Above-Ground Biomass and Carbon Stock of Ciletuh Mangrove Forest, West Java, Indonesia

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Abstract. Mangrove forest is a unique ecosystem that plays important roles to climate change control, as carbon sink and CO$_2$ absorbing from the atmosphere. This research was aimed to estimate the potential of above-ground biomass and carbon stocks of Ciletuh mangrove forest, West Java, Indonesia. Mangrove forest area and occupation of dominant species were mapped using Geographical Information System, meanwhile species composition and forest structure was sampled using 198 plots (20 m x 20 m each) systematically spread out at studied forest area. Vegetation analysis data were used to estimate the potential of above-ground biomass and carbon stocks. Above-ground biomass and carbon stock of mangrove species was estimated using allometric models that already available. The results showed that mangrove forest in Ciletuh covered an area amounted to 8 ha. There were 18 tree mangrove species dominated by species of non-Rhizophoraceae belonging to 14 genera of 11 families. Above-ground biomass of Ciletuh mangrove forest was estimated at 31.78 t ha$^{-1}$, carbon stock at 14.93 t C ha$^{-1}$, and CO$_2$ absorption at 54.68 t ha$^{-1}$.

1. Introduction

Mangrove as an interface between marine and terrestrial ecosystems, believed to be highly productive [1], as it is able to provide various valuable forest products, as well as environmental services. Furthermore, the most important provisions related to climate change and global warming include carbon stock and the absorbent of CO$_2$ from the atmosphere [2, 3, 4, 5]. This is, converted into biomass and carbon, subsequently reducing the effect of greenhouse gases and finally maintaining the ecological functions of forests [6].

In relation to the issue of climate change and global warming, a method adopted in preserving the ecological functions of forests encompasses the implementation of REDD$^+$ mechanism (Reducing Emissions from Deforestation and Forest Degradation) [7], because deforestation contributes about 20% of the total emission [8]. In addition, the continuous decline and destruction of mangroves have been highlighted in recent years [9, 10, 1], hence they are considered as one of the most threatened ecosystems on the planet, with an estimated of 35% deterioration globally, during 1980 – 2000 [11]. These can certainly be overcome through the improvement of natural and plantation forests management systems [12], reported to be synergistic with social functions and economic value.

Estimating the potentials of biomass and carbon stock of a forest is one of the contributions of the REDD$^+$ mechanism [13]. Meanwhile, biomass data of an ecosystem is very useful for evaluating productivity patterns [14]. Conducting calculations in tropical forests is required to identify its potentials, as well as the effects on the carbon cycle (C) [15]. However, recent estimations suggest that
as much as 20Pg of C is currently being stored in mangrove biomass, sediments, and peat worldwide [4].

In addition, these are forests with a large carbon content which are capable of storing content of about three times greater than mainland tropical forests [4], and five times greater than that of highlands [16]. However, the estimation of its potentials in parts of the tropics is poor, and also the lack of understanding the mitigating climate change [17] is capable of inhibit involvement in the REDD’ mechanism. Furthermore, the estimation in tropical forests is generally highly needed, due to its capacity to store carbon, and subsequently reduce CO$_2$ levels in the atmosphere [12], making it an important step in planning sustainable mangrove protection and utilization. Furthermore, the purpose of this study is to estimate the potentials of above-ground biomass and carbon stock in the Ciletuh mangrove forest, West Java, Indonesia.

2. Method

2.1. Study site

The study was conducted within January – March 2017 at the Ciletuh mangrove forest, Sukabumi, Indonesia (7°11'10" S and 106°26'30"–106°26'60" E), possessing an area of 8 ha, with a temperature of about 28°C, and the highest rainfall was 753 mm month$^{-1}$.

2.2. Procedures

The observation of the structure and composition of the mangrove forest was carried out by constructing plots measuring 20 x 20 m in up to 198 units, positioned systematically on an area of 8 ha.

