

Impact of rehabilitation and status area change on land cover and carbon storage in Paliyan Wildlife Reserve, Gunung Kidul, Indonesia

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Abstract. Puspanti A, Kusumandari A, Faida LRW, Sudaryatno. 2021. Impact of rehabilitation and status area change on land cover and carbon storage in Paliyan Wildlife Reserve, Gunung Kidul, Indonesia. *Biodiversitas* 22: 3964-3971. This study analyzed the land cover change and carbon storage after the rehabilitation of Paliyan forest. This study mainly focused on the forest status during 1999-2019, especially after establishing a wildlife reserve forest and after rehabilitation activity. We used a combination of canopy density model, carbon conversion, and changes of management-related data to analyze land cover classes in two decades of 1999-2009 and 2009-2019 representing the change in status of the area, rehabilitation, and management dynamics through the time. The result shows that at baseline (1999), the status was still production plantation forest dominated by non-forest/open land with the most carbon storage in plantation forest of 5463.04 tons of carbon. In the first decade, important events occurred such as continuing illegal logging until 2001; change of area status to wildlife reserve forest; and initiation of rehabilitation in 2003. There was an increase in non-forest areas during the first decade, and carbon storage decreased mostly in plantation forests with only 867.71 tons of carbon remaining. In the second decade, rehabilitation has shown a positive impact in increasing forested areas, and altered non-forest to the forested area dominated by open forest/mixed agriculture area, followed by plantation forest, and secondary forest. In this decade, the legality of the area status and rehabilitation activity underwent to be more advance. The carbon storage also shows the positive result with the most increase of storage in plantation forest of 4072.932 tons carbon, or almost 4.7 times higher than that in 2009. Total carbon storage in 2019 was 13257.50 tons, or almost three times higher than that in 2009. The rehabilitation required a longer period to achieve a more dense forest condition as in 2019 the area was still dominated by open forest or agriculture. The smallholder farmers and high dependency of the surrounding community manage the land to feed their livestock, impede the rehabilitation and restoration process, and de-escalate the transition from non-forest to forest resulted in the more vegetated area. This result is important for stakeholders for designing appropriate forest-related policies and supporting further rehabilitation strategies.

Keywords: Carbon stock, land cover change, canopy density, reforestation, protected area

INTRODUCTION

Indonesia has one of the highest rates of primary forest loss in the tropics year 2001-2016 (Margono et al. 2014) and contributed around two-thirds of Southeast Asia total forest loss during 2005-2015 (Estoque et al. 2019). One of the common drivers of deforestation and forest degradation is timber harvesting, either legal or illegal (Sadono et al. 2020). Deforestation impacts on the environment such as biodiversity loss (Gibson et al. 2011; Houghton 2012; Barlow et al. 2016), degradation of habitats, impairment of water quality and quantity regulation services, air pollution, and emissions of climate change inducing greenhouse gases (GHGs) (Foley et al. 2011; Austin et al. 2019). Biodiversity in Indonesian forests was declined as reported from some references. Due to deforestation, primates in Sulawesi lost 14% of their habitat (Supriatna et al. 2020), 274 bird species in Sundaland experienced average habitat losses of 16% (Symes et al. 2018). Some species also become threatened with extinction due to the loss of forest cover, such as orangutan Sumatra *Pongo abelii*, orangutan Borneo *Pongo pygmaeus* (MoEF RI 2017), the Bali tiger

Panthera tigris balica and Javan tiger *Panthera tigris javanica* went extinct (Wibisono and Pusparini 2010), and also many species of birds, amphibians and plants are threatened (Sala et al. 2000; Sodhi et al. 2004).

Gunung Kidul is a regency in Yogyakarta province, located in the southern part of Java Island, Indonesia, where the southern part karst landscape dominates with various land configurations. Faida et al. (2011) stated that Gunung Kidul is part of *Pegunungan Seribu* that in the past time well known as a dense forest with many types of tropical vegetation. However, later this area experienced forest conversion for agriculture, plantation, and settlement. During the 1940s until the 1970s, Gunung Kidul was a poor district because of infertile and dry soils and lack of water supply. The deforestation from the 1800s massively occurred during Dutch colonization, for agricultural and plantation (Whitten et al. 1996). During Japan's colonization, deforestation became uncontrollable because of the high demand for logs to support the war and forest conversion to atrophy plantation and led to failure because of lack of biophysical understanding of the karst ecosystem (Nibbering 1991). After that period, Gunung

Kidul became very infertile, barren and dry, and popular in very poor areas (Sunkar 2008).

