THE INFLUENCE OF STAND DENSITY AND SPECIES DIVERSITY INTO TIMBER PRODUCTION AND CARBON STOCK IN COMMUNITY FOREST

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THE INFLUENCE OF STAND DENSITY AND SPECIES DIVERSITY INTO TIMBER PRODUCTION AND CARBON STOCK IN COMMUNITY FOREST. Stand density and species diversity are two indicators that are highly related to forest productivity. However, the effect of those variables on the productivity of community forest is rarely documented. This study evaluates the influence of stand density and species diversity on timber production and carbon stock in the community forest. The study area was located in Madiun District. A field survey was conducted in four different community forest sites, i.e. Morang, Kuwiran, Randualas, and Kare. The sampling technique was by quadrat method using a sample plot size of 25 m x 25 m. The number of sample plots used in this study was 64 units, which were evenly distributed in every site. Comparison of stand attributes among sites was examined by Kruskal-Wallis test and followed by Kruskal-Nemenyi test on the effects of stand density and species diversity on timber production and carbon stock were assessed separately for each parameter using the generalized least square regression test. The process of statistical analysis was applied using a significance level of 5%. Results show a significant difference in stand volume, aboveground biomass, and carbon stock among sites (P<0.05). This study also recorded a meaningful effect of stand density and species diversity on timber production and carbon stock of community forest, wherein stand density provided a higher effect ($R^2 = 0.68$; P<0.05) than species diversity ($R^2 = 0.26$; P<0.05).

Keywords: Community forest, carbon stock, stand density, species diversity, timber production

PENGARUH KERAPATAN TEGAKAN DAN KEANEKARAGAMAN JENIS TERHADAP PRODUKSI KAYU DAN SIMPANAN KARBON DI HUTAN RAKYAT. Kerapatan tegakan dan keanekaragaman jenis adalah dua indikator yang berkaitan erat dengan produktivitas hutan. Namun, pengaruh kedua variabel tersebut terhadap produktivitas hutan rakyat jarang didokumentasikan. Penelitian ini bertujuan untuk mengevaluasi pengaruh kepadatan tegakan dan diversitas jenis terhadap produksi kayu dan simpanan karbon di hutan rakyat. Lokasi penelitian terletak di Kabupaten Madiun. Survey lapangan dilakukan di empat lokasi hutan rakyat yang berbeda, yaitu Morang, Kuwiran, Randualas, dan Kare. Survey dilaksanakan dengan metode kuadrat menggunakan plot sampel 25 m x 25 m. Jumlah plot sampel yang digunakan dalam penelitian ini sekitar 64 unit yang tersebar merata di setiap lokasi. Perbandingan rerata karakteristik tegakan antar lokasi diuji dengan metode Kruskall-Wallis dan dilanjutkan dengan metode Kruskall-Nemenyi. Pengaruh kepadatan tegakan dan diversitas jenis terhadap produksi kayu dan simpanan karbon dievaluasi secara terpisah untuk setiap parameter menggunakan metode generalized least square regression. Pengujian statistik dilakukan dengan tingkat signifikansi 5%. Hasil penelitian menunjukkan terdapat perbedaan signifikan pada volume tegakan, biomassa permukaan, dan simpanan karbon antar lokasi (P<0,05). Penelitian ini juga menemukan adanya pengaruh penting kerapatan tegakan dan diversitas jenis terhadap produksi kayu dan simpanan karbon di hutan rakyat, dimana kepadatan tegakan memperlihatkan pengaruh yang lebih tinggi ($R^2 = 0,68$; P<0,05) dibandingkan diversitas jenis ($R^2 = 0,26$; P<0,05).

Kata kunci: Hutan rakyat, simpanan karbon, kepadatan tegakan, diversitas jenis, produksi kayu

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I. INTRODUCTION

Integration of industry development and climate change mitigation has become a fascinating challenge in sustainable forest management worldwide, particularly in tropical countries such as Vietnam, Malaysia, the Philippines, and Indonesia (Matsumoto, Oka, Mitsuda, Hashimoto, Kayo, Tsunetsugu, & Tonosaki, 2016). In this context, the existence of forests is expected to stabilize timber supply as raw materials for commercial industries and reduce greenhouse gas emissions into the atmosphere (Nunes, Meireles, Gomes, & Ribeiro, 2019). To realize those objectives, maximizing community forest management practice may provide an important contribution to ensure the stability of timber production and increase carbon stocks.