**Table 1.** The allometric equations used to estimate the biomass of each tree species in the Ciletuh mangrove forest

| Species                        | Allometric Equation | Dmax (cm) | Source |
|--------------------------------|---------------------|-----------|--------|
| *Avicennia officinalis*        | $W_\text{ag} = 0.251\rho D^{2.46}$ | 49        | [19]   |
| *A. marina*                   | $W_1 = 0.291 D^{2.260}$            | 35.2      | [21]   |
| *Aegiceras corniculatum*      | $W_\text{ag} = 0.168\rho D^{2.47}$ | 50        | [22]   |
| *Bruguiera cylindrica*        | $W_\text{ag} = 0.251\rho D^{2.46}$ | 49        | [19]   |
| *B. gymnorrhiza*              | $\log W_\text{ag} = -0.552 + 2.244 \log D$ | 61        | [23]   |
| *B. sexangula*                | $W_\text{ag} = 0.251\rho D^{2.46}$ | 49        | [19]   |
| *Cerbera manghas*             | $W_\text{ag} = 0.168\rho D^{2.47}$ | 50        | [22]   |
| *Excoecaria agallocha*        | $W_\text{ag} = 0.168\rho D^{2.47}$ | 50        | [22]   |
| *Heritiera littoralis*        | $W_\text{ag} = 0.168\rho D^{2.47}$ | 50        | [22]   |
| *Hibiscus tiliaeus*           | $W_\text{ag} = 0.168\rho D^{2.47}$ | 50        | [22]   |
| *Lumnitzera racemosa*         | $W_\text{ag} = 0.163 D^{2.37}$     | 12        | [24]   |
| *Mastixia trichotoma*         | $W_\text{ag} = 0.168\rho D^{2.47}$ | 50        | [22]   |
| *Pongamia pinnata*            | $W_\text{ag} = 0.168\rho D^{2.47}$ | 50        | [22]   |
| *Premna serratifolia*         | $W_\text{ag} = 0.168\rho D^{2.47}$ | 50        | [22]   |
| *Rhizophora apiculata*        | $W_\text{ag} = 0.235 D^{2.42}$     | 28        | [25]   |
| *R. mucronata*                | $W_\text{ag} = 0.105 D^{2.88}$     | 25        | [26]   |
| *Syzygium sp.*                | $W_\text{ag} = 0.168\rho D^{2.47}$ | 50        | [22]   |
| *Terminalia catappa*          | $W_\text{ag} = 0.168\rho D^{2.47}$ | 50        | [22]   |

$W_\text{ag}$, above-ground biomass (kg); D, stem diameter (cm); $\rho$, wood density (cm$^{-3}$)

*A. officinalis* ($\rho = 0.59$ g cm$^{-3}$); *A. corniculatum* ($\rho = 0.51$ g cm$^{-3}$); *B. cylindrica* ($\rho = 0.72$ g cm$^{-3}$); *B. sexangula* ($\rho = 0.74$ g cm$^{-3}$); *C. manghas* ($\rho = 0.38$ g cm$^{-3}$); *E. agallocha* ($\rho = 0.39$ g cm$^{-3}$) *H. littoralis* ($\rho = 0.79$ g cm$^{-3}$); *H. tiliaeus* ($\rho = 0.43$ g cm$^{-3}$); *M. trichotoma* ($\rho = 0.39$ g cm$^{-3}$); *P. pinnata* ($\rho = 0.54$ g cm$^{-3}$) *P. serratifolia* ($\rho = 0.55$ g cm$^{-3}$); *Syzygium* sp. ($\rho = 0.73$ g cm$^{-3}$); *T. Cattapa* ($\rho = 0.46$ g cm$^{-3}$) (Source, [26])
Moreover, several things were identified in each, including the species names, number of individual species, stem diameter, and tree canopy height (woody plants with a stem diameter of > 10 cm and height of > 1.5 m) [18]. The measurement of stem diameter was conducted at the position of 30 cm above the supporting root for Rhizophora spp. species and 1.3 m above ground level for others [19]. In addition, each of these was analyzed for density and width of the base area [20], in order to identify its dominance. Subsequently, the distribution in each plot was mapped out, using the Geographical Information System.