Indonesia's political situation in 1998 affecting many sectors including forest status led to land encroachment and illegal logging. Ji et al. (2018) described illegal logging as the entire supply and demand process of illegally logged timber. Paliyan forest is one of forested land karst landscapes and previously was plantation forest (BKSDA 2016). Like most forested areas in the southern part of Gunungkidul, this area experienced severe deforestation and lost almost all woody plants due to massive illegal logging during 1999-2001 (Sadono et al 2020). In response to the degradation of Paliyan forest, in 2000 the Ministry of Forestry appointed the area to change its status from production forest to wildlife reserve named Paliyan Wildlife Reserve (PWR) with a degraded initial condition (Ministerial Decree 171/2000), followed by the action of rehabilitation to restore the wildlife habitat such as macaque and other wildlife species (BKSDA 2016). In the following year, the Government carried out massive rehabilitation in cooperation with other institutions.

Carbon storage is one of the important environmental indicators of forest ecosystem service. Carbon stock of forest is determined in five carbon pools: above-ground biomass, below-ground biomass, litter, dead wood, and soil organic matter (IPCC 2006). While above-ground biomass consists of both live and dead plant material, most recent studies on biomass estimation have focused on the living component (vegetation) because of the prominence and as the central basis for carbon inventories (Kumar and Mutanga 2017). Presently, there are three approaches to calculate biomass, namely mathematical modeling, field measurement, and remote sensing (Hartoyo et al 2019). Field measurement is carried out using allometric models that correspond to specific tree species according to the type of forest (Krisnawati et al 2012; Zaki and Latif 2016). Field measurement results in the most accurate and precise method to estimate and monitor carbon storage, but this approach is expensive, impractical, and has limitations in covering a large area with difficult access (Bustamante et al 2016; Hartoyo et al 2019). Thus, remote sensing is the most important tool for measuring and monitoring carbon dynamics (IPCC 2006).

The study focused on the land cover change and carbon dynamic as a response to rehabilitation in this area is still limited. The Forest Canopy Density (FCD) model consists of biophysical phenomena for assessing forest-based status on canopy cover (Rikimaru et al. 2002). FCD is capable to detect forest cover changes, e.g. deforestation and forest degradation (Nandy et al. 2003; Chandrashekhar et al. 2005; Muhammad et al. 2014; Abdollahnejad et al. 2017). Meanwhile, the history of management of the area and rehabilitation history is also important to be understood, because the current outcomes of forest rehabilitation can only be adequately predicted if the historical process influencing forest rehabilitation are understood (de Jong 2010).

This study aims to investigate the impact of rehabilitation and status area change to land cover and

carbon storage in Paliyan Wildlife Reserve (PWR), Gunung Kidul District, Yogyakarta Province, Indonesia.

MATERIALS AND METHODS

Study area

The authors conducted this research in Paliyan forest, Gunung Kidul Regency, one of five regencies in the Province of Daerah Istimewa Yogyakarta. This regency is geographically located between 7°46' and 8°12' south latitude and 110 ° 21-110 ° 50' east longitude (BPS-Statistics of Daerah Istimewa Yogyakarta Province 2017). The regional topography of Gunung Kidul Regency is a mountainous region. There are three zones identified, namely Baturagung (200-700 m asl) in the North, Ledoksari (150-200 m asl) in the middle, and Karst Gunung Sewu (100-300 m asl) in the South. Paliyan forest with an area of 430 hectares is located in the southern part of Gunung Kidul that is included in karst landscape with various land configurations and is located in two sub-district, named Paliyan and Saptosari. The livelihood of the population depends primarily on the agricultural sector. The land has a relatively thin soil layer and is often known as *batu bertanah* or soil-soaked stones. The region has an average precipitation of 1881.94 mm/year (2011-2016) with an average number of rainy days of 92.22/year. The average temperature is 27.7°C, with the maximum and minimum being 32.4 °C and 23.2 °C respectively.