Several studies have documented the important role of community forest in maintaining industry's future viability and improving carbon sequestration (Sakurai, Rayamajhi, Pokharel, & Otsuka, 2004; Duguma et al., 2018; Luintel, Bluffstone, & Scheller, 2018; Poudyal, Maraseni, & Cockfield, 2020). A study recorded community forests, mainly in Java, supplies approximately 26% of timber demand for commercial industries such as construction, furniture, and plywood (Hakim, Dwiprabowo, & Effendi, 2009). This trend has been increasing rapidly since the declining productivity of state forests in the 1990s. The majority of Java industries nowadays highly depend on community forests for obtaining timber materials (Fujiwara, Awang, Widayanti, Septiana, Hyakumura, & Sato 2016). Furthermore, another study conducted in Madiun, East Java, reported that around 684.99 Mg CO_2 ha^{-1} had been absorbed by community forest per year (Setiahadi, 2017). These examples indicate the bargaining position of community forest to support the industry's sustainability and reduce emissions. However, community forest capability for timber production and carbon stock is affected by certain factors, like stand density and species diversity.

Many studies confirm that stand density and species diversity are two indicators of stand characteristics that strongly relate to timber production and carbon stock in the forest (Moore, Limited, Cown, Mckinley, & Sabatia, 2015; Uhl et al., 2015; Wegiel, Bembenek, Lacka, & Mederski, 2018). In general, stand density is defined as a degree of trees crowding per unit area, which is commonly determined based on the growth dimension or growing space ratio (Zeide, 2001; Lu, Zhang, Zhang, Duan, & Zhang, 2018; Padilla-Martínez, Corral-Rivas, Briseño-Reyes, Paul, López-Serrano, & Gadow, 2020).

Species diversity is the grade of biodiversity that is frequently assessed by considering individual members of species, population size, and species composition (Chen, 2006; Hu, Su, Li, Li, & Ke, 2015; Li, Su, Lang, Liu, & Ou, 2018). However, the relationship among stand density and species diversity with both parameters vary depending on the forest ecosystem type. A study conducted in a Korean pine forest (*Pinus koraensis*) located in China observed that higher stand density linearly increases timber production and carbon stock. The relationship between species diversity with both indicators creates hump-shaped curves (Cai, Di, Chang, & Jin, 2016). A study from the dry savannah forest in South-Eastern Tanzania reported that higher stand density and species diversity significantly improved timber production and carbon stock. Those variables have a linier relationship (McNicol, Ryan, Dexter, Ball, & Williams, 2018) Those explanations indicate that higher stand density and species diversity are not always followed by improved timber production and carbon stock.

This study investigates the effect of stand density and species diversity on timber production and carbon stock in the community forest. The research objects are focused on a type of community forest called *alas*, a kind of community forest located far from village settlement. It is hypothesized that the higher stand density and species diversity significantly increase timber production and carbon stock in

the community forest, wherein both parameters show the linear pattern.

II. MATERIAL AND METHOD

A. Study Site

This study was conducted in four different community forest sites located in Sub District Kare, Madiun. It consisted of several villages, i.e. Morang, Kuwiran, Randualas, and Kare (Setiahadi, 2017). The geographic position of the study site was at 7°41'1.42" to 7°45'31.14" S and 111°39'19.27" to 111°42'17.30" E (Figure 1). Topography was relatively gradient between 0–25%. Altitude varied from 100 to 500 m above sea level. The average daily temperature reached 29°C with a mean minimum of 25°C and a maximum of 35°C. Annual rainfall ranged from 1,554 to 1,754 mm yr^{-1} during the last ten years. Most of the rainfalls were recorded in December and January. The study sites had a dry period for almost five months, from July to October. Air humidity ranged from 70.5% to 85.6%. Soil types were dominated by alfisol. The details of soil properties in each site are presented in Table 1.

