Estimation of aboveground biomass and carbon stock in a pine-mahogany mixture stands at specific purpose forest area of Gunung Bromo, Karanganyar

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Abstract. Forest plays an important role on reducing the impact of global warming as carbon sink. Forest has an ability to absorb carbon on large scale and store it as biomass. This research was aim to determine the potential of aboveground biomass and carbon stock in pine-mahogany mixture stands in Specific Purpose Forest Area (SPFA) of Gunung Bromo. The systematic sampling with random start was used to determine the plot, and the distance between plots were 100 m. In total, there were 35 square plots, 20 × 20 m in size, that had been set up under the pine-mahogany mixture stands. This research was conducted by using non-destructive sampling method by measuring the tree volume. The pine-mahogany stands dominated by the trees with diameter class 20-30 cm. The tree density and stand volume were 431 trees/ha and 229.4 m³/ha. Estimated aboveground biomass, carbon stock, and CO₂ equivalent in pine stands were 136.53 ton/ha, 64.17 ton C/ha, and 235.29 ton/ha, while for mahogany stands were 33.01 ton/ha, 15.56 ton C/ha, and 57.04 ton/ha, respectively. Thus, the total biomass and carbon stock in pine-mahogany mixture stands were 169.63 ton/ha and 79.73 ton C/ha. Meanwhile, total CO₂-equivalent was 292.23 ton/ha.

1. Introduction
The increasing of greenhouse gases concentration in atmosphere causes global warming. Carbon dioxide (CO₂) is the largest greenhouse gas that reaches 77% of total concentration GHG (Green House Gasses) emission in the atmosphere [1]. World Business Council for Sustainable Development Forests (WBCSDF) stated that forest have an ability to reduce emissions up to 37% by 2030 and to keep the increasing of global temperature below 2°C [2]. The potential for carbon sequestration by forest can increase the role of forest in addressing global warming. Forest absorbs the atmospheric carbon (CO₂) through photosynthesis and stores it as plant biomass [3]. FAO [4] stated that worldwide average biomass from forest plantation was 109 ton/ha. Furthermore, Dixon et al [5] and Clark et al [6] reported that tropical forest stored 40% of terrestrial carbon total on earth.

Estimation of aboveground biomass is an important aspect of understanding the function of forest ecosystem as carbon sink [7]. The quantity of aboveground biomass was determined by the amount of carbon that absorbed by forests [8]. In addition, it also can be used to determine the role of forest ecosystems in wide range environmental condition [9].
Specific Purpose Forest Area (SPFA) of Gunung Bromo was an educational forest that managed by Universitas Sebela Maret. Pinus merkusii (pine) and Swietenia macrophylla (mahogany) were dominant tree species in this forest. Pine and mahogany planted in mixture stands. Pine and mahogany are commercial tree species that mainly planted to produce resin and wood for furniture. Instead of considering by its economic values only, those trees also have ecological function to absorb carbon from the atmosphere and reduce impact of global warming. Fauzi et al. [10] reported that carbon stock for pine stands was 161.38 ton C/ha. In addition, Sakuntaladewi et al. [11] showed that carbon stock for mahogany stands was 128.87 ton C/ha. However, biomass and carbon stock of pine-mahogany mixture stands at SPFA Gunung Bromo have not studied yet. Therefore, it was necessary to calculate aboveground biomass and carbon stock of pine-mahogany mixture stands at SPFA of Gunung Bromo. In addition, it was important to understand stands productivity and contribution of forest to reduce global warming.

This research was aimed to determine the potential of aboveground biomass and carbon stock in pine-mahogany mixture stands at SPFA of Gunung Bromo. In the present study, to estimate aboveground biomass, non-destructive sampling method was used. Tree height and diameter at breast height were measured to estimate tree volume. Furthermore, aboveground biomass and carbon stock were determined. This method was referred to the guideline of Kementerian Kehutanan [12] and the previous researches that have been reported by Rahman et al. [13], Malhi et al. [14], Khan et al. [15]. Furthermore, the CO₂ equivalent was also determined.

