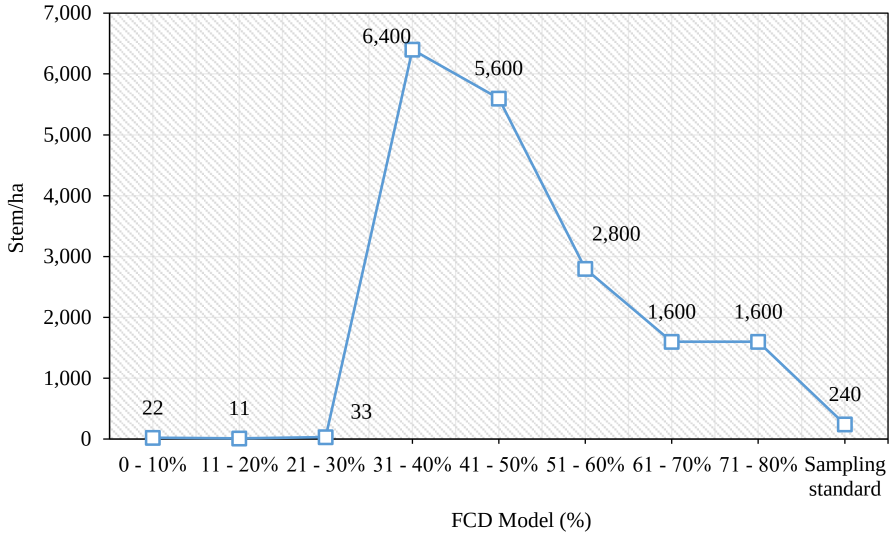

Figure 7. Sufficient level of sapling natural regeneration at the tropical peat swamp research site

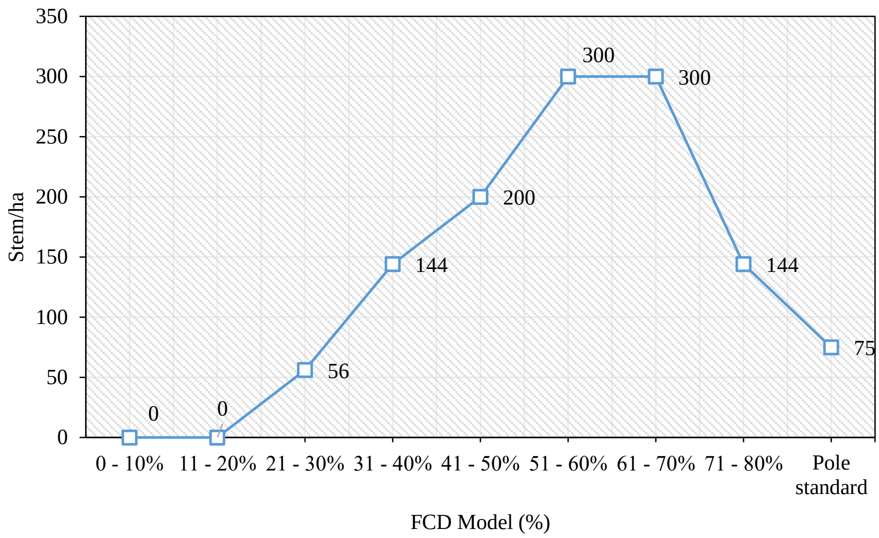

Figure 8. The density of pole in various forest cover density (FCD) in peat tropical forest

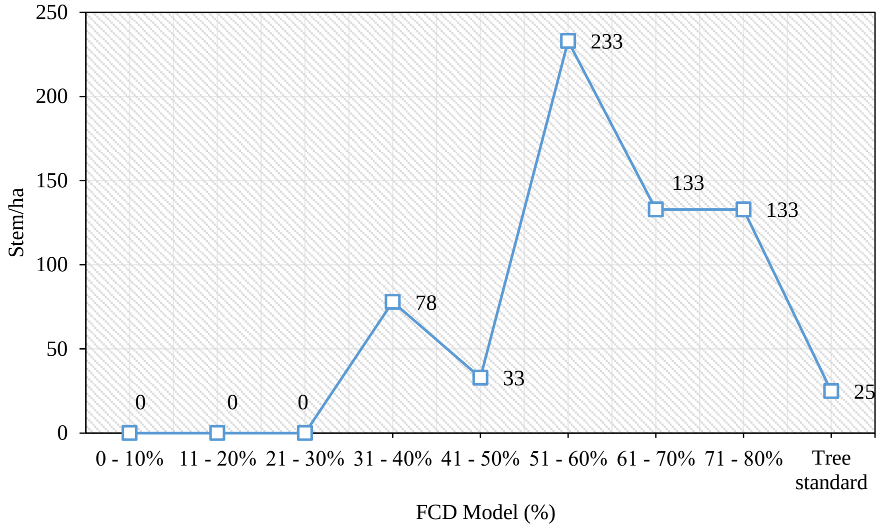

Figure 9. The density of trees in various forest cover densities (FCD) in peat tropical forest

Figure 9 shows the loss of young trees in the remaining areas burned in the 2015 and 2019 fires. Tree density begins to reach sufficient levels at FCD 31-80%. The field survey found that the highest stem density is achieved at 51-60% canopy cover. Referring to the assessment of the sufficiency of natural regeneration using the standards issued by Ministry of Forestry of Indonesia (Ministry of Forestry, 1994) and the Manual of Malayan Silviculture for Inland Forest (Wyatt-Smith and Panton, 1995), then FCD 1-30% means that the area needs to be revegetated. The field conditions in the canopy cover of FCD 1-30% show a wide and deep burned area, showing the loss of all types of growth from seedlings to young trees. Yuningsih et al. (2018) found that no tree seedlings could grow at the burn site three years after the fire.