B. Methods

Data from Setiahadi (2017) were used to examine the effect of stand density and species diversity on timber production and carbon stock in the location. The data were collected using the quadrat method. The sample plot's shape was square with a size of approximately 25 m
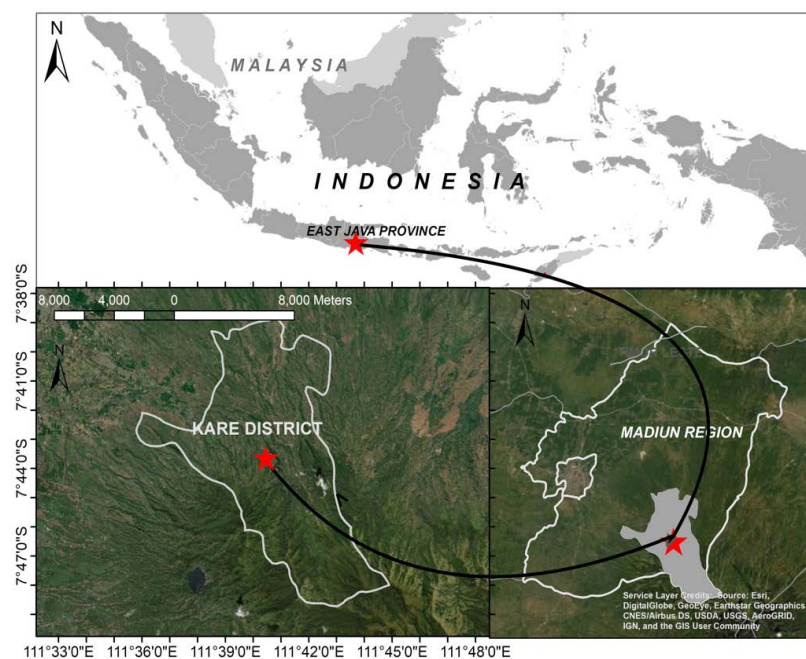

Figure 1. Study locations of community forests in Kare District

Table 1. Description of soil properties in four sites of community forests

Soil parameter	Site of community forest			
	Kuwiran	Morang	Randualas	Kare
Clay fraction (%)	39.00 ± 3.46	37.40 ± 3.13	36.80 ± 4.27	36.40 ± 2.88
Silt fraction (%)	24.60 ± 0.55	23.40 ± 0.55	27.00 ± 0.71	31.40 ± 0.89
Sand fraction (%)	36.20 ± 3.11	39.00 ± 2.74	36.40 ± 3.36	32.80 ± 1.92
Cation exchange capacity (cmolc kg^{-1})	15.00 ± 1.41	14.80 ± 1.64	14.40 ± 1.52	28.20 ± 2.28
Soil organic matter (%)	17.20 ± 7.82	14.00 ± 7.58	17.60 ± 9.66	23.60 ± 11.24
Soil acidity	5.46 ± 0.13	5.46 ± 0.13	5.36 ± 0.09	5.26 ± 0.09

x 25 m (Setiahadi, 2017). Sixteen observation plots have been established in every community forest; each site had a total sampling area of about 1 ha. The total measured plots used in this study were 64 units. Several parameters of individual trees were measured in each sample plot, including species, tree diameter (*d*), tree height (*h*), and tree volume (*v*). Tree diameter was measured using a phi band at 1.3 m from the aboveground, while tree height was estimated from above ground to top of the crown using a Haga altimeter. Then, individual tree volume was calculated by the following equation:

$$v = 0.25\pi \, d^2 \, h \, f \qquad \text{.................................(1)}$$

Where *f* was a constant form factor (0.6) for tropical tree species (Akossou, Arzouma, Attakpa, Fonton, & Kokou, 2013), to convert individual tree volume into tree biomass (B), the value of individual tree volume would be multiplied by the specific wood density (WD) and the biomass expansion factor (BEF) (Krisnawati, Imanuddin, & Adinugroho 2012). The detailed information about WD and BEF are presented in Table 2. Then, the tree biomass results were used to estimate carbon storage in every tree species (C) since approximately 50% of biomass is composed of carbon (Wirabuana et al., 2019). The detailed equations were:

$$B = V * WD * BEF \qquad \text{...........................(2)}$$
$$C = 0.5 * B \qquad \text{.......................................(3)}$$