2. Materials and methods

2.1. Description of the study site

The study was conducted on the mixed stands of pine (Pinus merkusii) and mahogany (Swietenia macrophylla) that located on the SPFA of Gunung Bromo, Karanganyar, Central Java. (7°34’56”S 110°59’26”E - 7°35’38”S 111°00’49”E, 244-362 m in altitude) (figure 1). SPFA of Gunung Bromo occupied 128.5 ha forest area that mainly dominated by pines. Pine-mahogany mixture stands were planted in the range of 1991-2007.

![Figure 1. Map showing the study site at SPFA of Gunung Bromo, Kabupaten Karanganyar, Central Java](image)

The average of air temperature, humidity, and light intensity at SPFA of Gunung Bromo were 31.8°C, 71.24% and 814 Cd, respectively. Meanwhile, the average annual rainfall was about 1966 mm/year. According to Schmidt and Ferguson [16], SPFA of Gunung Bromo was classified as type C.
Q value (average dry-wet month ratio) were 37.5% with 8 wet months, 3 dry months, and 1 humid month. In addition, the soil temperature, humidity, and pH were 26.8-30.9 °C, 1.4-7.5%, and 6.4-6.9, respectively.

2.2. Design of experiment
Field experiment was conducted on May 2019. The systematic sampling with random start was used to determine the plot. The distance between plots were 100 m. In total, there were 35 square plots, 20 × 20 m in size, had been set up under the pine-mahogany mixture stands (figure 1). This research was conducted by using non-destructive sampling method. In each sample plot, the diameter breast height (stem diameter at 1.3 m height) of all trees, with a diameter ≥10 cm, were measured. Furthermore, the tree diameter was classified by 10 cm interval. Those, the five class diameters were obtained for pine and mahogany in this study. In addition, all the total tree height (H) on those plots was also measured by hagameter.

2.3. Data analysis
The collected data were processed by Microsoft Excel spread sheet by submit the data into aboveground biomass and carbon stock conversion formula.

2.3.1. Stands density and volume. Stands density were determined by following formula [17-19]:

\[
\text{Stands density (trees/ha)} = \frac{\text{Total individu of species}}{\text{Plot area}}
\]

Furthermore, the tree volume were calculated by following formula:

\[
\text{Tree volume (m}^3\text{)} = 0.25\pi \times DBH^2 \times H \times f
\]

DBH, diameter breast height (m); H, tree height (m); f, correction factor 0.6 [12, 20].

2.3.2. Biomass. The biomass of pine and mahogany trees were calculated according to biomass measurement guidelines from Kementerian Kehutanan [12]. The aboveground biomass (AGB) for each tree were estimated by following formula:

\[
\text{AGB} = V \times WD \times BEF
\]

V, tree volume (m^3); WD, wood density (kg/m^3); BEF, biomass expansion factor. Wood density for pine and mahogany were 0.55 and 0.61 [21, 22] while BEF for pine and mahogany were 1.31 and 1.36 [12]. Furthermore, AGB for stand were also calculated.

2.3.3. Carbon stock. The amount of stored carbon was determined at 47% of tree biomass [23], [24]. Carbon stock of each tree was estimated by following formula:

\[
\text{Carbon stock (kg)} = \text{Biomass (kg)} \times C-\text{Organic}
\]

2.3.4. Carbon dioxide equivalent (CO2-equivalent). CO2-equivalent were calculated by using ratio of C relative atomic mass (12) and CO2 relative molecule (44) as described by Kementerian Kehutanan [12] and Racelis et al. [25] by following formula:

\[
\text{CO2-equivalent (ton/ha)} = \frac{44}{12} \times \text{carbon stock (ton/ha)}
\]

3. Results and discussion

3.1. Stands density and volume
Figure 2 shows the diameter class distribution of pine and mahogany trees at SPFA of Gunung Bromo. This figure explains the horizontal structure of pine and mahogany mixture stands at SPFA of Gunung
Bromo. The tree diameter was classified into five classes, namely 10-20, 20-30, 30-40, 40-50, and >50 cm. Based on tree diameter class, pine and mahogany trees that categorized as pole (DBH 10-20 cm) was 17.6 and 28.2% from the total tree number per ha, indicating that those trees might be the latest trees that planted at 2007 by Perum Perhutani as the previous administrator of Gunung Bromo forest.

