Carbon stored in tree biomass of Cigerendeng Research Forest, Ciamis, West Java

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Abstract. Trees naturally may contribute to climate change mitigation through photosynthesis process that absorbs carbon dioxide in the atmosphere and stored in their biomass. The amount of carbon stored in tree biomass depends on the size of tree, species, and population per area. This study aims to analyse the amount of carbon stored in Cigerendeng Research Forest (CRF), West Java that is managed by Forestry Research and Development Agency (FORDA). This forest is dominated by mahogany and dipterocarp species originally having been planted in Sumatera and Kalimantan starting from the 1930s. Species-specific allometric and general allometric are utilised to estimate the weight of the above ground biomass. Below ground biomass is estimated by allometric equation of Cairns et al (1997). The results of this study show that carbon stored in tree biomass of Cigerendeng Research Forest (CRF) in 2009 and 2015 were 156 and 199 ton per ha respectively, with relatively dominated by old trees. The growth of trees in the CRF area could store 43 ton per ha in 6 years (from 2009 to 2015). The CRF manager utilizes the CRF by selling its environmental services (i.e. amenity and carbon), instead of harvesting.

1. Introduction

Greenhouse gases (GHGs) concentration carbon dioxide, methane, and nitrous oxide have increased to unprecedented levels. CO\textsubscript{2} concentrations have increased by 40% since pre-industrial times mainly from fossil fuel combustion and land use change [1]. This caused the increase of global temperature of 0.8 from 1880 – 2012. The increase of global temperature caused many species shifting their geographical ranges, seasonal activities, migration patterns, abundances and species. climate change causes changing precipitation or melting snow in many regions that alter hydrological systems, water resources in terms of quality and quantity [2]. Arnell [3] predicts that by 2025 around 5 billion people out of 8 billion will be living in countries experiencing water stress.

Land use, land use change, and forestry (LULUCF) activities are the largest contributors for CO\textsubscript{2} emissions in Indonesia [4]. Indonesia through The President Regulation No 61/2011 commits to reduce its GHGs emissions by 26% in 2020 without international aid or by 41% with international aid [5]. Forestry and peat land sector (e.g. forest fire control, water management on peat land, forest rehabilitation, illegal logging, avoiding deforestation, and community development) will contribute to reduce 0.672 giga ton CO\textsubscript{2} equivalent (± 87% of total target of emission reduction).

Activities in forestry sectors for emission reductions, forest and land rehabilitation may contribute to absorb carbon dioxide in the atmosphere and store it in trees or vegetation biomass through photosynthesis process. Researches on forest biomass contribution on climate change mitigation have
been raising significantly in Indonesia. Studies of carbon stored in tree biomass on natural and plantation forests in Indonesia, have been extensively researched [6]. Researches on Carbon stored in tree biomass in urban forests have also been developed recently [7-12]. Forest carbon dynamics in plantation forests in Java are also investigated based on modelling on volume table of some commercial species [13-17].

However, only a little study has measured the growth of a multi-age multi-species forests for carbon sequestration. Several studies only reported the amount of carbon stored in tree biomass at time of the study, i.e. study on logged over forest in Kalimantan [18] and pristine forest in North Kalimantan [19]. This study aims to analyse the amount of carbon stored in Cigerendeng Research Forest (CRF), West Java that is managed by Forestry Research and Development Agency (FORDA). Detailed data from measured trees in CRF may contribute to the discussion on the forestry sector contribution on climate change mitigation in Indonesia mainly for policy makers.

2. Methods

2.1. General Information and Location
Cigerendeng Research Forest (CRF) was developed in 1938 in Dutch colony era as an arboretum for several dipterocarp species from Sumatera and Kalimantan. The CRF after Indonesian independence was formerly managed by Forestry Service of West Java, Perum Perhutani, and recently is managed by Forestry Research and Development Agency (FORDA). CRF is located at Kertahardja Village, Ciamis Regency, the eastern most of West Java Province. The average annual rainfall in CRF is 2,429 mm with the elevation of 50 m above sea level. The area of CRF is 7.62 ha consisted of 18 blocks with several species mostly from *Swietenia* sp. and dipterocarp species.

