Carbon stocks of Petungkriyono mixed forest as climate change mitigation

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Abstract. The Petungkriyono forest covers 53.88 km² at Pekalongan Regency with 54.6% composition of mixed forest (29.43 km²). This study aimed to estimate above-ground biomass and carbon stocks from five villages; Tlogopakis, Tlogohendro, Kayupuring, Yosorejo and Kasimpar. Non-destructive samples of 30 plots were conducted by designing plots with 0.04 ha and stand inventory involving diameter at breast height, height and number of trees. The result showed that the total estimated biomass from five villages was 3,006.10 Mg ha⁻¹ and carbon stocks were 1,442.93 Mg C ha⁻¹. The averages of biomass and carbon stocks were 601.22 Mg Ha⁻¹ and 288.59 Mg C ha⁻¹. This indicates that 2,943 ha area of Petungkriyono mixed forest has carbon stocks capacity up to 1,769,390.46 Mg C. The highest above-ground biomass contribution 59% tree compared with 41% poles. The significantly higher above-ground biomass describes higher carbon stocks long term storage of CO₂ to either mitigate or defer global warming. Climate change mitigation from carbon stocks can be obtained from CO₂ equivalents if well managed. Petungkriyono mixed forest may have considerable potential for mitigating climate change by carbon sequestration.

1. Introduction
The greatest potential of Petungkriyono forest is as an icon of Pekalongan regency area outstanding biodiversity of rare animals and endemic plants and a variety of genetic resources and germplasm. Petungkriyono forest is one of the resources that must be maintained, managed, utilized to give meaning to humanity. Forestry is an important sector in reducing emissions for negative net emissions such as sequestration of carbon in standing trees, long-lived forest product-biomass generated energy that substitutes for fossil fuel [1].

Above Ground Biomass (AGB) of standing live trees contributed more than 70% of carbon stocks and the mixture of different species influences the health of forest and enhancement of carbon storage [2]. Each vegetation has total biomass estimated from the product of area and biomass density. Loss of standing biomass either as harvested material or carbon sequestered in soil organic matter may be offset by long term carbon storage [3]. The capacity of the forest to absorb and store carbon, which ultimately improves the resilience of forest ecosystems against climate change to avoid dangerous climate change...
by conduct the ability of different plant species to absorb carbon, especially in the climate change mitigation effort because carbon sequestration describes long term storage of CO$_2$ to either mitigate or defer global warming [4]. The biggest greenhouse gases in global warming are CO$_2$. It contributes more than 55% of GHG content and forest acts as a carbon sink to overcome the increasing tendency of air temperature [5].

The previous studies tend to utilize integration with other ancillary data and most of the studies in tropical forests used regression equation to construct the allometric equations and relationship between above ground biomass [5][6][7]. This study's objectives were to conduct inventory on the biomass and C-stock estimation of Petungkriyono mixed forest as climate change mitigation. This article synthesizes the methodological approach for quantifying above-ground biomass and statistical approaches.

2. Material and methods

2.1. Description of the study sites

The study was conducted in the Petungkriyono forest, located in the forest area of the state-owned enterprise of Perhutani East Pekalongan. The total area of Petungkriyono regency is 73.58 km$^2$, where 73.2% or 53.88 km$^2$ was covered by forest. The Petungkriyono forest characteristics are mountainous tropical rain forest or a tropical lower montane rain forest located at an altitude of 700-1500 meters above sea level (masl) with typical monsoon climate temperatures 18-30 $^0$C. According to Schmidt and Ferguson's agri-climate classification, the Petungkriyono forest belongs to type C climate with a 33.3-60% quantity index. Astronomically, Petungkriyono forest is located at 7º08'30" S - 109º44'39" E, Pekalongan Regency, Central Java Indonesia.

2.2. Data collection

Data were collected twice in December 2018 and October 2019. The selection of sampling location used a purposive sampling method with consideration of contour or latitude. We took 30 plots from five zones or villages in Yosorejo, Kayupuring, Tlogopakis, Tlogohendro and Kasimpar. In each village, there were 6 plots and total plot was 30 plots to estimate carbon stocks from Petungkriyono mixed forest. We used a circle plot with an area of 0.04 ha and diameter of 11.29 m for trees and 5.66 m for poles. All living trees within these plots were measured the diameter at breast height > 10 cm and total height was recorded using a clinometer.