The results of tree measurements would be used to compute several stand characteristics, including quadratic mean diameter (D), mean height (H), stand volume (V), species diversity, stand density, aboveground biomass (AGB), and carbon stock (CS). The value of stand volume was determined as the sum of tree volumes in each sample plot, converted to hectare unit. A similar approach was also used to estimate AGB and CS at stand level. The stand volume parameter was frequently selected as an indicator for the forest ecosystem's capability for timber production (Merganič, Marušák, Merganičová, Stolariková, & Tipmann, 2013; Irauschek, Rammer, & Lexer, 2017).

To describe the degree of species diversity in the community forest, we selected three important variables, i.e. species richness, heterogeneity, and evenness. Species richness was calculated by Margalef Index (R1), while heterogeneity of species was estimated by Shannon-Wienner Index (H'). Then, species evenness was assessed using the Pielou-Evenness Index (J). The detailed equations for calculating those parameters were (Li, Su, Zhang, Zhou, Xie, Shi, & Gou, 2018):

$$R1 = S-1/\ln(N) \qquad \text{...................................(4)}$$
$$H' = -\sum (ni/N) (\ln ni/N) \qquad \text{...............................(5)}$$
$$J = H'/\ln(S) \qquad \text{.......................................(6)}$$

where S was the number of species, N represented total tree population, and ni described the sum of trees for each species.

To estimate stand density in the community forest, we adopted Reineke's Stand Density Index (SDI) concept using a modification developed by Sadono and Umroni (2012). Referring to the concept, the value of SDI could be determined by considering the relationship between the number of trees (N) and quadratic mean diameter (D). The specific formula for calculating SDI (Sadono & Umroni, 2012) is presented below.

$$SDI = N (20/D)^{-1.153} \qquad \text{...(7)}$$

Statistical analysis was processed using

Table 2. Specific wood density and biomass expansion factor for four species in community forests

No.	Species	WD (kg m^{-3})	BEF
1.	*Tectona grandis*	612.7	1.46
2.	*Swietenia macrophylla*	533.4	1.36
3.	*Acacia auriculiformis*	581	1.33
4.	*Falcataria mollucana*	310.6	1.34

Source: Krisnawati et al. (2012)

software R version 3.6.1 with a significance level of 5%. We selected the package agricolae to conduct data analysis. Descriptive analysis was done to identify the range of data distribution, comprising minimum, maximum, mean, standard deviation, and variation coefficient. Outlier test was detected using the box plot method. The Shapiro-Wilk test evaluated the normality of data. The Fligner-Killen test examined the homogeneity of variance among sites of community forest. Comparing stand attributes among observation sites was analyzed separately for each variable using Kruskal-Wallis, followed by Kruskall-Nemenyi (Tenzin & Hasenauer, 2016). Afterwards, the influence of stand density and species diversity on timber production and carbon stock in the community forest was assessed for every parameter using the general least square regression with the maximum likelihood method (Cai, Di, Chang, & Jin, 2016). The linear model pattern was used to evaluate the effect of stand density and species diversity on timber production and carbon stock.

III. RESULT AND DISCUSSION

A. Species Composition

Summarized results of the observation showed four species commonly planted in the study area, namely *Tectona grandis*, *Swietenia macrophylla*, *Acacia auriculiformis*, and *Falcataria mollucana* (Table 3). Among those species, it was documented that *T. grandis* became the most dominant species in every community forest site. Compared to others, this species had an abundance relative more than 80% in each site. The second position was occupied by *S. macrophylla* followed by *F. mollucana* in the third

rank. Meanwhile, *A. auriculiformis* had the lowest population. The study recorded that the number of species in the Kuwiran site was lower than in the other three sites because it only had three species..