![Figure 1. Cigerendeng Research Forest](image-url)
2.2. Data Collection
Tree census was conducted in 2009 and 2015 to identify and measure the dimension of each tree (diameter and height). All trees with DBH larger than 10 cm were identified and measured in the whole area during the research period.

2.3. Data Analysis
To estimate the weight of above ground biomass, several allometric equations were applied using species specific allometric to obtain more accurate estimation. For species with no species specific allometric, the general allometric equation from Chave, Andalo, Brown, Cairns, Chambers, Eamus, Fölster, Fromard, Higuchi and Kira [20] was used.

Allometric equations used for dipterocarp species are from Basuki, Van Laake, Skidmore and Hussin [21]:
\[
\ln AGB = -1.232 + 2.178 \ln D \quad \text{for } Dipterocarpus \ sp. \\
\ln AGB = -1.813 + 2.339 \ln D \quad \text{for } Hopea \ sp. \\
\ln AGB = -2.193 + 2.371 \ln D \quad \text{for } Shorea \ sp. \\
\ln AGB = -1.498 + 2.234 \ln D \quad \text{for mixed species}
\]
Allometric equations for Acacia auriculiformis and Dalbergia latifolia were from BPKH Wilayah XI [22]:
\[
AGB = 0.078(D^{1.7})^{0.502} \quad \text{for } Acacia \ auriculiformis \\
AGB = 0.7458(D^{2.2})^{0.6394} \quad \text{for Dalbergia \ latifolia}
\]
And for Swietenia macrophylla was from Adinugroho and Sidiyasa [23]:
\[
GB = 0.048(D)^{2.86}
\]
For other species where no species specific allometric equation available, we used the general allometric equation from Chave, Andalo, Brown, Cairns, Chambers, Eamus, Fölster, Fromard, Higuchi and Kira [20] for moist forest:
\[
AGB = \exp(-2.977 + \ln \rho D^{2.7})
\]
Where \( \rho \) is the wood density that is taken from Zanne, Lopez-Gonzalez, G.*, Ilic, Lewis, Miller, Swenson, Wiemann and Chave [24].

Root biomass was estimated by allometric equation of Cairns, Brown, Helmer and Baumgardner [25]:
\[
RB = \exp(-1.085 + 0.926 \ln AGB)
\]
The fraction of carbon stored in tree biomass is 0.47 [26].

Total amount of CO\(_2\) was calculated by multiplying the total carbon stored in tree biomass with the ratio of molecular weight of carbon dioxide and carbon i.e. (44/12).

3. Results and Discussion
In CRF, the total number of trees are 2,679 and 3,177 in 2009 and 2015 respectively (Table 1 and 2). The additional trees in CRF are mainly from natural regeneration. With semi-tolerant characteristics, there are two dipterocarp trees that increased significantly in numbers i.e. Shorea ovalis and Hopea mengarawan. The Total additional trees of Shorea ovalis in CRF were 187 trees in 6 years. With additional new trees with small DBH, the DBH average of Shorea ovalis decreased from 28.1 to 27.8 cm. Number of trees of Hopea mengarawan also increased significantly from 653 to 823 (i.e. 170 trees) in 6 years with DBH increment of 3 cm. Additional trees were also found from some dipterocarp species i.e. Dalbergia latifolia, Hopea odorata, H. sangal, Shorea pinanga, S. seminis, and S. sumatrana, several tree species were decreased in number i.e. Hopea bancana, Shorea johorensis, S. selanica, and S. stenoptera. There were new specii introduced in CRF in 2015 i.e. Archidendron sp. Sodaricum koetjapi and Vatica sp. The new specii entering the CRF may be resulted from natural regeneration.

