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Ecological Analysis of Community and Private Partnership in Tree Planting Program to Rehabilitate Degraded Lands: A Case Study in East Java, Indonesia

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Abstract

Community and private partnership (CPP) in tree planting initiative is potential to accelerate rehabilitation of degraded lands. Yet, empirical studies to analyse such programs are limited. Here, we analysed a CPP tree planting program in East Java, Indonesia by focusing on ecological aspects, i.e. vegetation cover changes, floristic diversity, above-ground carbon storage, and soil and microclimate conditions. Results showed that there was a striking increase in vegetation cover, yielding a total carbon sequestration of 3,853 tons, or equivalent to the reduction of 14,140 tons of CO_2 *emissions. On the other hand, co-benefits in term of floristic diversity at a landscape scale was low, and soil and micro-climate conditions were still marginal. This study provided empirical evidence that collaboration between communities and private entities in tree planting program can be effective in rehabilitation of degraded lands. Improvement in land management systems applied in tree planting through the implementation of mixed gardens or complex agroforestry is suggested if aiming for co-benefits in floristic diversity and soil properties. Our study recommends a broader adoption of a similar scheme in rehabilitation of degraded lands across Indonesia.*

Keyword: *ecosystem services, vegetation cover, floristic diversity, carbon storage, community forest*

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Introduction

Land degradation has become a major environmental problem in Indonesia. The Ministry of Environment and Forestry estimates that degraded lands in Indonesia reached 14 million ha (PDI KLHK, 2021), or if put into perspective it is equivalent to the combined land areas of Java, Bali, and Madura Islands. There are several causes of land degradation in Indonesia, yet forest conversion and mismanagement of land uses are the primary drivers of land degradation (Nawir et al., 2007; Tsujino et al., 2016). Land degradation can lead to environmental disasters, such as floods, landslides and fires(Wells et al., 2016; Santika et al., 2020). It decreases land productivity due to a reduction in vegetation cover and available water, soil erosion, and deterioration of soil qualities and microclimate conditions (Ziadat et al., 2022). Land degradation also contributes to the reduced capacity of carbon sequestration from land use, land-use change and forestry (LULUCF) '(Franzluebbers & Doraiswamy, 2007). Therefore, land rehabilitation is increasingly promoted to recover the biotic and abiotic conditions of a degraded landscape which can be done through reforestation, afforestation and tree planting program (Willemen et al., 2018).

Despite the various policies and programs that have been pledged to rehabilitate degraded lands in Indonesia, the efforts are inadequate to reduce the extent of degraded lands in the country. The Ministry of Environment and Forestry has targeted to rehabilitate of 1.1 million ha of degraded lands between 2016–2020 (PDI KLHK, 2021). Assuming this effort is carried out consistently by the government, it would require 70 years to rehabilitate the degraded lands across Indonesia (i.e. 14 million ha). Therefore, it requires a breakthrough to accelerate the rehabilitation of degraded lands, one of which is a broader involvement of actors in land rehabilitation.

Various actors or stakeholders may involve in rehabilitation of degraded lands which work either individually or collectively (Chazdon et al., 2017). In most cases, degraded lands are owned and managed by households, communities, companies and state, and this condition makes the rehabilitation efforts can be complicated (Chazdon et al., 2017). Nonetheless, there is an opportunity for participation and cooperation among stakeholders by sharing the resources owned by each actor. Governmental actors are considered to have the most influential role due to their strong position, with regard to their authority in public policy and decision-making, financial and material capacities, socio-political networks, and accumulation of forest-related information (Chazdon et al., 2017). Meanwhile, local communities are the majority of actors who have a direct role in day-to-day rehabilitation activities (Chokkalingam et al., 2005). Private-sector involvement is also important since they have financial resources to fund rehabilitation programs (Pandit et al., 2018). In addition, large-scale enterprises might also contribute in the form of corporate social responsibility (CSR) programs to compensate for the negative social and environmental impacts of their operations (Wolff & Klink, 2015). Other actors may include non-governmental organizations (NGOs), academic and scientific communities, consulting agencies, and communal groups (Nawir et al., 2007).

There is an increasing trend of collaboration and partnership among several actors in degraded land rehabilitation programs. These include the involvement of private enterprises to join with government and communities in reforestation, afforestation and tree planting projects as part of their sustainability strategies (Rashed & Shah, 2020). In some cases, the government attracts private sector to involve in land rehabilitation by offering various incentives (Chazdon et al., 2017), with specific schemes depending on the context of economic sector and land use activities of the enterprise. One form of private sector involvement in land rehabilitation is a tree planting program through CSR activity. In doing so, the company integrates a mix of company-owned sustainability tools, third-party social and environmental schemes and engagement of multi-stakeholder initiatives (Wolff & Klink, 2015).

The collaboration among government, communities and private sectors is argued to accelerate land rehabilitation (Pandit et al., 2018). In this regard, there is a good opportunity with high potential benefits for private enterprises to get involved in community-based tree planting programs. Community and private partnership (CPP) initiatives in rehabilitation of degraded lands have not been widely recognized and exposed. While such an initiative is potential to be promoted and up-scaled into policy at a national scale, or even global scale, the understanding regarding the effectiveness of CPP in degraded land rehabilitation is limited. Here, we analysed a CPP tree planting program in East Java, Indonesia by focusing on ecological aspects, namely vegetation cover changes, floristic diversity, above-ground carbon storage, and soil and microclimate conditions. We expected the results of this study can inform lessons learned from tree planting program for rehabilitation of degraded lands under CPP scheme and the feasibility of a similar scheme to be replicated in other contexts at a national and global scale.

Methods

Case study area and land-use history This study was located in Selobanteng Village, Banyuglugur District, Situbondo Regency, East Java Province, Indonesia (Figure 1). Selobanteng Village is geographically situated at S7°45'3" and E113°35'35", with a total area of approximately

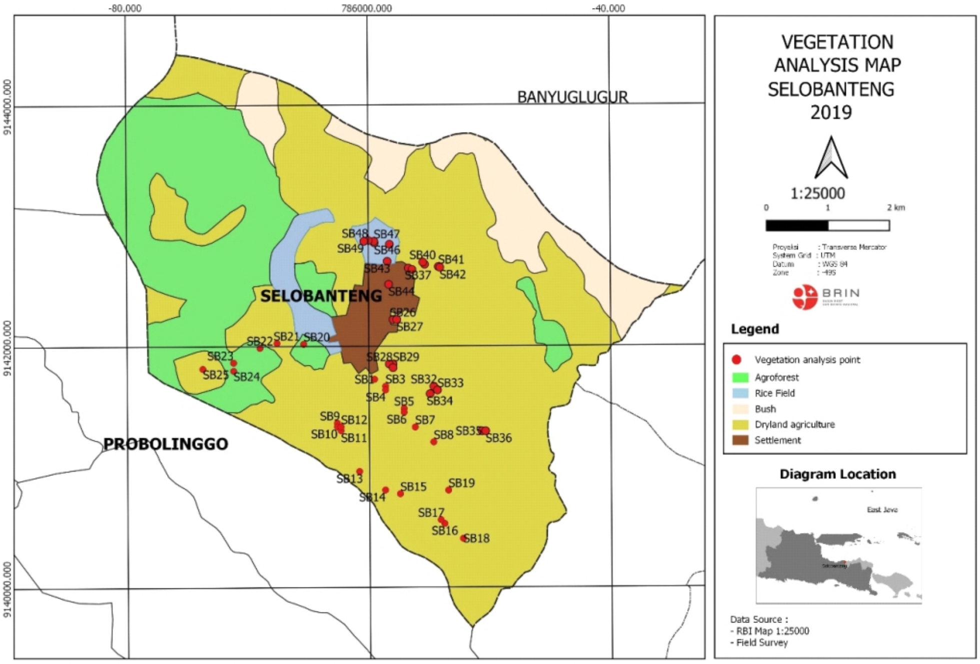

Figure 1 Location map and sampling plot of study area of Selobanteng CPP tree planting program.

1,165.50 ha. It is categorized as a dry lowland area with altitudes ranging from 200 to 450 m above sea level. Topography is flat to steep with slopes of 0–30°. Actual air temperature measured during the field survey was 30–40 °C, with a minimum relative humidity range of 24–61%. Annual rainfall (2014–2018) ranged 1,104–1,496 mm with dry month periods of 5 to 9 months, thus it can be classified as dry climate (BMKG Karangploso Malang, 2019).