Before being assigned as a wildlife reserve, Paliyan forest was a production forest with teak as the main product (BKSDA 2016). After being illegally harvested by local communities, this area lost more than 90% of forest cover and resulted in bare degraded land. In 2000, the rehabilitation started and then continued with more intensive rehabilitation by planting specific purpose tree species, such as fast-growing species, forage trees for wildlife, and native karst species.

Data collection

We carried out this research in PWR between September and November 2020. The collected data comprised two components, spatial data followed by ground check, and data obtained from interviews and focused group discussion. The main spatial data encompassed multi-temporal satellite imageries and vector boundary of PWR area (Table 1). We conducted a ground check and survey in the field to compare the condition between spatial data and real conditions by observing the condition of vegetation and canopy cover. We also studied some documents to obtain information about the change of status and management of the area through the time and rehabilitation strategies, the management of the area and rehabilitation to support this research. We acquired the Satellite imageries during the dry season to get clear images with no clouds because, in the tropical countries, the cloud-free Landsat images were available in the dry season than in the rainy season (Liu et al. 2015).

Data analysis

We observed the land cover change into three different times. The time consists of three major periods, which are 1999 as the baseline, the first decade (1999-2009), and the second decade (2009-2019)

Image pre-processing

The pre-processing step applies Geometries, atmospheric, image normalization, and Landsat imageries. Landsat imageries geometrically corrected to World Geodetic System (WGS) 1984 datum and Universal Transverse Mercator (UTM) coordinate system Zoner 49S using Ground Control Points (GCPs) derived from Indonesia based map.

Forest canopy density (FCD), land cover changes, and carbon storage

We employed the FCD model derived from various indices (Abdollahnejad et al. 2017; Bandyopadhyay et al. 2017) as follows: vegetation index (VI), shadow index (SI), the thermal index (TI), and bare soil index (BI). These four proposed indices exhibit important characteristics according to the amount of vegetation quantity and bare soil. Both VI and SI values have similar behavior and correlate positively with vegetation quantity, where these values increased with the increase in vegetation quantity (Abdollahnejad 2017). In contrast, TI value decreased with the increase in vegetation quantity. Meanwhile, the BI increased with the increase of bare soil. Using these indices with the proposed formula (Table 2), we calculate the FCD value in percentage for each pixel.

Land cover mapping was based on the land classification system of Indonesian National Standard (Standar Nasional Indonesia/SNI) No. 7645-2010 developed by the National Standardization Agency (Badan Standarisasi Nasional-BSN, 2010). Hence, we applied land

classification comprising of four land cover types based on the dominant land cover types and FCD values in the study area. The land cover types used in this research were non-forest, open forest, moderately dense forest, and dense forest for FCD values <10%, 10-40%, 40-70%, and >70%, respectively (Sadono et al. 2020). Furthermore, we analyze land use and calculate the areas of each land cover class. Total carbon storage of each land cover class was estimated using carbon storage conversion approach for national scale of corresponding land cover class (Tosiani 2015) as described in Table 3. The flowchart in Figure 1 describes the steps in the assessment of land cover and carbon storage changes.

Table 2. Formulas/algorithms used to calculate indices in the FCD model

Index	Formula
VI	
NDVI	$= (\text{NIR} - \text{Red}) / (\text{NIR} + \text{Red})$
AVI	$= (\text{NIR} \times (256 - \text{Red}) \times (\text{NIR} - \text{Red}) + 1)^{1/3}, (\text{NIR} - \text{Red}) > 0$
ANVI	= this index is derived from NDVI and AVI by PCA
SI	$= [(256 - \text{Blue}) \times (256 - \text{Green}) \times (256 - \text{Red})]^{1/3}$
TI	= this index is calibrated from the thermal data band
BI	$= [(\text{SWIR1} + \text{Red}) - (\text{Blue} + \text{NIR}) / (\text{SWIR1} + \text{Red}) + (\text{Blue} + \text{NIR})] \times 100 + 100$
VD	= this index is calculated from the first principal component of VI and BI
SSI	= this index is calibrated for the forested land
FCD	$= (\text{VD} \times \text{SSI} + 1)^{1/2} - 1$