Furthermore, the tree diameter, for both tree species, was mainly dominated by the trees with diameter range of 20-30 cm (Figure 2). These conditions indicate that the stands of pine and mahogany was even-aged, thus the tree growth might be similar. The obtained results in the present study were in concurring with our previous report [26]. Thus, the vegetation distribution of pine-mahogany mixed stands in SPFA of Gunung Bromo was in normal condition based on its stem diameter.

Figure 2 also clearly shows that the tree number was decreasing by increasing diameter class. It was hard to find large diameter trees in SPFA of Gunung Bromo. Based on the obtained result in the present study, in one ha only one tree that belongs to diameter class >50 cm (Figure 2). Thus, it was considered that might be those trees were intentionally left behind during clear cutting in the past by the previous administrator (Perum Perhutani).

The density of pine and mahogany were 346 and 85 trees/ha (Figure 2). Therefore, total density for pine-mahogany mixture stands were 431 trees/ha. Kusmana and Susanti [27] reported the stands density of pine trees in the natural forest at Hutan Pendidikan Gunung Walat (HPGW, Gunung Walat Educational Forest) was 44 trees/ha. By comparing the stands density of pine stand at SPFA of Gunung Bromo and HPGW, it was clear that the pine density at SPFA of Gunung Bromo was denser. Thus, it was considered that the biomass of pine at SPFA Gunung Bromo was higher than those in the natural pine stands at HPGW.

Figure 2. Diameter class distribution of pine and mahogany trees

Figure 3 shows stands volume of pine and mahogany at SPFA of Gunung Bromo. The highest stands volume was obtained from the diameter class of 30-40 cm for pine and mahogany, which were 84.45 and 16.08 m³/ha (Figure 3). Thus, it was in concurring to the data of aboveground biomass in Table 1, the highest biomass was obtained from the tree diameter class of 30-40 cm. In the present study, even though the stands density of diameter class 30-40 cm was lower than those in diameter class 20-30 (Figure 1), the total stands volume was higher, indicating that larger tree diameter was correspond to the higher values of tree biomass.
3.2. Aboveground biomass

Table 1 shows the mean values of aboveground biomass, carbon stock, and CO$_2$-equivalent of pine and mahogany at SPFA of Gunung Bromo. In total, aboveground biomass for pine-mahogany mixture stands was 169.63 ton/ha (Table 1). The highest aboveground biomass value was obtained from diameter class 30-40 cm for pine, 60.85 ton/ha, indicating that this tree diameter was dominant at SPFA of Gunung Bromo. On the other hand, the lowest biomass was obtained from diameter class >50 cm for mahogany, 1.94 ton/ha, indicating that the number of mahogany trees that reach diameter >50 cm was rare. It was in concord with data that presented on the figure 2.

In the present study, the trees were planted in the range of 1991-2007. Thus, the pine trees were estimated 13-29 year-old when this research was conducted. Aboveground biomass for the pine trees that belongs to diameter class 20-30 cm was 48.79 ton/ha (Table 1). The obtained results for aboveground biomass in class diameter 20-30 cm was lower compared to Saharjo and Wardhana [28] report. They reported that aboveground biomass for 15- and 16-year-old (mean diameter: 22 and 21 cm) pine trees were 90.79 and 76.46 ton/ha. Total aboveground biomass for pine was 136.53 ton/ha (Table 1). This value was lower compared to aboveground biomass of pine stands that reported by several researchers [29], [30], [31], [32]. Polosakan et al. [29] reported that the biomass for pine stands at 17- and 30-year-old planted in Gunung Bunder was 188.35 and 203.7 m$^3$/ha. In addition, Ahmad et al. [30] reported that the biomass for pine (P. merkusii stain Tapanuli), in the range diameter of 12-120 cm, in its natural habitat was 173.54 ton/ha. Biomass for pine stands at Hutan Pendidikan Gunung Walat (HPGW) Bogor was 141.79 ton/ha [31]. Ijazah and Sancayaningsih [32] reported the biomass for 30-year-old pine stands at Hutan Lindung Mangunan, Dlingo, Bantul 884.62 was ton/ha.