T. grandis dominated the land cover of community forest in the study area because societies in each village have widely planted it. Besides having a high price, the market availability of this species was also accessible. The history of community forest management also supported this fact in the study area wherein *T. grandis* was the first plantation species introduced to societies since the sites were located close to the state forest, managed by Perum Perhutani (Setiahadi, 2017). However, *T. grandis* required a long growing period to obtain the yield; thus, most villagers also planted other species that had faster growth than *T. grandis*, like *S. macrophylla*, *F. mollucana*, and *A. auriculiformis*. Thereby, most community forests in the study area comprised mixed-stand, which had high variation in growth and age distribution.

B. Stand Characteristics

Stand characteristics in each site varied and demonstrated fascinating trends (Table 4). Referring to the statistical analysis outcome, there was no significant difference in quadratic mean diameter, mean height, and stand density indexes among sites of community forests (P>0.05). Similar results were also documented in species diversity parameters, including richness, heterogeneity, and evenness (P>0.05). In contrast, different outputs were observed in stand volume, aboveground biomass, and carbon stock, in which those parameters differed significantly among sites (P<0.05).

Our study observed the highest timber

Table 3. Species composition in each site of community forest based on the relative abundance of species

No.	Species	Composition (%)			
		Kuwiran	Morang	Randualas	Kare
1.	*Tectona grandis*	88.94	80.28	83.48	83.78
2.	*Swietenia macrophylla*	8.26	16.92	14.42	13.72
3.	*Acacia auriculiformis*	2.80	0.64	0.44	0.64
4.	*Falcataria mollucana*	-	2.16	1.66	1.86

Table 4. Comparison of stand attributes in each site of community forest, covering quadratic mean diameter (D), average height (H), stand volume (V), aboveground biomass (AGB), carbon stock (CS), richness (R1), heterogeneity (H'), evenness (J), and stand density (SDI)

Observation variable	Site of community forest				p-value
	Kuwiran	Morang	Randualas	Kare	
D (cm)	13.31 ± 1.77 a	13.67 ± 1.29 a	13.57 ± 1.22 a	13.08 ± 1.71 a	0.687^{ns}
H (m)	13.08 ± 1.78 a	13.89 ± 0.83 a	13.88 ± 0.83 a	12.90 ± 1.61 a	0.574^{ns}
V (m^3 ha^{-1})	96.81 ± 32.54 a	171.02 ± 51.69 a	170.20 ± 51.59 a	98.87 ± 35.89 c	0.001^*
AGB (Mg ha^{-1})	86.03 ± 13.27 a	126.70 ± 20.16 b	116.38 ± 20.12 b	73.31 ± 18.57 c	0.001^*
CS (Mg ha^{-1})	43.23 ± 6.64 a	73.35 ± 10.08 b	69.19 ± 10.06 b	41.65 ± 9.29 c	0.001^*
R1	0.28 ± 0.08 a	0.33 ± 0.12 a	0.33 ± 0.10 a	0.29 ± 0.09 a	0.987^{ns}
H'	0.29 ± 0.09 a	0.45 ± 0.17 a	0.49 ± 0.17 a	0.33 ± 0.12 a	0.179^{ns}
J	0.32 ± 0.11 a	0.58 ± 0.20 a	0.63 ± 0.18 a	0.31 ± 0.11 a	0.172^{ns}
SDI	416 ± 146 a	500 ± 139 a	503 ± 138 a	426 ± 144 a	0.200^{ns}

Remarks: *indicated a significant difference at α 5%, ^{ns} showed non-significant difference at α 5%, the similar letter in a row showed non-significant difference among sites

production and carbon stock of community forest in Morang, followed by Randualas in the second position and Kare in the third place. The lowest rank was noted in Kuwiran. The growth performance of the community forest in Morang was higher than in the other sites because its stand had greater dimensions. The bigger quadratic mean diameter, average height, and stand density, respectively, could be indicated, even though those parameters did not present significant differences. Many kinds of literature explained that greater stand dimension growth increases its timber production and carbon stock because the quantity of tree volume has increased (Gevaña, Camacho, & Camacho, 2017; Lu et al., 2018; Padilla-Martínez et al., 2020). According to the results, it was shown clearly that the degree of timber production and carbon stock in Morang was higher by approximately 43.58% and 22.43% than Kuwiran and Kare, respectively.