The estimation of the above-ground biomass (AGB) of each species was established at the study site, using the available biomass allometric equations (Table 1). Furthermore, the carbon stock and CO₂ absorption of each were determined based on the formula [13],

\[
\begin{align*}
C_{ag} &= 0.47 W_{ag} \\
\text{CO}_2 &= 3.67 C_{ag}
\end{align*}
\]

Where \(C_{ag}\) is the above-ground carbon stock and \(W_{ag}\) is the above-ground biomass of a species.

### 3. Result and discussion

The vegetation analysis results (Table 2) show the Ciletuh mangrove forest to have 18 mangrove tree species, which originated from 14 genera of 11 families, where each consisted of 8 major, 2 minor, and 8 association types. The stem diameters ranged from 10 – 70 cm, with canopy height ranging between 4 – 20 m.

| Species      | Family           | Information         |
|--------------|------------------|---------------------|
| A. officinalis | Acanthaceae      | Major mangrove      |
| A. marina    | Acanthaceae      | Major mangrove      |
| A. corniculatum | Primulaceae   | Minor mangrove      |
| B. cylindrical | Rhizophoraceae  | Major mangrove      |
| B. gymnorrhiza | Rhizophoraceae  | Major mangrove      |
| B. sexangula | Rhizophoraceae  | Major mangrove      |
| C. manghas   | Apocynaceae      | Mangrove associate  |
| E. agallocha | Euphorbiaceae    | Minor mangrove      |
| H. littoralis | Malvaceae        | Mangrove associate  |
| H. tiliaceus | Malvaceae        | Mangrove associate  |
| L. racemose  | Combretaceae     | Major mangrove      |
| M. trichotoma | Cornaceae        | Mangrove associate  |
| P. pinnata   | Fabaceae         | Mangrove associate  |
| P. serratifolia | Verbenaceae  | Mangrove associate  |
| R. apiculata | Rhizophoraceae   | Major mangrove      |
| R. mucronata | Rhizophoraceae   | Major mangrove      |
| Syzygium sp. | Mrytaceae        | Mangrove associate  |
| T. cattapa   | Combretaceae     | Mangrove associate  |

The trees in the Ciletuh mangrove forest generally had a comparably significant number of species in relation with several other locations along the southern coast of Java Island (Table 3). This region is famous for its large sea waves, so the sea waves are capable of inhibiting the arrival of propagules or seeds [28]. In addition, the area also shows dominance in pioneer trees, including Avicennia spp. and Sonneratia spp., except in Alas Purwo, which indicates it to be in the stage of secondary succession [29]. This was as a result of possible disturbances in the past that probably lead to the reduction in old mangroves [30], unlike in Alas Purwo, which is located in the protected National Park area, where old trees are dominant.
Table 3. The number of tree species in mangrove forests along the southern coast of Java Island, Indonesia

| Location                        | Dominant Species     | Number of Species | Source         |
|---------------------------------|----------------------|-------------------|----------------|
| Dua Island, Banten              | A. marina            | 11 [31]           |                |
| Ciletuh, Sukabumi, West Java    | A. officinalis       | 18 This study     |                |
| Sancang Forest, Garut, West Java| Sonneratia caseolaris| 3 [32]            |                |
| Bulaksetra, Pangandaran, West Java| A. alba              | 14 [33]           |                |
| Rawa Timur, Cilacap, Central Java| A. marina            | 13 [30]           |                |
| Alas Purwo, Banyuwangi, East Java| R. apiculata        | 13 [34]           |                |

A large number of species in Ciletuh were as a result of it being located in the transitional zones with the mainland, which has been proven by numerous mangrove associations to be the main type of coastal forests. In addition, at this location, there were also human interventions in the form of plantations of several species of mangroves.

The largest individual density and the base area were identified in A. officinalis, which measured 62 ind ha$^{-1}$ and 51.47 m$^2$ ha$^{-1}$, respectively (Table 4). Furthermore, large number of density and basal area indicates this species to be the most dominant in Ciletuh, followed by E. agallocha, and Rhizophora spp.