Previously, most areas in Selobanteng Village were bare lands used for dryland agriculture. However, such land management did not provide sufficient livelihood sources for the farmers since the area has limited water availability and the soil qualities were marginal due to the natural conditions of the area, resulting in low productivity of agricultural crops. In 2009, a partnership in a tree planting program was initiated and arranged between a coal-fired thermal power plant company and the villagers (hereafter called Selobanteng CPP tree planting program). Prior to the CPP program, socializations were conducted by the company to raise awareness and capture communities' commitments to rehabilitate degraded land as well as to improve their livelihoods. Under the partnership arrangement, the company provided tree seedlings (approximately 10,000 to 20,000 seedlings year^{-1}) and composts on the planting sites. The communities received the seedlings to be planted and maintained on their lands. The number of seedlings and composts received by each farmer varied according to the size of the land and the willingness of the farmer stated in a proposal submitted to the farmer group leader. From the perspective of the company, such arrangements incurred low costs since they did not bear the planting and maintenance costs as occurred in several land rehabilitation programs (Nawir et al., 2007).

From 2010 to 2018, in total 196,500 tree seedlings had been planted scattered on farmers' land. Because the decision of planting was on the farmers, there was high variability in planting pattern, distance, density and location. In some cases, there was a regular pattern of planting on a parcel of land with a particular distance and density, but in other cases, the seedlings were planted irregularly, often along the perimeter settlements, paddy fields, gardens, and roads and trails. The planted seedlings comprised mostly of teak (105,000 seedlings) followed by gmelina (85,000 seedlings), robusta coffee (6,000 seedlings), and some fruit trees (500 seedlings) such as breadfruit, jackfruit, mangoes, etc. The consideration of the tree species selection was based on their economic value and community preference through previous surveys and interviews. In addition, several capacity building activities for the farmers to support the CPP program were conducted including plant propagation techniques and composting. Other actors were also involved during the CPP tree planting program including the regional government through Environmental Services Agency and Forestry Service Agency in socializations and plantings, as well as academic and scientific communities in monitoring-evaluation and training (PT POMI-PT Paiton Energy, 2015).

Vegetation cover changes Remote sensing analysis was employed to estimate the vegetation cover changes. We used Landsat 8 Operational Land Imager (OLI) satellite provided by the United States Geological Survey (USGS), which generates 16-bit imageries at 30 m×30 m resolution of multispectral bands (4.5 pixels acre^{-1}). The acquisition data used in this study was based on the age of tree planting program including 2014 (5 years), 2016 (7 years) and 2019 (10 years) with 10% cloud cover (Table 1). Ideally, 2009 imagery data is needed as a baseline of pre-reforestation condition, however, it cannot be obtained since Landsat 8 OLI was first released in 2013.

The satellite imageries acquired were then processed using normalized difference vegetation index (NDVI) method. NDVI is a sensitive numerical indicator related to plant photo-synthetic active radiation. This index shows a positive correlation with green biomass, green leaf area index, chlorophyll content, and leaf nitrogen content. It basically measures the vegetation cover on the land surface over wide areas, which is represented by different greenness levels. NDVI is a ratio combination of the visible red (RED) and near-infrared (NIR) bands, centered at 0.660 μm and 0.840 μm, respectively. NDVI values were determined using Equation *[1]* (Mather & Koch, 2011).

$$NDVI = \frac{NIR - RED}{NIR + RED} \qquad [1]$$

NDVI values range from -1 to 1 in which a value below 0 indicates the presence of clouds, ice, or snow, while values between 0 and 0.1 indicate the barren land and values above 0.1 indicate the vegetation. In this study, we classified the NDVI values into five vegetation cover categories, i.e. 0–0.2 as non-vegetation; 0.2–0.3 as less vegetation; 0.3–0.4 as moderate vegetation; 0.4–0.5 as dense vegetation; and 0.5–1 as very dense vegetation (Mather & Koch, 2011).

Vegetation diversity analysis Vegetation analysis was carried out using a purposive sampling method since there was high variability in the land management. Nested observation plots were established along the transect line intersecting the contour. Three layers of vegetation were observed in each plot, comprised of 2×2 m^2 for understory (plant height <1.5 m), 5×5 m^2 for saplings to represent young/immature trees (plant diameter ≤10 cm, plant height ≥1.5 m), and 10×10 m^2 or 20×20 m^2 for trees to represent adult/mature trees (plant diameter >10 cm). Two subplots were employed for tree layer, depending on the land management of each individual farmer's situation. In some cases, a farmer has a large size parcel of land that could

Table 1 The satellite imageries data used in this study

Year	Date of acquisition	Imagery	Path/Row
2014	2-12-2020	LC08_L1TP_118065_20141120_20200910_02_T1	118/065
2016	7-10-2020	LC08_L1TP_118065_20160704_20200906_02_T1	118/065
2019	7-10-2020	LC08_L1TP_118065_20191118_20200825_02_T1	118/065

facilitate a 20×20 m^2 plot, but in other cases, the parcel was quite small and could only fit 10×10 m^2 plot. Furthermore, the species name and the number of individuals encountered per layer were recorded (Soerianegara & Indrawan, 1998).

In total, 81 sampling plots were established in Selobanteng, covering an area of 21,300 m^2 and representing several land management types, including community forest (CF) of teak or gmelina monoculture, a combination of teak and gmelina, and mixed gardens (Figure 1). Thus, the vegetation analysis conducted in this study reflected gamma diversity (γ-diversity) since it represented the diversity at a landscape scale.

The floristic diversity indices analysed included importance value, Shannon-Wiener diversity, Margalef species richness, and Pielou species evenness. The formulas and class criteria for each diversity index refer to Krebs (1978), as shown in Equation *[2]* until Equation *[5]*.

Importance value index (IVI) = Relative density (RDe) + Relative frequency (RF) + Relative dominance (RDo) *[2]*

Shannon-Wiener diversity index $(H') = -\Sigma pi \times \ln pi$ *[3]*

note: $pi = \frac{n_i}{N}$, n_i = number of individuals of species-*i*, and N = total individuals of all species. The diversity level is low if H'<1; moderate if 1.0≤H'≤3.0, and high if H'>3.0.

Species richness index $(R) = \frac{(S-1)}{\ln(N)}$ *[4]*

note: S = total number of species, N = total individuals of all species. The species richness is low if R<3.5; moderate if 3.5≤R≤5.0; and high if R>5.0.

Species evenness index $(E) = \frac{H'}{\ln(S)}$ *[5]*

note: H' = diversity index, S = total number of species. The evenness is low if 0.0<E≤0.4; moderate if 0.4<E≤0.6; and high if 0.6 < E ≤ 1.0.

Above-ground carbon storage estimation The above-ground carbon storage was assessed for the two major species planted *i.e.* teak and gmelina. We sampled trees representing several different planting years to obtain on-the-ground data to develop a carbon increment model. In total, 823 teak trees and 801 gmelina trees were used to estimate carbon storage. The samples of teak consisted of 145, 151, 135, 318, and 74 individuals representing planting years of 2010, 2011, 2012, 2014, and 2015 with average diameters of 14.22, 12.80, 11. 21, 8.27, and 6.72 cm, respectively. While gmelina samples consisted of 70, 51, 67, 96, 180, 158, 132, and 47 individuals representing planting years of 2011, 2012, 2013, 2014, 2015, 2016, 2017, and 2018 with average diameters of 22.00, 21.58, 17.04, 13.53, 10.87, 8.51, 7.63, and 4.37 cm, respectively.

The rapid carbon stock appraisal (RaCSA) method developed by Hairiah et al. (2011) was employed to estimate the carbon storage in above-ground biomass at individual tree levels. There were several allometric equations developed to calculate above-ground biomass in tropical forests (Chave et al., 2005), however, most of them are well-suited for plot-based estimation, often using permanent sample plots. While such equations are ideal, they can not necessarily be applied in our study due to the absence of permanent sample plots and high variability of land management and planting patterns (often in an irregular manner), resulting in diverse conditions at plot levels. Therefore, we used the generic allometric equation by Ketterings et al. (2001) as suggested by Hairiah et al. (2011) to estimate tree-level above-ground biomass in agroforestry systems, formulated as shown in Equation *[6]*.

$$AGB = 0.11\rho D^{(2.62)} \qquad [6]$$

note: *AGB* = above-ground biomass of each tree (kg), *ρ* = wood density, *D* = the tree diameter at breast height (cm).