Note: Landsat bands: visible bands: blue, green, red; NIR: Near-Infrared; SWIR: Swing Infrared, Indices: VI: Vegetation Index; NDVI: Normalize Difference Vegetation Index; AVI: Advanced Vegetation Index; ANVI: Advanced Normalized Vegetation Index; BI: Bare Soil Index; TI: Thermal Index; VD: Vegetation Density; SSI: Scaled Shadow Index; FCD: Forest Canopy-Density. (Rikimaru et al. 2002)

Table 1. List of spatial data used for accessing land cover

Data	Date of acquisition	Source
Landsat TM, Path/Row 120/65, spatial resolution 30 m	1999/09/06	USGS ¹
Landsat TM, Path/Row 120/65, spatial resolution 30 m	2009/08/16	USGS ¹
Landsat 8, Path/Row 120/65, spatial resolution 30 m	2019/09/13	USGS ¹
Vector Boundary of Paliyan Wildlife Reserve	2017	BKSDA Yogyakarta

Table 3. Classification of forest density into land cover class, identified land use, and carbon storage estimation using conversion approach of carbon storage for national scale (Tosiani 2015)

Forest canopy density	Land cover class	Identified land use	Carbon storage (ton of Carbon ha ⁻¹)
<10%	Non-forest	Open land	2.5
10-40%	Open forest	Mixed dryland agriculture/agroforestry	30
40-70%	Moderately dense forest	Plantation forest	98.38
>70%	High dense forest	Secondary forest	98.84