Diameter of Acacia auriculiformis was the same in 2009 and 2015 that may be affected by nutrient and light competition with dominant specii (i.e. dipterocarp and Swietenia macrophylla). However, the
height of *Acacia auriculiformis* increased for about 1 meter in 6 years as a result of light competition. Tree biomass and carbon in CRF is presented in Table 3 and 4. The total carbon stored in above ground and root tree biomass of CRF in 2009 were 117 and 39 ton C per ha respectively or in total equal to 572 ton CO₂. Whereas in 2015 the total carbon stored in tree biomass in above ground and root biomass were 149 and 49 ton C per ha respectively or equal to 728 ton CO₂ per ha. The total amount of carbon stored in CRF is relatively lower than in natural forest in Kalimantan [19], or logged over forest [18].

**Table 1. Trees in CRF stand in 2009**

| Species                                      | Population | Diameter (cm) | Height (m) |
|----------------------------------------------|------------|---------------|------------|
| Acacia auriculiformis                        | 1          | 49.3          | 12.0       |
| Dalbergia latifolia Roxb.                    | 37         | 31.3          | 13.6       |
| Hopea mengerawan Miq.                        | 653        | 24.9          | 23.1       |
| Hopea bancana Boerl.                         | 6          | 43.1          | 19.3       |
| Hopea odorata Korth                          | 27         | 35.3          | 18.1       |
| Hopea sangal Roxb.                           | 21         | 34.4          | 18.5       |
| Shorea joheorensis                           | 5          | 24.7          | 19.8       |
| Shorea lamelata Sym.                         | 1          | 86.5          | 24.0       |
| Shorea leprosula Miq.                        | 16         | 28.7          | 23.0       |
| Shorea macrophylla King                      | 1          | 26.4          | 20.0       |
| Shorea ovalis Bl.                            | 266        | 28.1          | 22.7       |
| Shorea pinanga Scheff                        | 32         | 21.5          | 16.5       |
| Shorea selanica Bl.                          | 42         | 27.1          | 22.5       |
| Shorea seminis V.Sl.                         | 39         | 20.4          | 16.2       |
| Shorea stenoptera Burck.                     | 6          | 20.8          | 21.2       |
| Shorea sumatrania Burck.                     | 1          | 21.3          | 20.0       |
| Sweitenia macrophylla King                   | 1525       | 36.2          | 13.8       |
| **Total population and average diameter and height** | 2679       | 32.0          | 17.3       |

**Table 2. Trees in CRF stand in 2015**

| Species                                      | Population | Diameter (cm) | Height (m) |
|----------------------------------------------|------------|---------------|------------|
| Acacia auriculiformis                        | 1          | 49.3          | 11.0       |
| Archidendron pauciflorum                    | 1          | 18.8          | 6.5        |
| Dalbergia latifolia Roxb.                    | 51         | 33.6          | 13.7       |
| Dipterocarpus verrucosus Foxw                | 7          | 39.0          | 14.1       |
| Hopea mengerawan Miq.                        | 823        | 27.9          | 18.5       |
| Hopea bancana Boerl.                         | 3          | 30.3          | 13.3       |
| Hopea odorata Korth                          | 31         | 39.9          | 17.4       |
| Hopea sangal Roxb.                           | 67         | 22.8          | 16.9       |
| Shorea joheorensis                           | 2          | 22.4          | 10.5       |
| Shorea lamelata Sym.                         | 1          | 89.1          | 30.0       |
| Shorea leprosula Miq.                        | 28         | 28.8          | 16.0       |
| Shorea macrophylla King                      | 1          | 66.8          | 20.0       |
| Shorea ovalis Bl.                            | 453        | 27.8          | 16.2       |
| Shorea pinanga Scheff                        | 64         | 19.3          | 12.7       |
| Shorea selanica Bl.                          | 37         | 31.7          | 15.7       |
| Shorea seminis V.Sl                          | 67         | 18.9          | 10.8       |
| Shorea stenoptera Burck.                     | 1          | 47.7          | 27.0       |
| Species                  | Above ground biomass (kg/ha) | Root biomass (kg/ha) | C-stored in above ground biomass (ton C/ha) | C-stored in root biomass (ton C/ha) | Total C-stored in tree biomass (ton C/ha) | Total CO₂ stored in tree biomass (ton CO₂/ha) |
|--------------------------|------------------------------|----------------------|---------------------------------------------|-----------------------------------|------------------------------------------|-----------------------------------------------|
| *Shorea sumatrana* Burck | 12                           | 19.6                 | 14.3                                        |                                   |                                         |                                               |
| *Sodaricum koetjapi*     | 1                            | 14.0                 | 6.0                                         |                                   |                                         |                                               |
| *Sweitenia macrophyla* King. | 1523                      | 37.7                 | 12.1                                        |                                   |                                         |                                               |
| *Vatica sp.*             | 2                            | 21.3                 | 16.0                                        |                                   |                                         |                                               |
| **Total population and average diameter and height** | **3177** | **32.4** | **14.6** |                                   |                                         |                                               |