The average wood density of teak is 0.64 tons m^{-3} while gmelina is 0.48 tons m^{-3} (Zanne et al., 2009). Since carbon makes up about half of the biomass, to get the amount of carbon storage per tree, the AGB calculating result was multiplied by a standard factor of 0.5 (Hairiah et al., 2011).

The carbon increment modelling was performed using the age parameter as a predictor (independent variable) to estimate the mass of carbon per tree at a certain age (Stephenson et al., 2014). This model was built using tree samples in the field plotted on a scatter diagram to obtain the regression equation. The regression equation with the highest coefficient of determination (R^2) was then chosen as the carbon model to estimate the carbon per tree at a certain age. The total carbon sequestered (in 2019) is the accumulation of carbon per tree at a certain age multiplied by the number of seedlings planted in a given year and the survival percentage.

Environmental data collection and analysis Environmental data consisting of micro-climate factors and soil properties were recorded from the sampling plots representing four land management types at Selobanteng (i.e. monoculture of teak, monoculture of gmelina, a combination of teak and gmelina, and mixed gardens). Micro-climate factors were observed including maximum air temperature and relative air humidity using a thermohygrometer Dekko 642N and the intensity of sunlight with a lux meter LX-1102. The altitude of the sampling plots was also recorded using a GPS.

The soil samples were taken at a depth of 010 cm using disturbed and undisturbed methods, with 48 replications per land management type. The undisturbed soil samples were taken using a cylindrical soil sampler with a diameter of 6.7 cm and a height of 8 cm (Yulistyarini et al., 2016). The analysis of soil physical properties included soil texture by pipette method and bulk density (BD) using gravimetric to the undisturbed soil samples. While, the chemical soil characteristics analysed consisted of pH value (pH H_2O), organic C (Walky and Black method), total N (Kjeldahl method), C/N ratio, P (Bray1 method), exchangeable K, and cation exchange capacity (CEC) (extraction method using NH4OAc 1 N pH 7). Statistical tests were performed subjected to environmental data using SPSS 16.0. The Duncan test was used to determine the significant difference with a 95% confidence level. The technical soil analysis methods and classsification criteria for soil properties were referred to SRI (2009).

Results and Discussion

Vegetation cover changes based on NDVI Although satellite imageries prior to tree planting program were not available, it can be predicted that in the first five years there was an increase in vegetation cover due to the program. During the first five years, the tree seedlings experienced a growing period and were not ready to be harvested (Tiryana, 2016). In the second five years, it was found that the vegetation cover continued to increase until the 7th year of the program. As evidently by the NDVI maps and values (Figure 2, Table 2), there was a significant increase in areas with dense and very dense vegetation cover during five (in 2014) to seven years (in 2016) after tree planting, while areas with less and moderate dense vegetation cover were markedly reduced. For example, there was more than a 25-fold increase in areas with dense vegetation during 20142016 and a ten-fold decrease in areas with less vegetation during the same period (Table 2). This is understandable since as many as 190,000 seedlings of teak and gmelina had been planted between 2010 and 2018 with 130,000 seedlings alone planted in the first five years (Table 4 and Table 5).

Interestingly, in the 10 years after reforestation (2019), there was a 66.11% decline in areas with very dense vegetation cover which changed to dense and moderate

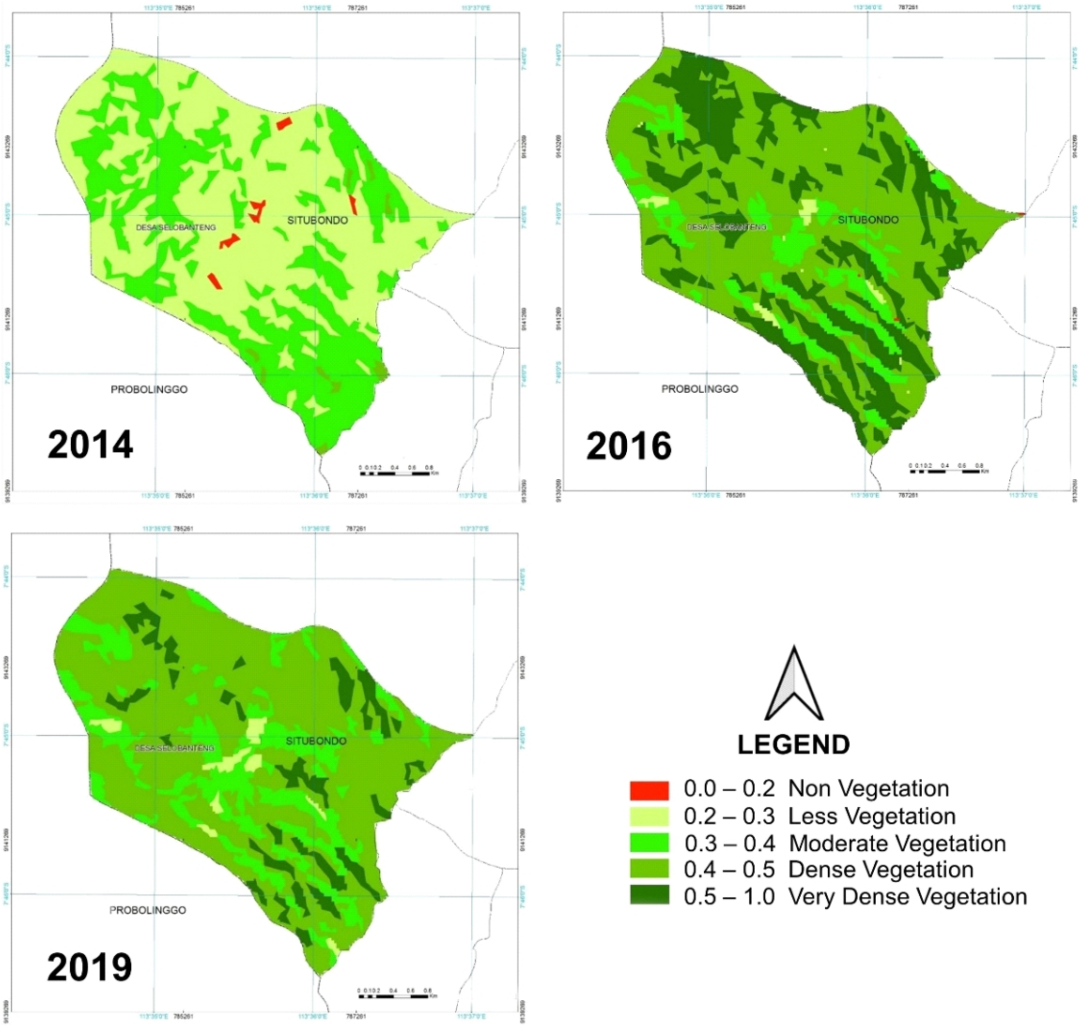

Figure 2 NDVI map of vegetation cover changes in Selobanteng.

Table 2 Extent of each vegetation cover class of Selobanteng in 2014, 2016, and 2019

Vegetation density class	NDVI range	Extent area (ha)		
		2014 (5-year)	2016 (7-year)	2019 (10-year)
Non vegetation	0.0–0.2	8.50	0.36	0.00
Less vegetation	0.2–0.3	687.61	60.48	25.27
Moderate vegetation	0.3–0.4	456.95	196.56	244.46
Dense vegetation	0.4–0.5	12.44	582.86	785.07
Very dense vegetation	0.5–1.0	0	325.25	110.22

Notes: Total area of analysis was approximately 1,165.50 ha vegetation. Early harvesting of the trees (mostly gmelina) by farmers driven by economic needs became the main reason for the decreasing vegetation cover from 2016 to 2019. The young trees harvested can be sold to raise income (Rahmawati et al., 2021). Any harvested trees with diameters greater than 10 cm can be used for construction timber while the smaller ones are suitable for firewood.