Compared to other sites, the existence of community forest in Randualas indicated the greatest species diversity, particularly related to heterogeneity and evenness (Table 4). Statistically, it also had an equal stand density, timber production, and carbon stock to Morang. Based on these findings, community forest capability for timber production and carbon stock in the study area could be classified into two groups, i.e. low class (Kuwiran and Kare) and high class (Randualas and Morang).

Reviewed from the diversity of species, most community forest in the study area had low diversity based on the range value of richness, heterogeneity, and evenness (Table 4). It was caused by the low number of species and their population in each location. The majority of tree species in every site was dominated by *T. grandis* (Table 3). Although it consisted of multi-species, the community forest was principally a type of forest ecosystem commonly established by villagers. In this case, the use of silvicultural prescription was relatively limited and conducted depending on the community's preference. Interestingly, most of the communities preferred to grow trees that potentially provided financial benefit. Therefore, community forest stand attributes, especially for tree diversity, situated in a transition phase between monoculture plantation and natural forest (Filqisthi & Kaswanto, 2017).

C. Effect of Stand Density and Species Diversity on Timber Production and Carbon Stock

Stand density and species diversity significantly affected timber production and carbon stock in community forest (P<0.05) (Table 5). Unfortunately, the meaningful effect

Table 5. Results of the best-fit generalized least square regression for exploring the effect of stand density and species diversity on timber production and carbon stock in community forest

Response variable	Predictor variable	R^2	Estimate	SE	t Stat	P-value
Timber production	Stand density (SDI)	0.681	0.262	0.023	11.500	<0.001*
	Richness (R1)	0.031	60.863	51.884	1.173	0.247ns
	Heterogeneity (H')	0.268	106.861	24.428	4.374	<0.001*
	Evenness (J)	0.128	35.162	14.020	2.508	0.056ns
Carbon storage	Stand density (SDI)	0.676	0.109	0.010	11.282	<0.001*
	Richness (R1)	0.025	22.963	21.911	1.048	0.300ns
	Heterogeneity (H')	0.266	41.785	10.593	3.944	<0.001*
	Evenness (J)	0.104	13.334	5.983	2.229	0.051ns

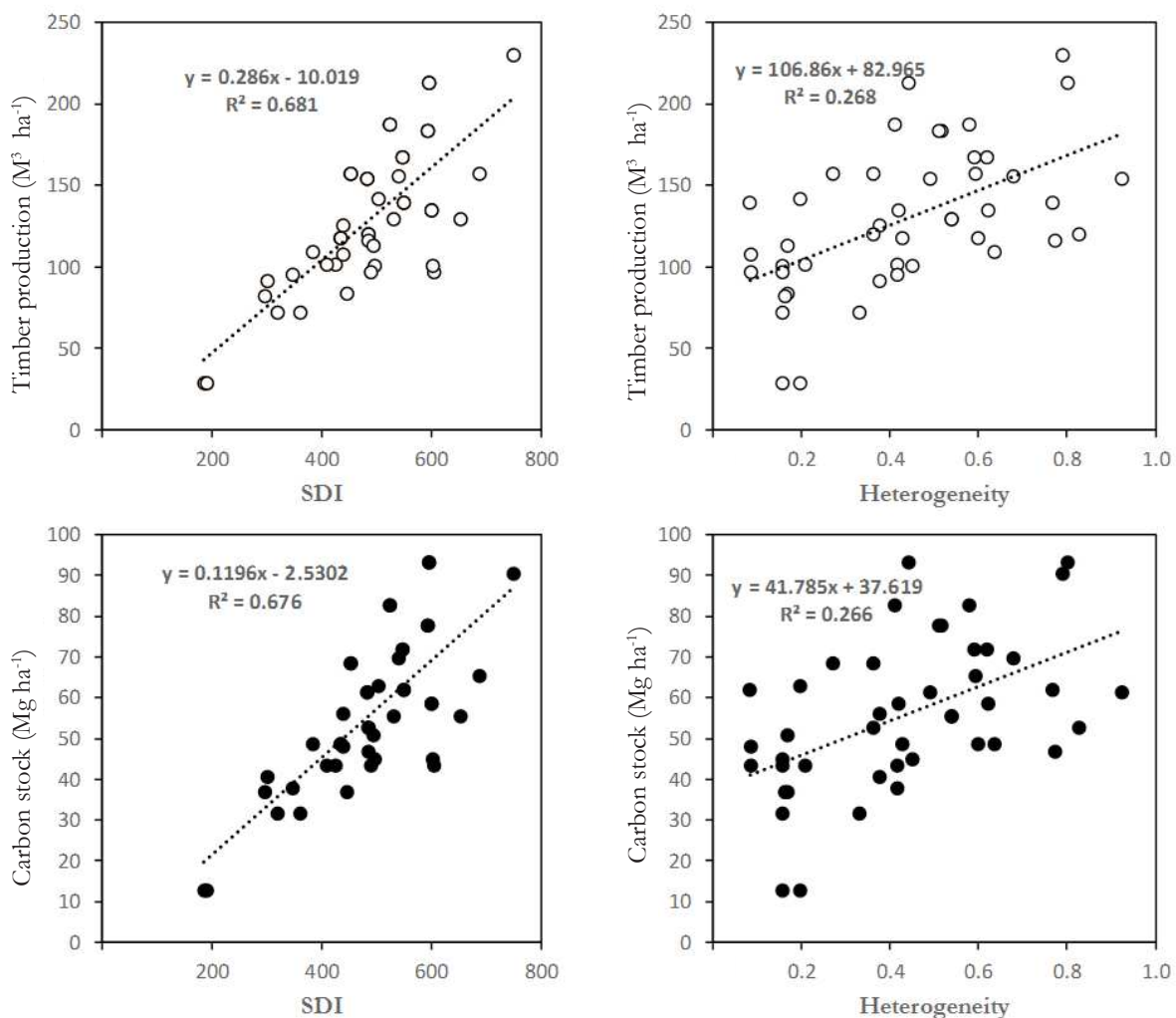Remarks: *indicated a significant difference at α 5%, ns showed non-significant difference at α 5%