2.3. Data analysis

Estimating above-ground biomass was an essential aspect of carbon stocks studies, with non-destructive sampling and comprises forest inventory with correlation analysis. Each tree's volume was calculated depended on the diameters, tree species and total height using formula (1). The total volume was the sum of volume of each tree. Above-ground biomass was calculated by multiplying biomass volume with biomass expansion factor using the Allometric equation from previously researched [8]. The formula is given below:

\[
V_{\text{tree}} = 0.25\pi \left( \frac{D}{100} \right)^2 \times H \times F \quad (1)
\]

\[
BV = (\Sigma V_{\text{tree}} \times \text{Species Density}) \div \text{Plot Area} \quad (2)
\]

\[
AGB = BV \times BEF \quad (3)
\]

\[
AGB = BV \times BCEF \quad (4)
\]

Where $V_{\text{tree}}$ = volume tree (m$^3$), $BV$ = Biomass Volume (m$^3$), $AGB$ = (Kg), BEF (Biomass Expansion Factor), Density (kg/m), $D$ = diameter at breast height 1.3 m (cm), $H$ : height (m), $F$ = correction factor (0.6), $BCEF$ = Biomass conversion and expansion factor IPCC (2006).
This equation (1) measured volume selected for each tree, and equation (2) biomass volume for the sum of the total tree volume multiplied with species density and divided by plot area. AGB calculation as the model performed well across varied forest types and bioclimatic conditions based on equation (3) and (4). We used equation (3) if the value of BEF from specific tree already available, but if not available we used equation (4) if BV > 190 tons/ha, value of BEF = 1.74 and if BV < 190 tons/ha, the value of BEF = \exp \{3.213-0.506 \times \ln(BV)\}). The equation (5) was used if the wood density unavailable, so the aboveground biomass estimation used BCEF value default from IPCC (2006).

To calculate C Stocks of the trees by multiplied the biomass with carbon fraction. We used the default IPCC 2014 value of carbon fraction 0.48 for dryland forest because the specific carbon fraction value from ecosystem type does not exist [7]. Carbon sequestration obtained from carbon stocks value multiplied by conversion factor C to CO\textsubscript{2} value 44/12 = 3.67 [9]. The relationship between carbon stocks with INP was analyzed using Pearson’s correlation coefficient (r) and multiple linear regression (MLR) models.

3. Results and discussion.
Quantifying carbon stocks of tropical forests by estimating the total above-ground biomass is very important and can be conducted via two approaches, which are destructive and non-destructive that were using allometric equations [10]. For non-destructive methods, diameter at breast height is the most commonly used parameter for biomass prediction and it can be easily measured from the field with great precision [8]. Carbon stocks are estimated by crossing its biomass to the value of carbon fraction of trees at dryland forest, which is 0.48 [11].

The majority of above-ground terrestrial organic carbon and wood density are important carbon sink factors for estimating the biomass. The forest biomass carbon storage in both above ground and below ground from the low zones to the high zones with large differences and characteristics [12].

| Villages     | Biomassa (Mg C ha\textsuperscript{-1}) | Carbon stock (Mg C ha\textsuperscript{-1}) | CO\textsubscript{2} equivalent (Mg C ha\textsuperscript{-1}) |
|-------------|----------------------------------------|------------------------------------------|----------------------------------------------------------|
| Tlogopakis  | 752.28                                 | 361.10                                   | 1,325.24                                                 |
| Tlogohendro | 616.64                                 | 295.99                                   | 1,086.28                                                 |
| Yosorejo    | 46.14                                  | 22.15                                    | 81.29                                                    |
| Kasimpar    | 359.09                                 | 172.36                                   | 632.56                                                    |
| Kayupuring  | 1,231.95                               | 591.33                                   | 2,170.18                                                  |
| Sum         | 3,006.10                               | 1,442.93                                 | 5,295.55                                                  |
| Average     | 601.22                                 | 288.59                                   | 1,059.11                                                  |

Table 1 shows that the total biomass from five villages at Petungkriyono mixed forest was 3,006.10 Mg C ha\textsuperscript{-1} and carbon stocks 1,442.93 Mg C ha\textsuperscript{-1}. The average biomass and carbon stocks were 601.22 Mg C ha\textsuperscript{-1} and 288.59 Mg C ha\textsuperscript{-1}, respectively. This indicated that the 2,943 ha area of Petungkriyono mixed forest had carbon stocks' capacity up to 1,769,390.46 Mg C. The highest above-ground biomass contributed up to 59% tree compared with 41% poles.

The highest biomass (1,231.95 Mg C ha\textsuperscript{-1}) and carbon stocks (591.33 Mg C ha\textsuperscript{-1}) were found at Kayupuring, but the lowest biomass (46.14 Mg C ha\textsuperscript{-1}) and carbon stocks (22.15 Mg C ha\textsuperscript{-1}) were found at Yosorejo. Furthermore, the highest biomass at Kayupuring influenced by the average diameter at breast height from trees was > 30 cm.
Based on estimation value of the total above-ground biomass in the five villages, Petungkriyono mixed forest was one of a large area of dryland forest with significant potential for carbon sequestration. The emission factor is associated with the average of carbon storage and multiplied by the area occupied by carbon sequestration or storage potential. To assess the study site's potential for climate change mitigation, the total carbon storage was converted to CO$_2$ equivalent by multiplying the atomic weight difference between C and CO$_2$ (44/12). The sum of CO$_2$ equivalent from five villages was 5,295.55 ton ha$^{-1}$ and the average of carbon storage that was stored and incorporated carbon into the forest vegetation was 1,059.11 ton h$^{-1}$. The forest's high capacity to absorb and store carbon ultimately improves the resilience of forest ecosystems against climate change.