3.5. Landscape of Revegetation Areas in Tropical Peat Swamps

From the results of the field observations, it appears that the landscape that needs to be revegetated contains areas that are often flooded for a very long period of time, even in the dry season. The flooded areas are the Klaru and Sebangau landscapes. Long-term flooded peat swamps without drainage require different revegetation techniques (Figure 10). The paludiculture technique is recommended for rehabilitation of these types of landscapes (Tata and Susmianto, 2019; Tan et al., 2020). Jessup et al. (2020) and Ramdhan and Siregar (2018) stated that a landscape approach that is carried out in a participatory manner and involves the community around the site is an appropriate approach for peatland restoration.

The results show that the frequently flooded areas for revegetation represent about 21,589.9 ha or 13.8% of the studied area. These flooded areas are generally located to the left and right of the river and in areas that have subsided after fire (Table 2). This is consistent with the findings of Ohkubo et al. (2021) and Anshari et al. (2021) that puddling and subsidence of peat soils occur after fires.

Table 2. Distribution of revegetation area according to species resistance to flooding

Symbol	Landscape description	Hectare	%
(green)	Non degraded area	121,204.5	77.8
(yellow)	Area requires revegetation with peat swamp forest vegetation	12,974.4	8.3
(red)	Long period flooded area requires revegetation with flood resistence species	21,568.9	13.8
Total		155,747.8	100.0

4. CONCLUSION

Our spatial mapping of the ex-mega rice project identifies eight areas with different levels of FCD. Field observations revealed that these eight different areas have different levels of natural revegetation. When forest cover is 1-30% of the FCD model, natural regeneration is insufficient and revegetation is required. This study shows that 34,543 ha or 22.1%

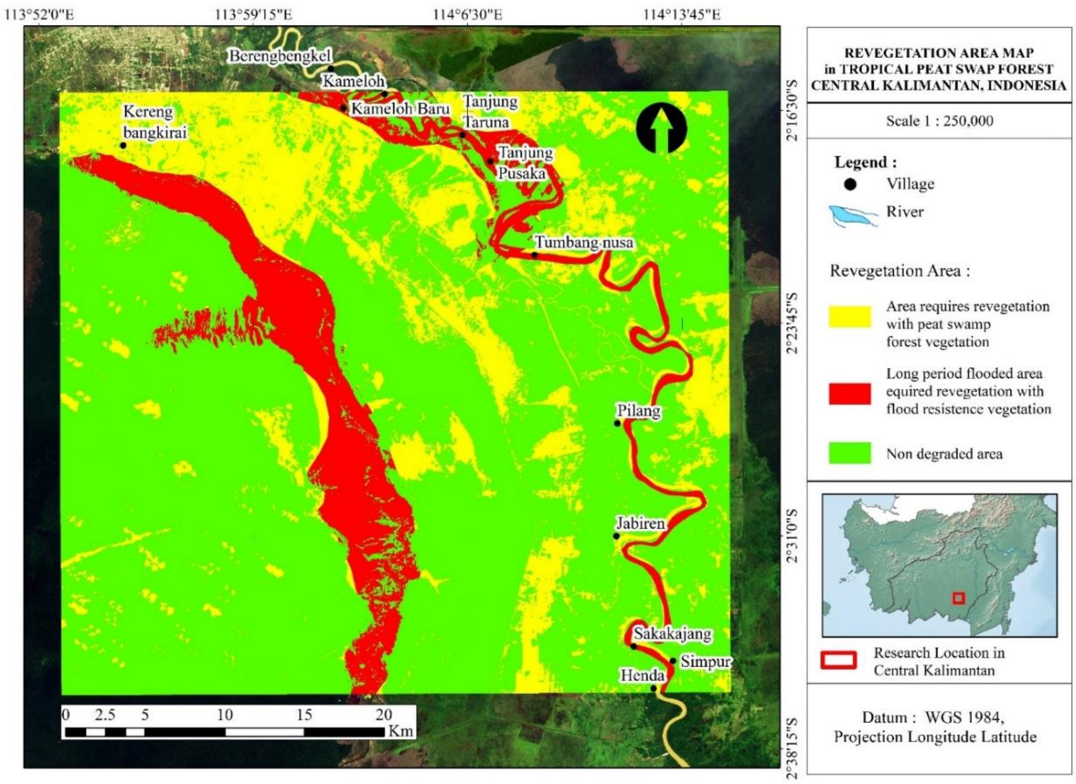

Figure 10. Spatial distribution of revegetation areas in the study locations of tropical peat swamps in Central Kalimantan by species resistance to flooded

of the area of the Ex-Mega Rice Project needs rehabilitation. The results of this survey provide information regarding the natural revegetation in the study area and which areas require rehabilitation. This information is essential to develop a peatland rehabilitation strategy and increase the likelihood of success. Tropical peat swamp areas that are always flooded during the rainy season and for several months afterward interfere with the analysis in the FCD. The water puddles cause the FCD mapper to overestimate forest structure in the prediction. To avoid this, it is better if the mapping is done with the FCD mapper using Landsat 8 OLI on the peak dry season image.

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