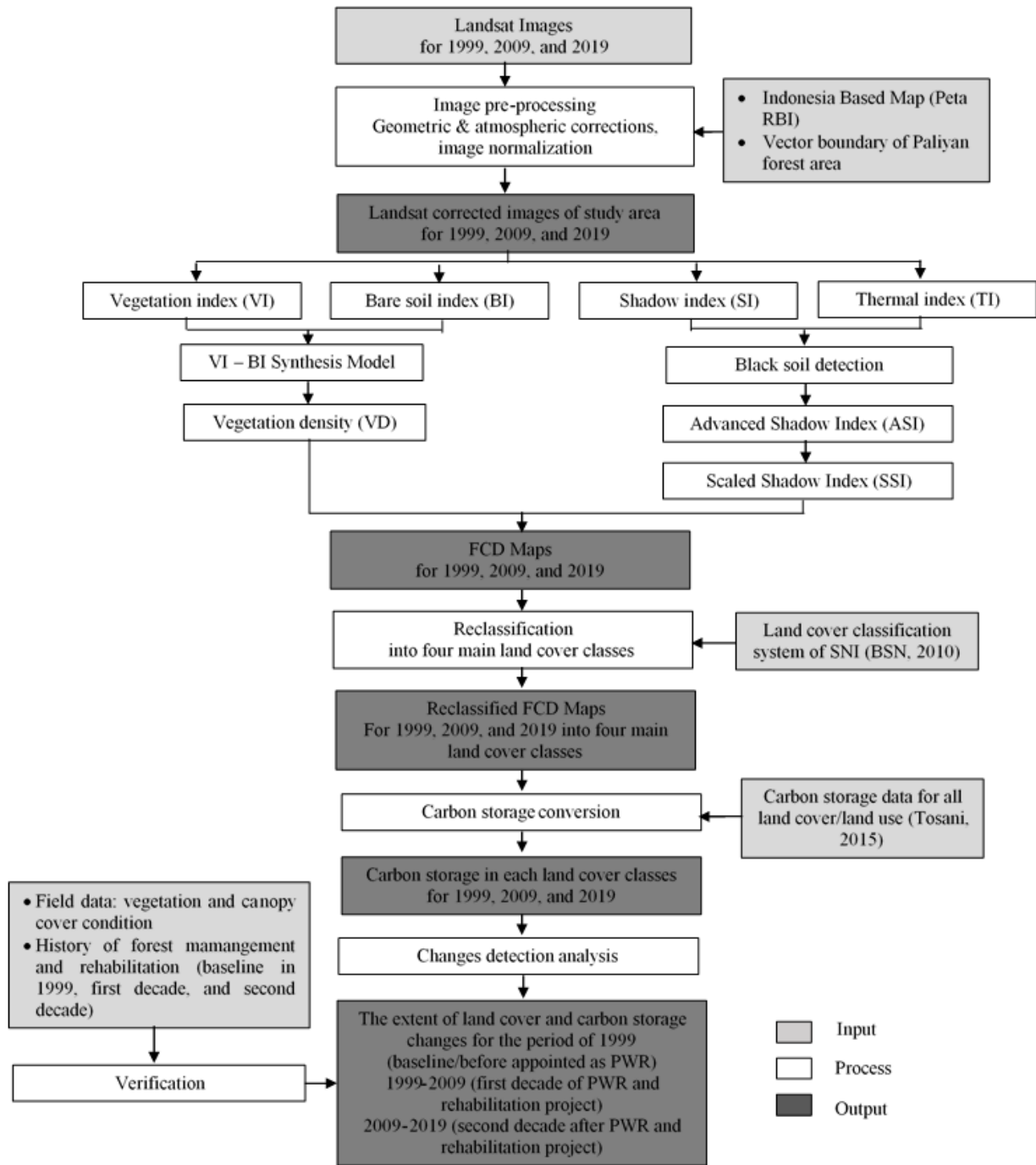


Figure 1. Flowchart summarizing the steps involved in the assessment of land cover and carbon storage change in Paliyan forest

RESULTS AND DISCUSSION

The timeline of rehabilitation process

Figure 2 shows the timeline of the rehabilitation process, status change of the area, and important events from 1999 to 2019.

Land cover change

Forest canopy density through the time in PWR is shown in Table 4.

The baseline of this study is set in 1999, as in this year, the political situation in Indonesia had changed. In the following years after 1999, the condition also led to massive illegal logging in Paliyan forest. In this baseline year, the area was dominated by non-forest/open land (54%). Only 0.99% of the area was covered by dense secondary forest and 17.9% of the area was considered as moderately dense forest in the form of plantation forest dominated by teak wood.

In 2009, i.e. 10 years after baseline, it was found the change of the land cover of the area. During this period,

there were some changes in this area. Started in 1999 and a couple of years after, illegal logging occurred in this area. The status of Paliyan forest changed from production forest to wildlife reserve forest followed by rehabilitation activities. In 2009, the area was dominated by non-forest or open land (76.93 % from the total area) and increased 64.2% from the baseline. The open forest, moderately dense forest, and high dense forest showed reverse conditions by showing the decreasing number of areas. A high number of changes showed in a moderately dense forest in the form of plantation forest with 84.1% decreasing from the baseline.

Carbon storage decreased in the first decade and gradually increased in the second decade because the land cover increased. During the first decade, the greatest loss of carbon storage was in plantation forest around -4595.33 tons of carbon. Plantation forest then indicated a carbon storage increase of 3205.22 tons of carbon during the second decade. The highest increase of carbon storage was in mixed dryland agriculture/agroforestry with a total increase of 5869.8 tons of carbon. Total carbon storage of PWR in 2019 was 13257.5 tons with the highest number of carbon storage found in agroforestry (8607.60 tons),

followed by plantation forest (4072.93 tons), secondary forest (320.24), and non-forest area (256.72 tons).

Discussion

The obtained results indicated that there were changes in land cover under different periods in Paliyan forest. The baseline started in the year 1999 because this year is the initial year of political instability while the status of Paliyan forest was still production forest with teak wood as the main timber product. The management of the area back then was by local government authority under Provincial Forest Agency. This year was also the starting of the explosion of illegal logging which occurred from 1999 to 2001. Previous studies also have stated the explosion of illegal logging caused by political instability (marked by the fall of Soeharto regime) in Indonesia during the late 1990s (Burges et al. 2012). This massive illegal logging caused the huge change of forest area to non-forest area (deforestation). This finding is also similar to the previous study stated that the highest level of annual deforestation rates in Indonesia was recorded from 1996 through 2000 which was higher than the annual deforestation rate from 2003 through 2017 (MoEF 2018).