Composition, structure, and diversity of vegetation The results of vegetation analysis at a landscape scale of Selobanteng CF showed that at least 143 plant species were recorded, including 131 genera and 53 families. The most common plant species at all layers found were from the family Leguminosae followed by Moraceae, Malvaceae, Lamiaceae, Poaceae, and Sapindaceae. The understory layer in Selobanteng CF was mostly composed of perennial shrubs, followed by tree seedlings, grasses, lianas, and herbaceous plants (Figure 3). The understory is an important structural and functional component of forest ecosystems such as for regeneration, nutrient cycling and microclimatic buffering (Hapsari et al., 2020). However several understory species with high IVI were included as invasive species which need to be monitored including *Chromolaena odorata*, *Achyranthes aspera*, *Lantana camara*, and *Pennisetum purpureum* (Figure 3). The utilization of understory plants particularly the invasive species by the community should be encouraged to control the population such as for animal feeders, firewood, compost, etc.

Meanwhile, the teak (*Tectona grandis*) and gmelina (*Gmelina arborea*) were the most important species with highly significant IVI at sapling and tree layers due to the CPP planting program. Other important species were *Coffea canephora*, *Leucaena leucocephala*, *Dysoxylum gaudichaudianum*, *Lannea coromandelica*, *Schoutenia ovata*, *Albizia procera*, *Ficus* spp. etc. (Figure 3). *Schleichera oleosa, Falcataria moluccana, Alstonia scholaris*, and *Mangifera indica* were also recorded. Most of them were considered popular species for the community's livelihoods such as timber, firewood, fruits and nuts, animal feed, natural dye, etc. in which typical species in CFs (Puspitojati et al., 2014).

The floristic community structure indicated that the landscape in the studied area was dominated by human-managed lands which were characterized by the high dominance of few species at the sapling and tree layers (Figure 3), and a low diversity and evenness indices at the tree layer (Table 3). Nonetheless, the dominance of invasive species at the understory layer (Figure 3), and the high values

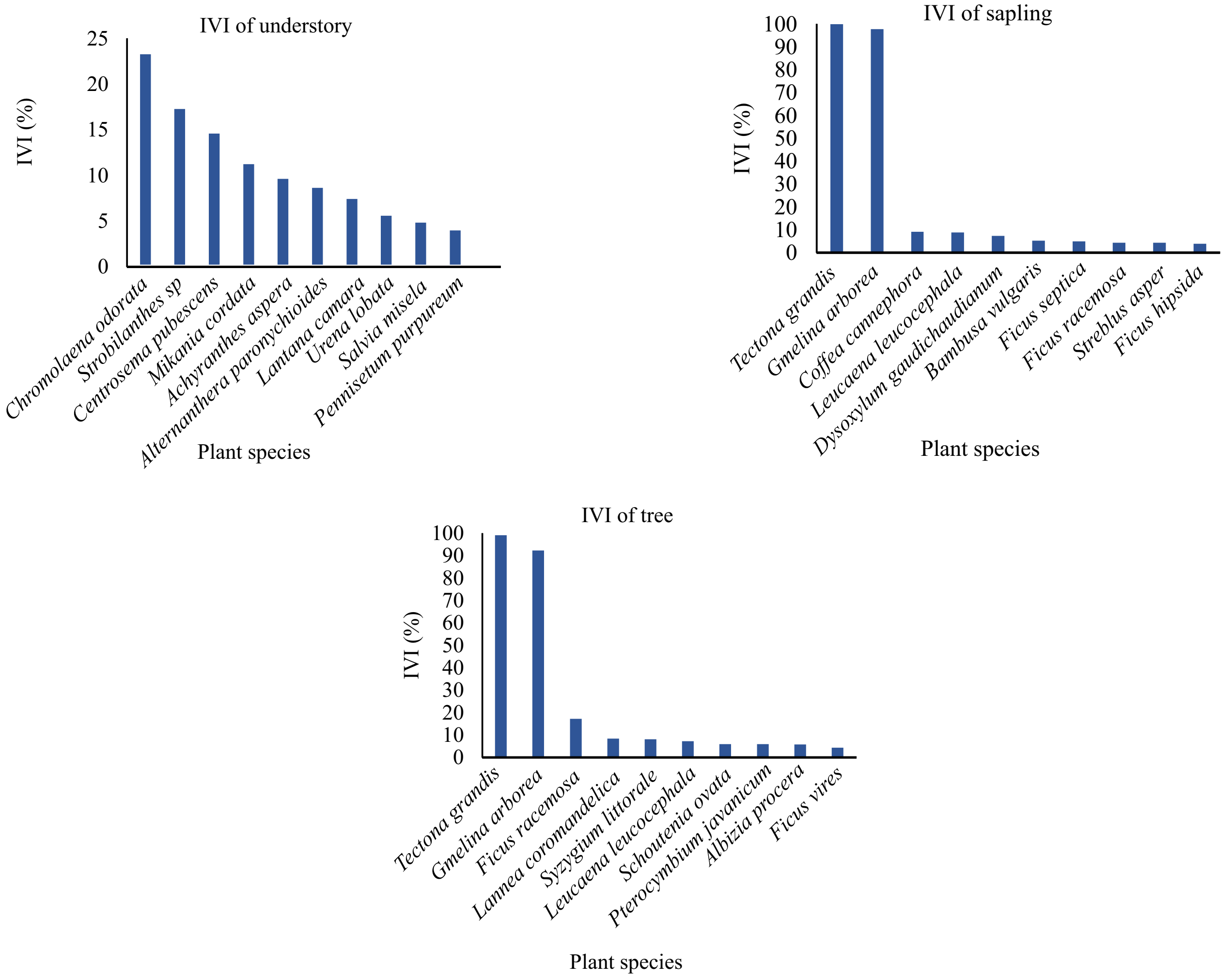

Figure 3 The ten most important value plant species at understory, sapling, and tree layers in Selobanteng CF (landscape scale).

of diversity, richness and evenness indices at this layer (Table 3) suggest that the landscape was not intensively managed (Paudel & Sah, 2015).

Furthermore, the monoculture system in the Selobanteng CF due to the CPP tree planting program has resulted in the rapid development of commercial tree species i.e. teak and gmelina. However, it contributed to the low diversity indices and reduction of the less/non-commercial and native species in the area. Therefore, it is encouraged to do enrichment planting of multiple plant species and to change the land management type from monoculture to mixed garden (agroforest). Mixed gardens contributed to higher diversity indices than coffee, cocoa, clove, cashew and coconut monocultures (Siarudin et al., 2017).

Carbon storage estimation of teak and gmelina Results showed that the carbon mass per tree in teak was lower than that in gmelina at the same age. For example, at the age of 8 years, teak had an average carbon mass of 35 kg C tree^{-1}, while gmelina had three times higher (108 kg C tree^{-1}) (Figure 4). This finding is understandable because teak is a slow-growing tree species meanwhile gmelina is a fast-growing tree.

Further, the carbon mass of both teak and gmelina increased with age, but the carbon mass per tree at the same age showed high variation as indicated by large standard deviations (Figure 4). This high variation was possibly due to several reasons such as differences in seedling quality in terms of age, size and provenance; seedling handling techniques, planting and maintenance including transportation, planting hole depth, fertilizer addition, planting spacing, and pruning of branches; biophysical conditions of planting site including soil conditions, elevation, slope and water availability (Sadono, 2019; Rahmawati et al., 2021).

The regression equation for the carbon increment model

Table 3 Plant community structure and diversity indices in Selobanteng CF

Layer	Species number	Density (individual ha^{-1})	Diversity index (H’)	Richness index (R)	Evenness index (E)
Understory	105	60,216	3.52	13.73	0.76
Sapling	49	6,168	1.62	6.73	0.42
Tree	36	602	0.43	4.89	0.12