For mahogany, the total aboveground biomass was 33.10 ton/ha (Table 1). Purwanto et al. [33] reported that the biomass for mahogany in community forest in Nglanggeran village was 23.12 ton/ha. Racelis et al. [25] reported the aboveground biomass for mahogany plantations, 25 cm in average diameter, in Philippines was 902.20 ton/ha. Based on the obtained results, aboveground biomass of pine and mahogany stands at SPFA of Gunung Bromo was lower compared to other locations.
Table 1. Mean values of aboveground biomass, carbon stock, and CO$_2$-equivalent of pine and mahogany at SPFA of Gunung Bromo

| Species     | Diameter Class (cm) | Total      |
|-------------|---------------------|------------|
|             | 10-20 | 20-30 | 30-40 | 40-50 | >50  |          |
| Above-ground biomass (ton/ha) |       |       |       |       |       |          |
| Pine        |       |       |       |       |       | 136.53   |
| Mahogany    | 7.17  | 48.79 | 60.85 | 17.41 | 2.32  | 169.63   |
| Total       |       |       |       |       |       | 169.63   |
| Carbon stock (ton C/ha) |       |       |       |       |       |          |
| Pine        | 3.37  | 22.93 | 28.60 | 8.18  | 1.09  | 64.17    |
| Mahogany    | 1.37  | 5.47  | 6.27  | 1.54  | 0.91  | 15.56    |
| Total       | 4.74  | 28.40 | 34.87 | 9.72  | 1.99  | 80.47    |
| CO$_2$-equivalent (ton/ha) |       |       |       |       |       |          |
| Pine        | 12.36 | 84.09 | 104.86| 30.00 | 3.99  | 235.29   |
| Mahogany    | 5.02  | 20.05 | 22.99 | 5.64  | 3.34  | 57.04    |
| Total       | 17.38 | 104.14| 127.85| 35.64 | 7.33  | 292.33   |

Figure 4 shows the relationship between tree diameters and estimated aboveground biomass in pine and mahogany. Based on the Figure 4, the increasing stem diameter was followed by the increasing amount of biomass. The tree diameter had strong positive correlation to its biomass [34], [35], [36]. Kwatrina et al. [34] reported that in *Eucalyptus grandis*, the stem diameter showed strong correlation to biomass ($r = 0.836$) and C storage ($r = 0.825$). In addition, the tree diameter increases with age. Thus, it was considered that an old trees stored more carbon than young trees [36], [37], [38].

Figure 4. Relationship between tree diameters and estimated aboveground biomass in (a) pine and (b) mahogany

3.3. Carbon stock

The stands biomass has strong correlation to the potential stored carbon. Several researchers have reported that tree diameter, stands density, and tree species diversity correlated to the increasing of stored carbon trough increasing tree biomass [37], [39], [40], [41]. Figure 5 shows relationship between stands density and stored carbon in pine and mahogany. Based on those figure, it was clear that the tree diameter giving the most significant effect on the value of stored carbon rather than stands density. The highest stored carbon was obtained from diameter class 30-40 cm. This results was in accordance to the data that showed in Figure 3, the highest values of biomass was obtained from diameter class 30-40 cm. Therefore, it was considered that the estimation of stands potency as carbon
storage can be predicted from it’s stands biomass. Brown [42] reported that 50% of forest biomass was carbon. Thus, the amount of potential carbon storage will increase as increasing on biomass.

| Diameter class (cm) | Pine-Stand density | Mahogany-Stand density | Pine-Carbon stock | Mahogany-Carbon stock |
|---------------------|--------------------|------------------------|-------------------|-----------------------|
| 10-20               |                    |                        |                   |                       |
| 20-30               |                    |                        |                   |                       |
| 30-40               |                    |                        |                   |                       |
| 40-50               |                    |                        |                   |                       |
| >50                 |                    |                        |                   |                       |