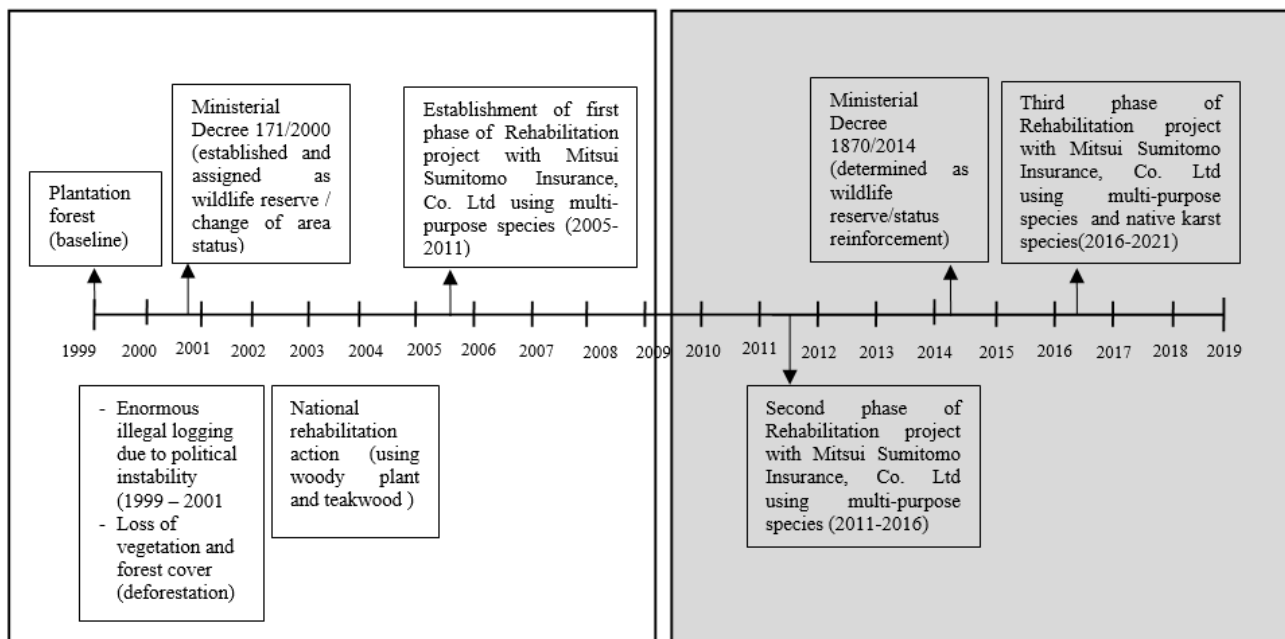


Figure 2. Timeline of rehabilitation phases and change of area status of Paliyan forest during 1999-2019 described by related policies and events based on document review and interview.

Table 4. Classification of forest canopy density into land cover class and identified land use in 1999, 2009, and 2019

Forest canopy density	Land cover class	Identified land use	Area (ha)		
			1999	2009	2019
<10%	Non-forest	Open land	203,4	334,08	102,69
10-40%	Open forest	Mixed dryland agriculture (agroforestry)	171,27	91,26	286,92
40-70%	Moderately dense forest	Plantation forest	55,53	8,82	41,4
>70%	High dense forest	Secondary forest	4,05	0,09	3,24

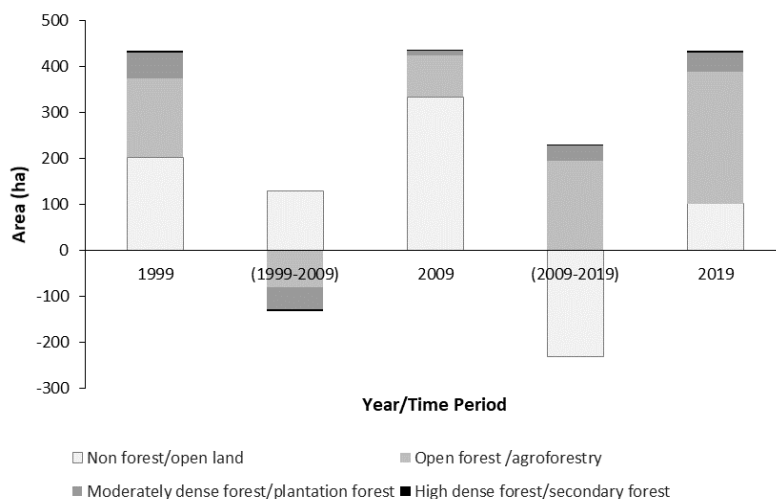


Figure 3. Stacked histogram of land cover and changes in the 434.25 ha investigated area during 20 years (period 1999-2009, 2009-2019)