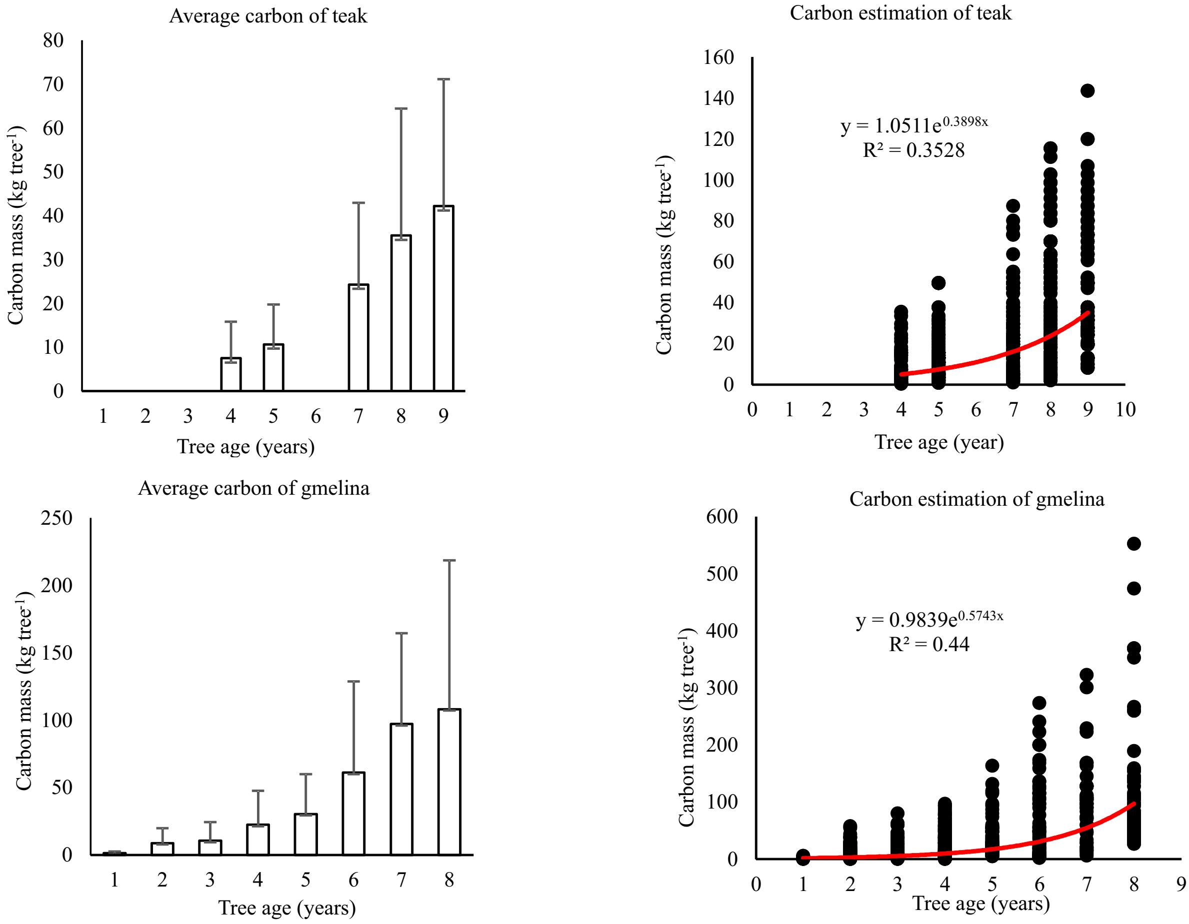

Figure 4 The average carbon mass and carbon estimation model of teak (above) and gmelina (below) in Selobanteng CF.

of both teak and gmelina followed an exponential curve (Figure 4); where at a young age the plant growth was relatively stagnant then at a certain age will increase rapidly and then stagnate again at old age. This growth pattern is in accordance with the growth pattern of tropical forests in Indonesia (Budiharta et al., 2014). Further, the coefficient of determination (R^2) of both teak and gmelina were considered low, i.e. 0.3528 and 0.44, respectively (Figure 4).

While there was uncertainty in estimating carbon stock as shown by error bars in Figure 4, on average the CPP tree planting program in Selobanteng CF has produced 1,106 tons of carbon sequestration from teak planting (Table 4), while gmelina has produced 2,746 tons (Table 5), totaling 3,852 tons of carbon storage. The total carbon sequestered by teak planting was less than half of gmelina planting even though the total number of teak seedlings planted was higher, i.e. 105,000 versus 85,000, respectively. The slower growth rate and the lower survival percentage of only 51% also affected the total carbon sequestered by the teak stands (PT POMI-PT Paiton Energy, 2015).

Assuming a planting space of 5×5 m^2 (400 individuals ha^{-1}), the total carbon stored by the CPP tree planting program in Selobanteng was 16.8 tons C ha^{-1} for teak and 69.1 tons C ha^{-1} for gmelina. This value is considered equivalent to some previous studies, such as teak stands aged 110 years in Blora, Central Java stored 10.213.6 tons C ha^{-1} (Ginting & Prayogo, 2018); teak stands aged 5 years in Magetan, East Java stored 8.73 tons C ha^{-1} (Lukito & Rohmatiah, 2013); gmelina stands aged 8 years in Kutai Kartanegara, East Kalimantan stored 58.5 tons C ha^{-1} (Agus et al., 2001); and gmelina stands aged 29 years in Tasikmalaya, West Java stored 64 tons C ha^{-1} (Siarudin & Indrajaya, 2017).

The carbon storage per hectare from the CPP tree planting program using teak and gmelina in Selobanteng was considered high when compared to other land rehabilitation programs and secondary dryland forests. For example, land rehabilitation program in the Brantas watershed area in Batu, East Java after 13 years, yielded 8.96 tons C ha^{-1} (Fiqa et al., 2018); in secondary forest of Gunung Mas, Central Kalimantan after five years produced 42.48 tons C ha^{-1} (Astuti et al., 2019); and in rehabilitation zone of secondary dry land forest in Meru Betiri and Bromo Tengger Semeru,

Table 4 Teak planting and carbon sequestered in Selobanteng CF (2010–2019)

Years	Tree age (in 2019)	Number of seedlings	Survival (%)	Average carbon per tree (kg)	Total carbon (kg)
2010	9	15,000	51	42.23	321,917.35
2011	8	30,000	51	35.55	542,017.04
2012	7	0	0	0	0
2013	6	20,000	51	10.90	110,773.69
2014	5	20,000	51	10.69	108,692.01
2015	4	0	0	0	0
2016	3	0	0	0	0
2017	2	20,000	51	2.29	23,296.18
2018	1	0	0	0	0
Total plantings		105,000		Total carbon (kg) Total carbon (ton)	1,106,696.27 1,106.70

Table 5 Gmelina planting and carbon sequestered in Selobanteng CF (2010–2019)

Planting years	Tree age (in 2019)	Number of seedlings	Survival (%)	Average carbon per tree (kg)	Total carbon (kg)
2010	9	5,000	67	172.86	582,876.32
2011	8	0	0	0	0
2012	7	20,000	67	97.15	1,310,389.86
2013	6	0	0	0	0
2014	5	20,000	67	30.29	408,526.99
2015	4	20,000	67	22.40	302,115.56
2016	3	20,000	67	10.56	142,444.00
2017	2	0	0	0	0
2018	1	0	0	0	0
Total plantings		85,000		Total carbon (kg) Total carbon (ton)	2,746,352.73 2,746.35

East Java contributed to 28.70 tons C ha^{-1} and 55.29 tons C ha^{-1}, respectively (Rochmayanto et al., 2014). However, the CPP tree planting program in Selobanteng yielded a lower carbon stock when compared to the reclamation of post-coal mining site in East Kalimantan in which the planting of various plant species after 9 years produced carbon of 90.42 tons C ha^{-1} (Trimanto et al., 2021). The difference in the carbon sequestered among various projects, among others, is caused by the plant species chosen for the rehabilitation. Plant species selection is important and considers many aspects including economic, social and ecological factors.

Environmental variables The teak and gmelina were preferable to be planted at the lower elevation due to the accessibility in planting, maintenance and transporting the timber. Across the four land management types observed, the environmental factors in terms of micro-climates showed no significant differences in relative air humidity and maximum air temperature, except for the light intensity (Table 6). The relative air humidity in the four land management types was relatively low and the maximum air temperature was relatively high. Meanwhile, the light intensity in the monocultures of teak and gmelina, and the combination of both were significantly higher than in mixed garden. Mixed garden is composed of mixed plant species with different ages and multi-layers' canopy cover, thus provides more shades from sunlight exposure than monoculture (Mulyana et al., 2011).

In terms of soil properties, the four land management types generally showed similar characteristics. It showed no significant differences in soil pH, N total, P and K, CEC, and bulk density (BD); except for the content of C organic and C/N ratio (Table 6). The soil textures of all land management types were classified as silty clay loam except in monoculture of teak (silty loam), with low BD of less than 1 g cm^{-3}. The soil texture and BD play important roles in the water and root penetrations, infiltration rate, the ability to bind liquids, and gaseous exchange (Usaborisut & Ampanmanee, 2015). Furthermore, the soil pH was categorized as slightly acidic to acidic with a low N-total. The available P and exchangeable K were classified as high to very high. Meanwhile, the cations available for plants to grow indicated by CEC value were categorized as moderate. Although there were significant differences, however, the C-organic and C/N ratio were still categorized as very low to low. This is likely due to the relatively short period after planting (i.e. max 10 years), the variability in planting pattern and the edaphic natural conditions of the studied area. Addition of organic matter/composts such as cattle or chicken manures and composts of leaves, rice hulls, rice straws, coffee hulls, etc. are suggested to increase the soil C/N ratio.