**Figure 5.** Relationship between stands density and stored carbon in pine and mahogany

Total carbon stock for pine stands was 64.17 ton C/ha (Table 1). Polosakan et al. [29] have been reported that carbon stock for 17- and 30-year-old pine stands were 86.8 and 96.5 ton C/ha. In addition, Indrajaya [43] have been reported the carbon stock for pine trees in several ages. He mentioned that the carbon stock for 10- and 30-year-old pine trees were 51-81 and 147-221 ton C/ha. Saharjo and Wardhana [28] also reported carbon stock for 15- and 16-year-old pine stands at KPH Cianjur were 50.09 and 43.40 ton C/ha. Furthermore, Ijazah and Sancayaningsih [32] also reported carbon stock for 30-year-old pine stands at Mangunan-Bantul was 442.31 ton C/ha. The carbon stock value for pine stands obtained in the present study was lower than those reported by Polosakan et al. [29], Indrajaya [43], Ijazah and Sancayaningsih [32] but higher than Saharjo and Wardhana [28].

For mahogany, the value for carbon stock was 15.56 ton C/ha (Table 1). Indrajaya [43] reported that the average carbon stored in mahogany was 82, 97, and 51 ton C/ha for 46, 34, and 23 years rotation, respectively. Racelis et al. [25] have been reported that the carbon stock for mahogany stands in plantation forest with 25 cm in diameter was 375.32 ton C/ha. Khan et al. [15] also reported that aboveground carbon stock in mahogany plantations in Bangladesh was 34.4 ton C/ha. In addition, Purwanto et al. [33] also reported carbon stock for mahogany with average diameter 18.4 cm was 11.56 ton C/ha. The carbon stock value for mahogany stands obtained in the present study was lower than those reported by Indrajaya [43], Racelis et al. [25] and Khan et al. [15] but higher than Purwanto et al [33].

In total, pine-mahogany carbon stock was 79.73 ton C/ha (Table 1). Heriyanto et al. [44] reported the total carbon stock of 5-year-old pine and 9-year-old mahogany stands at BKPH Manglayang Barat West Java was 40.86 ton C/ha. In addition, the information on the carbon stock in the mixture stands of pine-puspa and mahogany-puspa at HPGW were 113.87 and 65.52 ton/ha [45]. Total carbon stock of pine-mahogany stands in SPFA of Gunung Bromo was higher than Heriyanto [44].

3.4. CO2-equivalent

CO2 uptake by vegetation depends on the photosynthesis and respiration. In general, vegetation absorbs CO2 and produces O2 in photosynthesis. On the other hand, respiration was totally opposite
process. Vegetation can be told as carbon absorber, if the total amount of CO$_2$ absorbed during photosynthesis was higher rather than CO$_2$ released during respiration.

Table 1 also shows total CO$_2$-equivalent for pine and mahogany stands. CO$_2$-equivalent were 235.29 and 57.04 ton/ha for pine and mahogany stands. Polosakan et al. [29] reported CO$_2$ sequestration for 17- and 30-year-old pine trees were 318.5 and 354.2 ton/ha. Furthermore, Indrajaya [43] also reported CO$_2$ sequestration on the 10- and 30-year-old Shorea sp. plantations have an ability to absorb CO$_2$ 28.01, 172.83, and 274.86 ton/ha, respectively. Rahayu et al. [47] reported that the average of CO$_2$ sequestration of E. pellita were 254.669 ton/ha, while in teak (Tectona grandis) were 207.8 ton/ha [48]. Thus, it was considered that the CO$_2$-equivalent were varied for each tree species, age, and diameter.

4. Conclusion

The trees with diameter class 20-30 cm dominated the pine-mahogany stands at SPFA of Gunung Bromo. The tree density and volume for pine-mahogany mixture stands at SPFA of Gunung Bromo were 431 trees/ha and 229.4 m$^3$/ha. Estimated aboveground biomass, carbon stock, and CO$_2$ equivalent in pine stands were 136.53 ton/ha, 64.17 ton C/ha, and 235.29 ton/ha, while for mahogany stands were 33.01 ton/ha, 15.56 ton C/ha, and 15.56 ton C/ha, respectively. The tree diameter had strong positive correlation to its aboveground biomass and carbon stock for both tree species. Furthermore, CO$_2$ equivalent were varied for each tree species, age, and diameter.

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