Figure 2. Relationship among stand density and species diversity with timber production and carbon stock of community forest in Madiun

of species diversity on both parameters was only demonstrated by heterogeneity (P<0.05). This study shows that there was no essential influence of richness and evenness on timber production and carbon stock in community forest (P>0.05). The majority of community forests had similar species composition in which *T. grandis* was the most dominant species in these areas (Table 3). These findings were considerably different from the study published by Filqisthi and Kaswanto (2017), who reported that there was no significant effect of species diversity on stand attributes of community forests in West Java, mainly related to timber production and carbon stock. The results are also different with the study conducted by Cai et al. (2016) in China, who documented a high effect of richness on carbon storage in the Korean pine forest (*P. koraensis*). Nevertheless, this study reported a similar result to an observation undertaken by McNicol et al. (2018) in South-Eastern Tanzania, who noted a substantial influence of stand density and species diversity on timber production and carbon stock in dry savannah forest. Those comparisons strongly indicated that every type of forest would demonstrate the different relationship among stand density and species diversity with timber production and carbon stock, including community forest.

Our study observed a linear relationship among stand density and species diversity with timber production and community forest carbon stock. The greater stand density and species diversity increased timber production and carbon stock (Figure 2). This was similar to a study conducted by Gevaña et al. (2017) in the Philippines, who reported a linear relationship among stand density and species diversity with stand attributes in mangroves, like timber volume and carbon stock. In addition, it was recorded wherein stand density provided a higher effect (R^2=0.68) than species diversity (R^2=0.26) on the productivity of community forest (Table 5). This trend could have occurred since stand density was one of the stand parameters that described a degree of tree

crowding per unit area (Zeide, 2001). Higher stand density indicated a greater number of trees and bigger growth dimension because this parameter was determined by considering several growth attributes, such as number of trees, spacing, mean height, quadratic mean diameter, crown projection area, and crown diameter (Lu et al., 2018).

IV. CONCLUSION

Our study concluded that stand density and species diversity significantly affect timber production and carbon stock of community forest, wherein stand density provided greater influence than species diversity on both parameters. The meaningful effect of species diversity was only demonstrated by the heterogeneity aspect while there was not an important influence of richness and evenness on timber production and carbon stock of community forest.

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