CPP tree planting program to rehabilitate degraded lands: Future directions This study demonstrates that tree planting program using CPP scheme is very promising in accelerating the rehabilitation of degraded lands. This research provides empirical evidence that when social aspects were considered, for example by involving community and private sector aspiration and participation, the chance of success of land rehabilitation can be enhanced (Budiharta et al., 2016). Thus, there is an opportunity to replicate this scheme in broader contexts and with stakeholders across Indonesia.

The success of CPP tree planting program in this study was shown by the striking increase of recovered vegetation to replace areas with degraded vegetation conditions in just a

Table 6 Environmental factors of four land management types in Selobanteng CF. Similar letter in the same line shows no significant difference at a 95% confidence level with Duncan's test. Data are means (±) standard deviations (SD)

Environmental factors	Teak monoculture	Gmelina monoculture	Combination of teak and gmelina	Mixed garden
Altitude (m a.s.l.)	270.91±59.32^{ab}	271.50±1.08^{ab}	253.27±29.44^{a}	310.29±59.52^{b}
Micro-climate variables				
Relative humidity (%)	41.18±8.24^{a}	42.16±5.25^{a}	41.60±8.87^{a}	42.12±5.01^{a}
Temperature (°C)	34.81±3.46 ^{a}	34.65±2.19^{a}	35.02±2.49^{a}	34.27±1.45^{a}
Light intensity (lux)	36,088.57± 24,193.87^{ab}	47,481.82± 34,825.11^{ab}	57,475.56± 20,292.49^{b}	23,226.12± 27,435.85^{a}
Soil properties				
pH	5.7±0.1^{a}	5.73±0.1^{a}	5.27±0.6^{a}	5.41±0.4^{a}
C organic (%)	1.83±0.6^{b}	1.42±0.1^{ab}	0.77±0.8^{a}	1.21±0.5^{ab}
N total (%)	0.18±0^{a}	0.16±0^{a}	0.15±0^{a}	0.16±0^{a}
C/N ratio	9.50±0.7^{b}	8.67±0.6^{b}	4.28±3.5^{a}	7.27±2.5^{ab}
P2O5 Bray 1 (mg kg^{-1})	67.56±11.1^{a}	26.14±24.5^{a}	44.59±23.2^{a}	50.74±34.0^{a}
K (me 100 g^{-1})	1.29±0.1^{a}	1.01±0.4^{a}	0.76±0.3^{a}	1.13±0.8^{a}
CEC (me 100 g^{-1})	22.64±6.9^{a}	20.41±2.7^{a}	20.51±4.1^{a}	23.84±2.2^{a}
Bulk density (g cm^{-3})	0.65±0.0^{a}	0.75±0.1^{a}	0.79±0.1^{a}	0.77±0.1^{a}
Texture	Silty loam	Silty clay loam	Silty clay loam	Silty clay loam

period of ten years (Figure 2 and Table 2). This achievement with the main actors of local communities replicated the success of a well-known tree planting program in Gunungkidul, Yogyakarta where highly degraded lands can be turned into forested areas (Sabastian et al., 2014). Yet, there was a slight decrease in vegetation cover caused by early harvesting practices due to farmers' economic needs. To avoid this, the Ministry of Environment and Forestry has developed a soft loan policy by providing credit to farmers using the planted trees as collateral known as delayed harvesting loans (DHL) (Permen LH P.59/MenLHK-Setjen/2015).

The DHL is a soft loan with a small interest rate (6.5%) given to community forest farmers who already have trees. The farmers who need cash income can apply for the credit by pledging their timber trees (minimum diameter 15 cm) with a commitment not to harvest them for an agreed period of time (at least 8 years). Thus, the money can be used to meet their urgent needs and/or for their productive businesses. At least 19 farmers in Selobanteng were granted this DHL (SK Kepala Pusat Pembiayaan Pembangunan Hutan No. 81/P2H/OP/SET.1/3/2017) with a high hope that it will have a positive impact on controlling the early tree harvesting. However, some problems occurred during the implementation such as complicated and time-consuming bureaucracy, hurdles in payment mechanism, and lack of commitment (the farmers harvest the trees before the contract ends) (Lusiya et al., 2020). Simplification, yet prudent, mechanism of the soft loan is therefore recommended to attract the farmers to apply for the loan to safeguard their livelihoods before the planted trees reach adequate age to harvest.

The recovering vegetation resulted from the CPP tree planting program of teak and gmelina also resulted in carbon sequestration with a total of 3,853 tons (Table 4 and Table 5), or equivalent to 14,140 tons of carbon dioxide (CO_2-equivalent emissions) during a ten-year period. This is not negligible since coal-fired thermal power plants emitted CO_2 ranging from 807,000 to 18,185,000 tons in a year (Mittal et al., 2012). Thus, CPP tree planting program can be viewed as a win-win strategy to offset carbon emissions of private sectors to mitigate global warming while co-benefiting forest-based communities through the provision of livelihoods (Budiharta et al., 2018). Expanding a similar scheme to be obligatory for carbon-emitting companies will help Indonesia to achieve the nationally determined contribution (NDC) of carbon emissions reduction by 29% unconditionally and 12% through external support by 2030 (Tacconi & Muttaqin, 2019).

While benefiting vegetation cover and carbon sequestration, the area where CPP tree planting program was conducted did not harbour high flora diversity (Figure 3 and Table 3). This is predictable since the objective of the planting program was not only focused on biodiversity aspect. The land management system applied in the studied area was dominated by a monoculture of teak or gmelina stands, or a combination of both. If biodiversity becomes the consideration, mixed garden (agroforestry) is increasingly promoted as an agro-ecological system of land management that still accommodates biodiversity while maintaining the productivity of land for agriculture and forestry purposes (Bhagwat et al., 2008; Jose, 2012). In doing so, multiple plant species arranged in multiple layers (complex agroforestry) can be applied (Asase & Tetteh, 2010; Villamor et al., 2014). Nonetheless, it requires an assessment of land suitability of planted crops (Wotlolan et al., 2021). Also, the cost of planting multiple crops necessitates an upfront cost that might not affordable for many farmers (Scherr, 1995), implying another assistance is required to facilitate the financial investment in planting multiple crops as well as an extension on cultivation techniques.

In this study, mixed gardens provided better environmental factors in terms of light intensity compared to the other land management systems. Again, this finding strengthens the recommendation of applying mixed planting under agroforestry system to enhance environmental conditions as explained above. It will require an adjustment when estimating carbon benefits compared when only planting teak and gmelina. Our study revealed that there was no significant difference in soil chemical and physical properties, but it is believed that in the long run, multiple canopy layers might improve and protect soil quality (Martius et al., 2004; Gusli et al., 2020).

Conclusion

Scientific understanding of CPP in degraded land rehabilitation is still limited. Using a case study of a CPP of tree planting program in Selobanteng, Situbondo, East Java, we revealed this scheme is effective in increasing forest cover and carbon sequestration. Nonetheless, improvement in land management system by implementing tree planting in combination with several crop species to form complex agroforestry, instead of monoculture stands, is recommended to deliver co-benefits of biodiversity, edaphic and microclimate outcomes. Our study suggests a broader adoption of a similar scheme across Indonesia.

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Author Contributions

All authors have declared that L.H., T.Y., and S.B. are the main authors of this manuscript. L.H., T.Y., and S.B. conceptualization; L.H., T.Y., S.B., T., S.A.D., S.M. conducted the fieldwork and data collection; R.A.L., A.J. contributed the map study area and satellite imagery analysis; L.H., T.Y., S.B., T., S.A.D., S.M., J.D. performed the data analysis; L.H., T.Y., S.B., T., S.A.D., S.M., J.D. interpret the results and wrote the original manuscript; L.H., T.Y., S.B. reviewed, edited, and finalized the manuscript. All authors read and approved the final manuscript.