**Table 3.** Tree biomass and carbon of CRF in 2009

| Species                          | Above ground biomass (kg/ha) | Root biomass (kg/ha) | C-stored in above ground biomass (ton C/ha) | C-stored in root biomass (ton C/ha) | Total C-stored in tree biomass (ton C/ha) | Total CO₂ stored in tree biomass (ton CO₂/ha) |
|----------------------------------|------------------------------|----------------------|---------------------------------------------|-----------------------------------|------------------------------------------|-----------------------------------------------|
| *Sweitenia macrophyla* King.     | 178.0                        | 59.3                 | 83.6                                        | 27.9                              | 111.5                                    | 408.9                                         |
| *Hopea mengerawan* Miq.          | 37.3                         | 12.7                 | 17.5                                        | 5.9                               | 23.5                                     | 86.2                                         |
| *Shorea ovalis* Bl.              | 18.3                         | 6.0                  | 8.6                                         | 2.8                               | 11.5                                     | 42.0                                         |
| *Hopea odorata* Korth            | 2.7                          | 0.9                  | 1.3                                         | 0.4                               | 1.7                                      | 6.3                                          |
| *Shorea selanica* Bl.            | 2.4                          | 0.8                  | 1.1                                         | 0.4                               | 1.5                                      | 5.6                                          |
| *Hopea sangal* Roxb.             | 2.2                          | 0.7                  | 1.0                                         | 0.4                               | 1.4                                      | 5.1                                          |
| *Shorea leprosula* Miq.          | 1.9                          | 0.6                  | 0.9                                         | 0.3                               | 1.2                                      | 4.2                                          |
| *Dalbergia latifolia* Roxb.      | 1.7                          | 0.6                  | 0.8                                         | 0.3                               | 1.1                                      | 4.1                                          |
| *Hopea bancana* Boerl.           | 1.5                          | 0.4                  | 0.7                                         | 0.2                               | 0.9                                      | 3.3                                          |
| *Shorea seminis* V.Sl            | 0.8                          | 0.3                  | 0.4                                         | 0.1                               | 0.5                                      | 1.9                                          |
| *Shorea pinanga* Scheff          | 0.8                          | 0.3                  | 0.4                                         | 0.1                               | 0.5                                      | 1.9                                          |
| *Shorea lamelata* Sym.           | 0.6                          | 0.2                  | 0.3                                         | 0.1                               | 0.4                                      | 1.3                                          |
| *Shorea johorensis*              | 0.2                          | 0.1                  | 0.1                                         | 0.0                               | 0.1                                      | 0.4                                          |
| *Shorea stenoptera* Burck.       | 0.1                          | 0.1                  | 0.1                                         | 0.0                               | 0.1                                      | 0.3                                          |
| *Acacia auriculiformis*          | 0.1                          | 0.0                  | 0.1                                         | 0.0                               | 0.1                                      | 0.2                                          |
| *Shorea macrophylla* King.       | 0.0                          | 0.0                  | 0.0                                         | 0.0                               | 0.0                                      | 0.1                                          |
| *Shorea sumatrana* Burck         | 0.0                          | 0.0                  | 0.0                                         | 0.0                               | 0.0                                      | 0.1                                          |
| **Per ha**                       | **248.7**                    | **83.1**             | **116.9**                                   | **39.0**                          | **155.9**                                | **571.8**                                    |
| **Total in 7.62 ha**             | **1895.4**                   | **632.9**            | **890.8**                                   | **297.5**                         | **1188.3**                               | **4357.2**                                   |