The comparison of biomass and carbon stocks from five villages, Tlogopakis, Tlogohendro, Yosorejo, Kasimpar and Kayupuring is shown in Figure 1.

Figure 1. The comparison graph for biomass and carbon stocks from 5 villages.

Figure 1 shows that Kayupuring had the highest biomass and carbon stocks respectively, tended to have a high diameter tree and the lowest density among the other location. Kayupuring had demonstrated that the bigger diameter, the bigger biomass. Carbon stocks depend on total biomass in the tree, fertile soil and absorptivity of vegetation [13]. The result of this research concluded that Petungkriyono mixed forests had high potential carbon stocks. It means that above-ground biomass plays a key role in sustainable management and positively contributes to the global carbon cycle.

The changes in total biomass and carbon storage hence land-use changes in forest areas, have implications for carbon cycling through the emission of CO$_2$, a major greenhouse gas to the atmosphere [3]. The result of biodiversity index test by Shanon –Wiener was strongly high, which was 3.9, indicated that above-ground biomass from this study was markedly higher than another mixed forest at Central Java. A further reason for chosen Petungkriyono mixed forest for research site was the primary rain forest that had gradually accumulated carbon over centuries in both the vegetation and the soil. The comparison of carbon stocks and biomass from dominant species is shown in Figure 2.
Figure 2 shows 10 dominant species had high quantifying carbon, namely *Ficus benjamina* (481.4 Mg C ha\(^{-1}\)), *Bischofia javanica* (385.8 Mg C ha\(^{-1}\)), *Wuru banyu* (345.2 Mg C ha\(^{-1}\)), *Wuru kangkang* (261.7 Mg C ha\(^{-1}\)), *Castanopsis acuminatissima* (224.7 Mg C ha\(^{-1}\)), *Artocarpus elasticus* (213.7 Mg C ha\(^{-1}\)), *Schima wallichii* (189.6 Mg C ha\(^{-1}\)), *Ficus sp.* (181.7 Mg C ha\(^{-1}\)), *Nauclea lanceolata* (158.3 Mg C ha\(^{-1}\)), and *Sandoricum koetjapi* (153.4 Mg C ha\(^{-1}\)).

The highest biomass from *Ficus benjamina* species also supported the highest carbon stocks. Two of them was endemic species from Petungkriyono forest whereas the name of species and family remain unidentified. Besides species' name, the difference in tree sections wood density was an important factor of the biggest sources of errors and tends to be higher at breast height than at the top of the hole.

The comparison of mean value of cumulative between carbon stocks and Index Important value (INP) baseline across was done and highly significant (one way ANOVA, \(P<0.05\)) The result of the analysis of variance for cumulative carbon stocks is shown in Table 3. The cumulative carbon stocks in the Petungkriyono mixed forest appear to be tremendously higher than those in the baseline.

Among the others studied, the analysis outcomes and the implications for carbon emission and total carbon balance and contribution of oil palm in reducing potential carbon emissions is evaluated [3]. Biomass and carbon stocks estimation of *Pinus merkusii* plantation at Bunder Mount Halimun Salak National Park has been conducted biomass divided into 17-years and 30-years old pine. The estimation of biomass 17-years old pine was 188.3 Mg ha\(^{-1}\), carbon sink 86.8 Mg C ha\(^{-1}\) and carbon sequestration 318.5 Mg C ha\(^{-1}\), and the estimation of biomass 30-years old pine was 203.7 Mg ha\(^{-1}\), carbon sink 96.5 Mg C ha\(^{-1}\) and carbon sequestration 354.2 Mg C ha\(^{-1}\) [6].
Table 2. Analysis of variance of cumulative between carbon stocks and INP

| Sum of Squares | df  | Mean Square | F       | Sig.  |
|----------------|-----|-------------|---------|-------|
| Between Groups | 2,717,455.003 | 67 | 40,559.03 | 4.834 | 0.005 |
| Within Groups  | 83,911.959    | 10 | 8,391.196 |       |       |
| Total          | 2,801,366.962 | 77 |          |       |       |

The impact of carbon stocks could be used to contrast and clarify with different climates and other regions [4]. Above ground carbon from standing live trees in small estuarine mangroves of Geza and Mtimbwani Tanzania contributed 70% of total carbon stocks and 24.26% from below ground carbon. Forest structure and ecosystem densities are key elements to voluntary carbon market schemes. Conservation through carbon project is a potential opportunity for Geza and Mtimbwani Tanzania communities, providing the necessary resources to sustain mangroves' conservation and carbon sink function [2].

4. Conclusion
Petungkriyono mixed forest with the area 2943 ha plays an important role in mitigating climate change and has carbon stocks capacity up to 1,769,390.46 Mg C. The highest biomass and carbon stocks were found at Kayupuring 1,231.95 Mg C ha\(^{-1}\) and 591.33 Mg C Ha\(^{-1}\). This indicates that Kayupuring has a complex tropical forest structure and is crucial to maintain sustainability and biodiversity. This indicates that the value of carbon stocks describes long term storage of CO\(_2\) to either mitigate or defer global warming.

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