Disclosure Statement

The authors declare no conflict of interest. The funding sponsor had no role in the design of the study; in the collection, analysis, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

References

Agus, C., Karyanto, O., Hardiwinoto, S., Na'iem, M., Kita, S., Haibara, K., & Toda, H. (2001). Biomass productivity and carbon stock in short rotation plantation of *Gmelina arborea* Roxb. in tropical forest. *Indonesian Journal of Agricultural Sciences, 1*, 11–16.

Asase, A., & Tetteh, D. A. (2010). The role of complex agroforestry systems in the conservation of forest tree diversity and structure in southeastern Ghana. *Agroforestry Systems, 79*, 355–368. https://doi.org/10.1007/s10457-010-9311-1

Astuti, R., Wasis, B., & Hilwan, I. (2020). Carbon stock potential in rehabilitation land at Gunung Mas District, Central Kalimantan. *Media Konservasi, 25*, 140–148. https://doi.org/10.29244/medkon.25.2.140-148

Bhagwat, S. A., Willis, K. J., Birks, H. J. B., & Whittaker, R. J. (2008). Agroforestry: a refuge for tropical biodiversity?. *Trends in Ecology and Evolution, 23*, 261–267. https://doi.org/10.1016/j.tree.2008.01.005

[BMKG] Badan Meteorologi, Klimatologi, dan Geofisika Karangploso Malang. (2019). *Climate data in Banyuglugur District, Situbondo Regency, East Java, Indonesia 2014–2018*. Malang: Badan Meteorologi, Klimatologi, dan Geofisika, Stasiun Klimatologi Kelas II Malang.

Budiharta, S., Meijaard, E., Gaveau, D. L. A., Struebig, M. J., Wilting, A., …, & Wilson, K. A. (2018). Restoration to offset the impacts of developments at a landscape scale reveals opportunities, challenges and tough choices. *Global Environmental Change, 52,* 152–161. https://doi.org/10.1016/j.gloenvcha.2018.07.008

Budiharta, S., Meijaard, E., Wells, J. A., Abram, N. K., & Wilson, K. A. (2016). Enhancing feasibility: Incorporating a socio-ecological systems framework into restoration planning. *Environmental Science and Policy*, *64*, 83–92. https://doi.org/10.1016/j.envsci.2016.06.014

Budiharta, S., Slik, F., Raes, N., Meijaard, E., Erskine, P. D., & Wilson, K. A. (2014). Estimating the aboveground biomass of Bornean Forest. *Biotropica*, *46,* 507–511. https://doi.org/10.1111/btp.12132

Chave, J., Andalo, C., Brown, S., Cairns, M., Chambers, J., Eamus, D., ..., & Yamakura, T. (2005). Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia*, *145*, 87–99. https://doi.org/10.1007/s00442-005-0100-x

Chazdon, R. L., Brancalion, P. H. S., Lamb, D., Laestadius, L., Calmon, M., & Kumar, C. (2017). A policy-driven knowledge agenda for global forest and landscape restoration. *Conservation Letters*, *10*, 125–132. https://doi.org/10.1111/conl.12220

Chokkalingam, U., Sabogal, C., Almeida, E., Carandang, A.P., Gumartini, T., de Jong, W., ..., & Wibowo, L. R. (2005). Local participation, livelihood needs, and institutional arrangements: Three keys to sustainable rehabilitation of degraded tropical forest lands. In S. Mansourian., D. Vallauri., & N. Dudley (Eds.), *Forest restoration in landscapes* (pp. 405–414). New York: Springer. https://doi.org/10.1007/0-387-29112-1_58

Fiqa, A. P., Yulistyarini, T., & Arisoesilaningsih, E. (2018). Ecosystem services assessment after 13 years' restoration program in the Janitri Water Spring Conservation Area at Batu City. *Indonesian Journal of Environment and Sustainable Development*, *9*, 1–8. https://doi.org/10.21776/ub.jpal.2018.009.01.01

Franzluebbers, A. J., & Doraiswamy, P. C. (2007). Carbon sequestration and land degradation. In M.V.K. Sivakumar & N. Ndiang'ui (Eds.), *Climate and land degradation* (pp. 343–358). Heidelberg: Springer Berlin. https://doi.org/10.1007/978-3-540-72438-4

Ginting, T. T., & Prayogo, C. (2018). Estimation of carbon stock of teak forest (*Tectona grandis* Linn. F) using various allometric equations on various age classes of teak. *Jurnal Tanah dan Sumberdaya Lahan*, *5*, 10191026.

Gusli, S., Sumeni, S., Sabodin, R., Muqfi, I. H., Nur, M., Hairiah, K. Useng, D., & van Noordwijk, M. (2020). Soil organic matter, mitigation of and adaptation to climate change in cocoa–based agroforestry systems. *Land*, *9*, 323. https://doi.org/10.3390/land9090323

Hairiah, K., Dewi, S., Agus, F., Velarde, S., Ekadinata, A., Rahayu, S., & van Noordwijk, M. (2011). *Measuring carbon stocks across land use systems: a manual*. Bogor, Indonesia: World Agroforestry Center (ICRAF), SEA Regional Office.

Hapsari, L., Trimanto, & Budiharta, S. (2020). Spontaneous plant recolonization on reclaimed post-coal mining sites in East Kalimantan, Indonesia: Native versus alien and succession progress. *Biodiversitas*, *21*, 2003–2018. https://doi.org/10.13057/biodiv/d210527

Jose, S. (2012). Agroforestry for conserving and enhancing biodiversity. *Agroforestry Systems*, *85*, 1–8. https://doi.org/10.1007/s10457-012-9517-5

Ketterings, Q. M., Coe, R., Van Noordwijk, M., Ambagau, Y., & Palm, C. A. (2001). Reducing uncertainty in the use of allometric biomass equations for predicting above-ground tree biomass in mixed secondary forests. *Forest Ecology and Management*, *146*, 199–209. https://doi.org/10.1016/S0378-1127(00)00460-6

Krebs, C. J. (1978). *Ecology the experimental analysis of distribution and abundance*. New York: Harper and Row Publisher.

Lukito, M., & Rohmatiah, A. (2013). Biomass and carbon estimation of 5-year-old teak plantations (Case of Nusantara Superior Teak Plantation Forest (JUN) Krowe Village, Lembeyan District, Magetan Regency). *Jurnal*

Agritek, *14*, 1–23.

Lusiya, D. H., Darusman, D., & Nuryantono (2020). Implementation of loan for delaying timber harvesting for private forest in Blora Regency and Wonosobo Regencies, Central Java Province. *Jurnal Penelitian Sosial dan Ekonomi Kehutanan*, *17*, 117–135. https://doi.org/10.20886/jpsek.2020.17.2.117-135

Martius, C., Hofer, H., Garcia, M. V. B., Rombke, J., Forster, B., & Hanagarth, W. (2004). Microclimate in agroforestry systems in central Amazonia: Does canopy closure matter to soil organisms?. *Agroforestry Systems*, *60*, 291–304. https://doi.org/10.1023/B:AGFO.0000024419.20709.6c

Mather, P. M. & Koch, M. (2011). *Computer processing of remotely-sensed images*: *An introduction* (4th ed.). New York: John Wiley and Sons Ltd. https://doi.org/10.1002/9780470666517

Mittal, M. L., Sharma, C., & Singh, R. (2012, August 13–16). *Estimates of emissions from coal fired thermal power plants in India* [Conference presentation]. International Emission Inventory Conference. Florida, United States of America.

Mulyana, D., Budi, S. W., Wasis, B., & Wulandari, A. S. (2011). Perubahan lingkungan mikro pada berbagai penutupan lahan hasil revegetasi. *Jurnal Manajemen Hutan Tropika*, *27*, 24–28.

Nawir, A. A., Murniati., & Rumboko, L. (Eds.). (2007). *Forest rehabilitation in Indonesia: Where to after three decades?*. Bogor: Center for International Forestry Research (CIFOR).

Pandit, R., Parrotta, J., Anker, Y., Coudel, E., Morejón, C. F. D., Harris, J., ..., & Simelane, P. N. (2018). Responses to halt land degradation and to restore degraded land. In L. Montanarella, R. Scholes, & A. Brainich (Eds.), *The IPBES assessment report on land degradation and restoration* (pp. 435528). Secretariat Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Retrieved from https://www.ipbes.net/assessment-reports/ldr

Paudel, S. & Sah, J. P. (2015). Effects of different management practices on stand composition and species diversity in subtropical forests in Nepal: Implications of community participation in biodiversity conservation. *Journal of Sustainable Forestry*, *34*, 738–760. https://doi.org/10.1080/10549811.2015.1036298

[PDI KLHK] Pusat Data dan Informasi Kementerian Lingkungan Hidup dan Kehutanan. (Eds.). (2021). *Statistik 2020 Kementerian Lingkungan Hidup dan Kehutanan*. Jakarta: Kementerian Lingkungan Hidup dan Kehutanan.