**Table 4.** Tree biomass and carbon of CRF in 2015

| Species                          | Above ground biomass (kg/ha) | Root biomass (kg/ha) | C-stored in above ground biomass (ton C/ha) | C-stored in root biomass (ton C/ha) | Total C-stored in tree biomass (ton C/ha) | Total CO₂ stored in tree biomass (ton CO₂/ha) |
|----------------------------------|------------------------------|----------------------|---------------------------------------------|-----------------------------------|------------------------------------------|-----------------------------------------------|
| *Sweitenia macrophyla* King.     | 205.0                        | 67.4                 | 96.4                                        | 31.7                              | 128.0                                    | 469.5                                         |
| *Hopea mengerawan* Miq.          | 60.6                         | 20.3                 | 28.5                                        | 9.5                               | 38.0                                     | 139.3                                         |
| *Shorea ovalis* Bl.              | 29.7                         | 9.9                  | 14.0                                        | 4.6                               | 18.6                                     | 68.3                                          |
| *Hopea odorata* Korth            | 4.2                          | 1.4                  | 2.0                                         | 0.7                               | 2.6                                      | 9.6                                           |
| *Hopea sangal* Roxb.             | 3.7                          | 1.2                  | 1.7                                         | 0.6                               | 2.3                                      | 8.4                                           |
| *Shorea selanica* Bl.            | 3.1                          | 1.0                  | 1.5                                         | 0.5                               | 1.9                                      | 7.1                                           |
| *Shorea leprosula* Miq.          | 2.8                          | 0.9                  | 1.3                                         | 0.4                               | 1.7                                      | 6.3                                           |
| *Dalbergia latifolia* Roxb.      | 2.5                          | 0.9                  | 1.2                                         | 0.4                               | 1.6                                      | 5.9                                           |
| *Dipterocarpus verrucosus* Foxw  | 1.5                          | 0.5                  | 0.7                                         | 0.2                               | 0.9                                      | 3.5                                           |
| *Shorea pinanga* Scheff          | 1.4                          | 0.5                  | 0.6                                         | 0.2                               | 0.9                                      | 3.2                                           |
| *Shorea seminis* V.Sl            | 1.2                          | 0.5                  | 0.6                                         | 0.2                               | 0.8                                      | 2.9                                           |


The increase of carbon stored in CRF in 6 years during this research conducted was 42.6 ton C or 157 ton CO₂. The increment of carbon stored in CRF is relatively lower than those in pine plantation forest in Java that stored carbon for more than 200 ton CO₂ in 5 years for all site class III-VI [16] in age class of < 20 years. At the age class of 20-25, the amount of carbon stored in pine plantation is similar to that in CRF. However, at the older age class of pine forest (i.e. > 25 years where the average DBH is > 30 cm), the increment of carbon stored in pine forest biomass becomes slower than that in CRF (i.e the increment are between 13-18 ton CO₂/ha)[16]. With relatively old dominated trees, the growth of CRF is relatively low. Some new born trees entering the lowest diameter class may still grow and increase the amount of carbon stored in tree biomass of CRF in 6 years. The size of the trees affects on the amount of carbon stored in tree biomass, e.g. the biggest tree in CRF, *Shorea lamelata* Sym. (only one tree) with 89 cm DBH and 20 m height stored carbon in its biomass for about 0.4 ton per ha. For comparison, *Shorea sumatrana* with diameter 21 cm only stored 0.01 ton carbon per ha.