Table 4. The potentials of above-ground biomass, carbon, and CO$_2$ absorption of the Ciletuh mangrove forest

| Species          | Density (ind ha$^{-1}$) | BA (m$^2$ ha$^{-1}$) | Biomass (t ha$^{-1}$) | Carbon (t ha$^{-1}$) | Absorption of CO$_2$ (t ha$^{-1}$) |
|------------------|--------------------------|----------------------|-----------------------|-----------------------|----------------------------------|
| A. officinalis   | 62                       | 51.47                | 16.96                 | 7.97                  | 29.25                            |
| A. marina        | 7                        | 3.17                 | 1.64                  | 0.77                  | 2.84                             |
| A. corniculatum  | 5                        | 3.88                 | 0.06                  | 0.03                  | 0.10                             |
| B. cylindrical   | 5                        | 1.74                 | 1.59                  | 0.75                  | 2.74                             |
| B. gymnorrhiza   | 3                        | 0.78                 | 1.80                  | 0.85                  | 3.11                             |
| B. sexangular    | 2                        | 0.70                 | 0.99                  | 0.46                  | 1.70                             |
| C. manghas       | 1                        | 0.26                 | 0.09                  | 0.04                  | 0.15                             |
| E. agallocha     | 22                       | 11.51                | 0.003                 | 0.001                 | 0.004                            |
| H. littoralis     | 1                        | 0.36                 | 4.15                  | 1.95                  | 7.15                             |
| H. tiliaceus      | 9                        | 9.01                 | 0.78                  | 0.36                  | 1.34                             |
| L. racemose      | 9                        | 5.59                 | 2.56                  | 1.20                  | 4.42                             |
| M. trichotoma    | 1                        | 0.10                 | 0.55                  | 0.26                  | 0.95                             |
| P. pinnata       | 3                        | 0.40                 | 0.01                  | 0.003                 | 0.01                             |
| P. serratifolia  | 1                        | 0.03                 | 0.22                  | 0.10                  | 0.38                             |
| R. apiculata     | 17                       | 6.52                 | 0.21                  | 0.10                  | 0.36                             |
| R. mcroneae      | 15                       | 8.49                 | 0.04                  | 0.02                  | 0.06                             |
| Syzygium sp.     | 1                        | 0.28                 | 0.08                  | 0.04                  | 0.14                             |
| T. catappa       | 1                        | 0.45                 | 0.07                  | 0.03                  | 0.11                             |
| Total            | 165                      | 104.75               | 31.78                 | 14.93                 | 54.68                            |

The studied area has a total AGB of 31.78 t ha$^{-1}$, with a carbon stock of 14.93 t C ha$^{-1}$, and CO$_2$ absorption of 54.68 t CO$_2$ ha$^{-1}$ (Table 4). Moreover, the greatest potentials were found in A. officinalis recording 16.96 t ha$^{-1}$ for AGB, 7.97 t ha$^{-1}$ for Carbon, and 29.25 t ha$^{-1}$ for CO$_2$, respectively. This was due to the abundance of the individual species, accompanied with the elevated BA value, which were shown to influence a positive linear relationship with the potentials of biomass, carbon, and CO$_2$ absorption. However, BA has a stronger relationship (r = 0.90) in comparison with the density (r = 0.84). This was in line with other studies, including [35], [36], and [37]. However, density does not significantly influence the increasing in biomass in comparison with BA [36].
Based on the distribution of dominant species in each plot (Figure 1), the Ciletuh mangrove forest was divided into 10 dominant species, including *A. officinalis*, *A. marina*, *B. cylindrica*, *B. gymnorrhiza*, *L. racemosa*, *H. tiliaceus*, *A. corniculatum*, *E. agallocha*, *R. apiculata*, and *R. mucronata*, and the most dominant species was *A. officinalis*. This spread throughout almost the entire observation plots, indicating it as the largest source of biomass, carbon, and CO$_2$.