Puspitojati, T., Mile, Y. M., Fauziah, E., & Darusman, D. (2014). *Hutan rakyat: Sumbangsih masyarakat pedesaan untuk hutan tanaman.* Yogyakarta: PT Kanisius.

PT POMI-PT Paiton Energy. (2015). *Environment baseline approach* (Final Report). PT POMI-PT Paiton Energy, Sekola KONANG, Laboratorium Lingkungan dan Bioteknologi Perairan-Institut Teknologi Sepuluh Nopember Surabaya, Komunitas Mitra Tani Hutan Desa Selobanteng. Probolinggo: PT POMI-PT Paiton Energy.

Rahmawati, R. B., Hardiwinoto, S., Widiyatno, Budiadi Amin, Y., & Hasanusi, A. (2021). Space planting, competition, and productivity of a seven-year-old clonal teak plantation in the East Java monsoon forest area. *Jurnal Manajemen Hutan Tropika*, *27*, 123–131. https://doi.org/10.7226/jtfm.27.2.123

Rashed, A. H., & Shah, A. (2021). The role of private sector in the implementation of sustainable development goals. *Environment, Development and Sustainability*, *23*, 29312948. https://doi.org/10.1007/s10668-020-00718-w

Rochmayanto, Y., Wibowo, A., Lugina, M., Butarbutar, T., Mulyadin, R. M., & Wicaksono, D. (2014). *Carbon stocks in various forest and plant types in Indonesia* (2nd ed.). Yogyakarta: PT Kanisius.

Sabastian, G., Kanowski, P., Race, D., Williams, E., & Roshetko, J. M. (2014). Household and farm attributes affecting adoption of smallholder timber management practices by tree growers in Gunungkidul region, Indonesia. *Agroforestry Systems*, *88*, 257–268. https://doi.org/10.1007/s10457-014-9673-x

Sadono, R. (2019). Effects of competition on the crown width allometry for dominant trees on good sites of vegetative clonal teak (*Tectona grandis* Linn. f.) in Java, Indonesia. *Jurnal Manajemen Hutan Tropika*, *25*, 104–114. https://doi.org/10.7226/jtfm.25.2.104

Santika, T., Budiharta, S., Law, E. A., Dennis, R. A., Dohong, A., Struebig, M. J., ..., & Wilson, K. A. (2020). Interannual climate variation, land type and village livelihood effects on fires in Kalimantan, Indonesia. *Global Environmental Change*, *64*, 102–129. https://doi.org/10.1016/j.gloenvcha.2020.102129

Scherr, S. J. (1995) Economic factors in farmer adoption of agroforestry: Patterns observed in Western Kenya. *World Development*, *23*, 787–804. https://doi.org/10.1016/0305-750X(95)00005-W

Siarudin, M., & Indrajaya, Y. (2017). Carbon stock dynamics of gmelina (*Gmellina arborea* Roxb.) based agroforestry in private forest, Tasikmalaya and Banjar District, West Java. *Jurnal Wasian*, *4*, 3746.

Siarudin, M., Winara, A., Indrajaya, Y., Badrunasar, A., Rahayu, S., & Roshetko, J. M. (2017). *Agroforestry and Forestry in Sulawesi Series: Biodiversity of tree species in agroforestry community forests in the Balangtieng Watershed, South Sulawesi* [Working Paper No. 253]. Bogor: World Agroforestry Center (ICRAF), SEA

Regional Office.

Soerianegara, I., & Indrawan, A. (1998). *Ekologi hutan indonesia*. Bogor: Fakultas Kehutanan IPB.

[SRI] Soil Research Institute. (2009). *Technical manual: Chemical analysis of soil, plants, water and fertilizers* (2nd ed.). Bogor: Soil Research Institute, Ministry of Agriculture.

Stephenson, N., Das, A., Condit, R., Russo, S. E., Baker, P. J., Beckman, N. G., ..., & Zavala, M. A. (2014). Rate of tree carbon accumulation increases continuously with tree size. *Nature*, *507*, 90–93. https://doi.org/10.1038/nature12914

Tacconi, L., & Muttaqin, M. Z. (2019). Policy forum: Institutional architecture and activities to reduce emissions from forests in Indonesia. *Forest Policy and Economics*, *108*, 101980. https://doi.org/10.1016/j.forpol.2019.101980

Tiryana, T. (2016). Simulating harvest schedule for timber management and multipurpose management in teak plantations. *Jurnal Manajemen Hutan Tropika*, *22*(1), 1–12. https://doi.org/10.7226/jtfm.22.1.1

Trimanto, Hapsari, L., & Budiharta, S. (2021). Integrating indicators of natural regeneration, enrichment planting, above-ground carbon stock, micro-climate and soil to assess vegetation succession in post-mining reclamation in tropical forest. *Turkish Journal of Botany*, *45*, 457–467. https://doi.org/10.3906/bot-2103-35

Tsujino, R., Yumoto, T., Kitamura, S., Djamaluddin, I., & Darnaedi, D. (2016). History of forest loss and degradation in Indonesia. *Land Use Policy*, *57*, 335–347. https://doi.org/10.1016/j.landusepol.2016.05.034

Usaborisut, P., & Ampanmanee, J. (2015). Compaction properties of silty soils in relation to soil texture, moisture content and organic matter. *American Journal of Agricultural and Biological Sciences*, *10*, 178–185. https://doi.org/10.3844/ajabssp.2015.178.185

Villamor, G. B., Le, Q. B., Djanibekov, U., Van Noordwijk, M., & Vlek, P. L. G. (2014). Biodiversity in rubber agroforests, carbon emissions, and rural livelihoods: An agent-based model of land-use dynamics in lowland Sumatra. *Environmental Modelling and Software*, *61*, 151–165. https://doi.org/10.1016/j.envsoft.2014.07.013

Wells, J. A., Wilson, K. A., Abram, N. K., Nunn, M., Gaveau, D. L. A., Runting, R. K., ..., & Meijaard, E. (2016). Rising floodwaters: Mapping impacts and perceptions of flooding in Indonesian Borneo. *Environmental Research Letters*, *11*, 064016. https://doi.org/10.1088/1748-9326/11/6/064016

Willemen, L., Nangendo, G., Belnap, J., Bolashvili, N., Denboba, M. A., Douterlungne, D., ..., & Hahn, T. (2018). Decision support to address land degradation and support restoration of degraded land. In L. Montanarella, R. Scholes, & A. Brainich (Eds.), *The IPBES assessment report on land degradation and restoration* (pp. 591648). Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Retrieved from https://www.ipbes.net/assessment-reports/ldr

Wolff, F., & Klink, D. (2015). *The private sector, CSR and sustainable land use: Recent trends*. Berlin: Öko-Institut. Retrieved from https://www.ecologic.eu/sites/default/files/project/2021/%C3%96ko-Institut_GLOBALANDS_Private%20sector%20CSR%20and%20sust%20land%20use.pdf

Wotlolan, D. L, Lowry, J. H., Wales, N. A., & Glencross, K. (2021). Land suitability evaluation for multiple crop agroforestry planning using GIS and multi-criteria decision analysis: A case study in Fiji. *Agroforestry Systems*, *95*, 1519–1532. https://doi.org/10.1007/s10457-021-00661-3

Yulistyarini, T., Fiqa, A. P., & Laksono, R. A. (2016). Conservation area at Cirebon Quarry (Mt. Blindis) and its potency in carbon sequestration. *Jurnal Biologi Indonesia*, *12*, 49–55.

Zanne, A. E., Lopez-Gonzalez, G., Coomes, D. A., Ilic, J., Jansen, S., Lewis, S. L., & Chave, J. (2009). *Global wood density database*. Dryad Identifier. Retrieved from http://hdl.handle.net/10255/dryad.235

Ziadat, F., Zdruli, P., Christiansen, S., Caon, L., Monem, M. A., & Fetsi, T. (2022) An overview of land degradation and sustainable land management in the Near East and North Africa. *Sustainable Agriculture Research*, *11*, 1–11. https://doi.org/10.5539/sar.v11n1p11