The largest contributor in storing carbon in tree biomass was *Swietenia macrophylla* that can store 112 and 128 ton carbon per ha in 2009 and 2015 respectively. *Swietenia macrophylla* stored the largest carbon in its biomass because it has the largest population in the CRF (i.e. 1525 and 1523 in 2011 and 2015 respectively). Dipterocarp species with high population and relatively high dimension of trees also stores relatively much, e.g. *Hopea mengarawan* and *Shorea ovalis* stored carbon of 38 and 19 ton in 2015. For relatively sparse density trees with relatively small in size trees, the carbon stored in their biomass are also low. For example, *Archidendron pauciflorum* and *Sodaricum koetjapi* only stored carbon for < 0.01 ton per ha in 2015.

4. Conclusions
Tree growth may absorb carbon dioxide in the atmosphere through photosynthesis process. The amount of CO₂ absorbed in tree biomass depends on the size, population, and species of the tree. Carbon stored in tree biomass of Cigerendeng Research Forest (CRF) in 2009 and 2015 were 156 and 199 ton per ha respectively. With relatively dominated by old trees, the growth of trees in Cigerendeng Forest Research (CRF) area might store 43 ton per ha in 6 years (from 2009 to 2015). The largest contributor in storing carbon in tree biomass in CRF was *Swietenia macrophylla* that can store carbon 112 and 128 ton per ha in 2009 and 2015 respectively.

References
[1] IPCC 2007 Mitigation of climate change Summary for Policymakers 10.
[2] IPCC 2014 Climate change 2014: synthesis report. Contribution of Working Groups I II and III to the Fifth Assessment Report of the intergovernmental panel on Climate Change. IPCC, Geneva, Switzerland 151.
[3] Arnell N W 1999 Climate change and global water resources Global environmental change 9 S31-S49.
[4] Baumert K A, Herzog T and Pershing J 2005 Navigating the numbers: Greenhouse gases and international climate change agreements.

[5] Thamrin S 2011 Indonesia’s national mitigation actions: paving the way towards NAMAs. In: CCXG/Global Forum on Environment Seminar on MRV and Carbon Markets, pp 28-9.

[6] Masripatin N 2011 Cadangan karbon pada berbagai tipe hutan dan jenis tanaman di Indonesia: Kementerian Kehutanan, Badan Penelitian dan Pengembangan Kehutanan, Pusat Penelitian dan Pengembangan Perubahan Iklim dan Kebijakan).

[7] Indrajaya Y 2015 Karbon tersimpan dalam biomassa pohon di hutan kota Taman Tegalega, Bandung. In: Seminar Nasional Sewindu BBTHGBK Mataram, (Mataram, Lombok: Balai Penelitian Kehutanan Hasil Hutan Bukan Kayu).

[8] Indrajaya Y and Mulyana S 2015 Karbon tersimpan dalam biomassa pohon di hutan kota Taman Maluku, Bandung 

[9] Indrajaya Y and Mulyana S 2016 Kontribusi hutan kota PT PINDAD dalam penyerapan karbon di Kota Bandung. In: Seminar Nasional III - S2 PKLH FKIP UNS (Surakarta: Universitas Sebelas Maret).

[10] Indrajaya Y and Mulyana S 2016 Karbon dalam biomassa pohon di Taman Lalu Lintas Ade Irma Suryani Nasution, Bandung Albasia 12 64-73.

[11] Indrajaya Y and Mulyana S 2017 Jasa lingkungan serapan karbon pohon penyusun hutan Tempat Pembuangan Akhir (TPA) Bandengan Jepara. In: Inovasi dan Kreasi Memanjakan Jawa Tengah, ed S Dwiamoko, et al. (Semarang: Badan Perencanaan Pembangunan, Penelitian dan Pengembangan Daerah (BAPPEDA) Provinsi Jawa Tengah).