![Map of Tree Distribution](image)

**Figure 1.** Map of the distribution of dominant tree species of the Ciletuh mangrove forest

The potentials of biomass, carbon stock, and CO$_2$ absorption in the mangrove of Ciletuh were greater than that of Pemalang, Pohuwato (Gorontalo), and Jor Bay (East Lombok), although comparably lower than what was observed in other regions (Table 5). It was probably resulted in the bigger tree’s diameter and height as well as more diverse mangrove tree species grow in mangrove of
Ciletuh than those of mangrove grow in Pemalang, Pohuwato, and Jor Bay. Similar condition was also occurred in mangrove forest of Cilacap [37]. Mangrove forest biomass tends to bigger to be closer to the inland [38]. Table 5 shows the most significant source of biomass, carbon, and CO$_2$ along the southern coast of Java Island (Pemalang, Serang, and Banyuwangi) to be found in Avicennia spp., a pioneer species that grows closer to the seas or rivers, while the Rhizophora spp. most are scattered far from the sea and close to the inland [39, 40, 41].

Table 5. The potentials of biomass, carbon stock, and CO$_2$ absorption of mangrove forest trees in several locations in Indonesia

| No. | Location                        | Dominant Species       | Biomass (t ha$^{-1}$) | Carbon (t C ha$^{-1}$) | Absorption of CO$_2$ (t CO$_2$ ha$^{-1}$) | Reference |
|-----|---------------------------------|------------------------|-----------------------|------------------------|-------------------------------------------|-----------|
| 1   | Sukabumi, West Java             | A. officinalis         | 31.78                 | 14.93                  | 54.68                                     | This study|
| 2   | Serang, Banten                  | A. marina              | 237.80                | 109.39                 | 401.45                                    | [42]      |
| 3   | Pemalang, Central Java          | Avicennia sp.          | 9.39                  | 4.32                   | 15.85                                     | [42]      |
| 4   | Banyuwangi, East Java           | Rhizophora sp.         | 159.17                | 73.22                  | 268.71                                    | [42]      |
| 5   | Pohuwato, Gorontalo Province    | A. marina              | 431.78                | 198.61                 | 728.89                                    | [43]      |
| 6   | East Lampung                    | Rhizophora mucronata   | 27                    | 13.36                  | 49.03                                     | [44]      |
| 7   | Jor Bay, East Lombok            | Sonneratia alba        | 22.90                 | 10.763                 | 39.50                                     | [45]      |
| 8   | Kubu Raya, West Kalimantan      | R. apiculata           | 438.79                | 219.53                 | 805.67                                    | [46]      |
| 9   | Bandar Bakau, Dumai             | Xylocarpus granatum    | 115.85                | 57.91                  | 212.53                                    | [47]      |
| 10  | Kemujan Island, Karimunjawa     | Excoecaria agallocha, Ceriops tagal | 182.62 | 91.31 | 335.11 | [48] |
| 11  | Mamuju, West Sulawesi           | -                      | 245.96                | 115.6                  | 424.25                                    | [49]      |

Differences potentials of biomass, carbon stock, and CO$_2$ absorption were considered because of the climate disparities, including the rate of rainfall and temperature [50,51,36]. In addition, stand age [52] and the sampling design used [53] can influence the structure and composition of stands [54] used in estimating the potential of biomass, carbon storage, and CO$_2$ absorption. The distinction between diverse locations indicates the large variation of biomass and carbon stock productivity, hence, conducting related studies are important, especially because it is one of the contributions of the REDD’ mechanism [13].

4. Conclusion

The potential of above-ground biomass (AGB) of the Ciletuh mangrove forest was amounted to be 31.78 t ha$^{-1}$, with a carbon stock of 14.93 t C ha$^{-1}$, and CO$_2$ absorption of 54.68 t CO$_2$ ha$^{-1}$. Meanwhile, the greatest potential was observed in A. officinalis as a dominant mangrove tree species, which has the highest individual density and basal area.
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