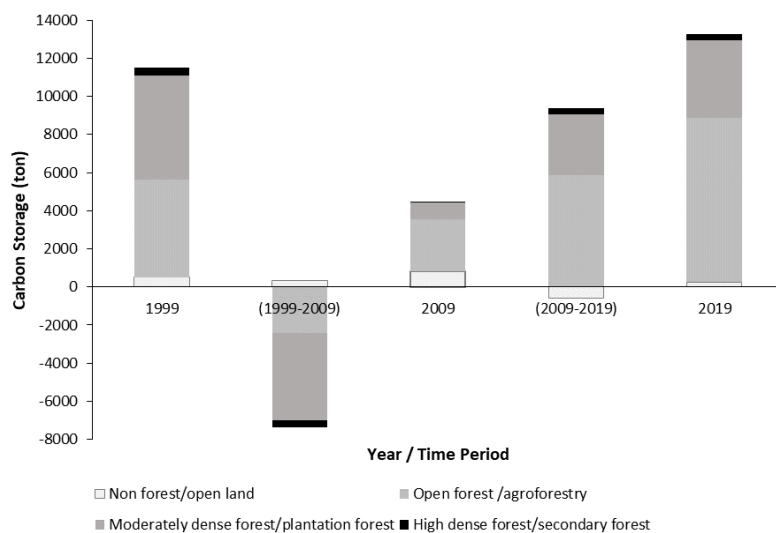


Figure 4. Stacked histogram of carbon storage and changes in the 434.25 ha investigated area during 20 years (period 1999-2009, 2009-2019)

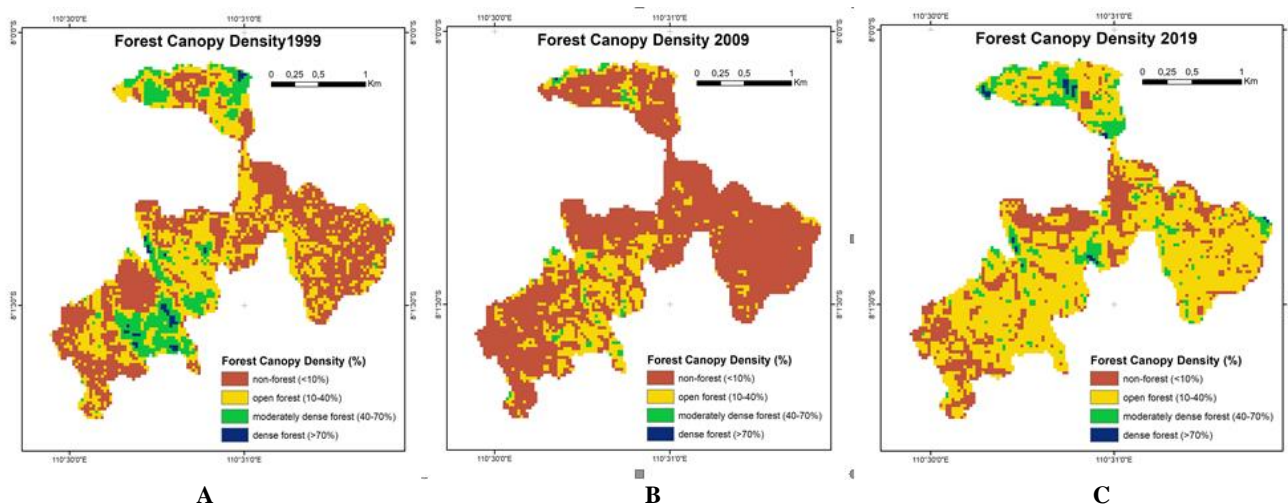


Figure 5. Forest canopy density map in the three different years: A. 1999, B. 2009, C. 2019