[12] Indrajaya Y, Sudomo A and Mulyana S 2015 Dinamika karbon tersimpan dalam biomassa hutan tanaman mahoni di Jawa. In: Seminar Nasional Restorasi DAS: Mencari Keterpaduan di Tengah Isu Perubahan Iklim, (UNS Surakarta, Indonesia).

[13] Indrajaya Y 2015 Cadangan karbon hutan bekas tebangan pada beberapa kelas tempat tumbuh di Jawa. In: Seminar Nasional Geografi UMS 2015, ed Priyono, et al. (Surakarta: Universitas Muhamadiyah Surakarta).

[14] Indrajaya Y 2015 Cadangan karbon hutan bekas tebangan pada beberapa kelas tempat tumbuh di Jawa. In: Seminar Nasional Geografi UMS 2015, ed Priyono, et al. (Surakarta: Universitas Muhamadiyah Surakarta).

[15] Indrajaya Y 2016 Dinamika karbon tersimpan dalam biomassa hutan tanaman mahoni di Jawa. In: Seminar Nasional Restorasi DAS: Mencari Keterpaduan di Tengah Isu Perubahan Iklim, (UNS Surakarta, Indonesia).

[16] Indrajaya Y 2016 Dinamika karbon tersimpan dalam biomassa hutan tanaman mahoni di Jawa. In: Seminar Nasional Restorasi DAS: Mencari Keterpaduan di Tengah Isu Perubahan Iklim, (UNS Surakarta, Indonesia).

[17] Indrajaya Y 2016 Dinamika karbon tersimpan dalam biomassa hutan tanaman mahoni di Jawa. In: Seminar Nasional Restorasi DAS: Mencari Keterpaduan di Tengah Isu Perubahan Iklim, (UNS Surakarta, Indonesia).

[18] Indrajaya Y 2016 Dinamika karbon tersimpan dalam biomassa hutan tanaman mahoni di Jawa. In: Seminar Nasional Restorasi DAS: Mencari Keterpaduan di Tengah Isu Perubahan Iklim, (UNS Surakarta, Indonesia).

[19] Indrajaya Y 2016 Dinamika karbon tersimpan dalam biomassa hutan tanaman mahoni di Jawa. In: Seminar Nasional Restorasi DAS: Mencari Keterpaduan di Tengah Isu Perubahan Iklim, (UNS Surakarta, Indonesia).

[20] Chave J r, Andalo C, Brown S, Cairns M A, Chambers J, Eamus D, Fölster H, Fromard F, Higuchi N and Kira T 2005 Tree allometry and improved estimation of carbon stocks and balance in tropical forests Oecologia 145 87-99.

[21] Basuki T, Van Laake P, Skidmore A and Hussin Y 2009 Allometric equations for estimating the above-ground biomass in tropical lowland Dipterocarp forests Forest Ecology and Management 257 1684-94.
[22] BPKH Wilayah XI 2009 Allometrik berbagai jenis pohon untuk menaksir kandungan biomassa dan karbon di hutan rakyat Kementrian Kehutanan, Jakarta.
[23] Adinugroho W C and Sidiyasa K 2006 Model pendugaan biomassa pohon mahoni (Swietenia macrophylla King) di atas permukaan tanah Jurnal penelitian Hutan dan Konservasi alam 3 103-17.
[24] Zanne A E, Lopez-Gonzalez, G.*, C, D.A., Illic J, Jansen, S., Lewis S L, Miller R B, Swenson N G, Wiemann M C and Chave J 2009 Global wood density database.
[25] Cairns M A, Brown S, Helmer E H and Baumgardner G A 1997 Root biomass allocation in the world's upland forests Oecologia 111 1-11.
[26] IPCC 2006 IPCC Guideline 2006 Guidelines for national green house gas inventories. IPCC).