In the first decade of this study (1999-2009), there was a huge decrease in the forest area. In contrast, the vegetated area increased in the second decade (2009-2019). A previous study explained that there was a land transition from open land to the vegetated area (dominated by forest plantation) during 2000-2012 at all the landscape zones in Gunung Kidul (Wardhana et al. 2012). Another study located near PWR also indicated increases in the vegetated area because of community forest during 2003-2018 (Sadono et al., 2020). Rehabilitation project conducted by the government namely *Gerakan Nasional Rehabilitasi Hutan dan Lahan* (GNRHL) started in 2003 and continued in 2004 using woody plants, mainly teakwood. GNRHL did not completely cover the degraded area. There was a higher non-vegetated area than rehabilitated area during this project. The following project, the Mitsui Sumitomo Insurance Co.Ltd (MSI), covers a larger area than GNRHL project and committed to rehabilitating all degraded areas. In the first decade, GNRHL resulted in a larger land cover area than MSI project that had not shown the increasing land cover. The plant death rate was high due to several causes, such as extreme dry season; unestablished environmental conditions to enable plant growth; anthropogenic disturbance from agricultural activities in the area. However, in the second decade, the land cover had changed from previously dominated by non-forest areas to a vegetated area (mixed dryland agriculture, plantation forest, and secondary forest). Karst landscape zone where Paliyan forest is located was the most degraded than other landscape zones, and it had the dynamic transition pattern because of rehabilitation (Wardhana et al. 2012).

Although rehabilitation did not show a significant increase of land cover at the initial stage, eventually rehabilitation in PWR demonstrated the changes of land cover from non-forest area to forest area comprising of three different land-uses. It consists of open forest or agroforestry, plantation forest, and secondary forest with a significant impact on carbon storage of PWR. In 1999 as the baseline, the area was dominated by non-forest area, with a total of 11.509,94 tons of carbon storage. A decade after the baseline, the area was still dominated by non-forest area with a decrease amount of carbon storage of 4.449,61 tons of carbon. At the end of the study in 2019, the dominated area of PWR area was changed from non-forest to open forest/agroforestry with a total of 13.257,50 tons of carbon storage. Rehabilitation has altered the damaged forestland to the vegetated forest area and eventually enhancing carbon stock (Sadono et al. 2020). In a fully stocked forested area, the aboveground vegetation stores mainly the amount of carbon (Sil et al. 2017). The improvement of land cover and carbon storage due to forest rehabilitation has contributed to climate change mitigation efforts through the REDD+ program, especially in increasing the forest biomass stock and carbon sequestration (Beyene et al. 2016; Manaye et al. 2019). In the second decade, the forest canopy density increased gradually, indicated that the denser the forest canopy, the greater the average carbon storage (Pandey et al. 2014).

Finally, this research concludes that during the first decade started from 1999, there was a change in the status of Paliyan forest: from plantation forest to protected forest (wildlife reserve) which has a higher implementation in the conservation of the area. This decade was the explosion of illegal logging, land cover change from forested area to non-forested area (deforestation), and initiation of rehabilitation activity of PWR. During the second decade, characterized by more established rehabilitation activity, reversely to the first decade, there was a change in the non-forest area in 2009 to the forest area in 2019 (dominated by open forest/agriculture area, followed by plantation forest and secondary forest respectively) which followed by an increase of carbon storage of PWR. This rehabilitation activity still needs a longer period to achieve a more dense forest condition as in 2019 the area was still dominated by open forest/agriculture. This condition needs to be improved in terms of management of the area such as reducing area for agriculture activities, protecting the plantation forest and secondary forest from disturbance and human interference to obtain the more productive forest with higher carbon storage.

Our study illustrated that the use of remote sensing carbon conversion had been useful for demonstrating the change of land cover and carbon dynamics as the impact of area status change and rehabilitation activity during the last two decades from 1999 to 2019. Rehabilitation has resulted in the transition of non-forest areas to forested / more vegetated areas. Thus, the increase of vegetated areas has also given an impact on the improvement of carbon storage. This data and information are important for related stakeholders in further action in the management of the area and for designing next rehabilitation plan.

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