Carbon uptake and stock potency in Tunda Island mangrove ecosystem, Serang, Banten, Indonesia

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Abstract. Research on carbon uptake and stock potency in Tunda Island mangrove ecosystem was conducted from April to June 2016. The aims of the present study were to analyze carbon stock and uptake, identify the mangrove species most able to take up and store carbon, and estimate the carbon price of Tunda Island mangrove ecosystem. Transects were established at six stations, representative of the southern and eastern areas of mangrove vegetation in Tunda Island. Results show that the biomass of Tunda Island mangrove ecosystem was 196.76 ton/ha, the carbon stock was 91.48 ton/ha, and carbon uptake was 335.06 ton/ha. At the tree and sapling level, the greatest carbon stock and uptake value was found in *Excoecaria agallocha* species with 107.47 ton/ha and 392.23 ton/ha, respectively. Tunda Island mangrove ecosystem has an estimated total carbon price of Rp. 88,690,382–Rp. 221,725,955 per hectare.

Keywords: Biomass, carbon stock, carbon uptake, mangrove ecosystem, Tunda Island

1. Introduction
The Intergovernmental Panel on Climate Change [1] defines climate change as any change in the climate within a certain time interval as a result of natural variation or human activity (anthropogenic factors). Climate change is caused by an alarming increase of greenhouse gases (GHGs) in the atmosphere [2]. Mitigation efforts such as increasing carbon uptake and reducing carbon emissions are necessary to reduce GHGs emission and minimize the impacts of climate change [3]. Forest ecosystem plays an essential role in mitigation action as photosynthesis process take up carbon from the atmosphere. The amount of CO2 absorbed by plants can be revealed by a measurement of carbon biomass stored within [4, 5]. According to Donato et al. [6, 7], mangroves are able to take up and store more carbon compared to the other types of forests.

One of the mangrove ecosystems can be found in Tunda Island, Serang District, Banten Province. However, infrastructure development threat mangrove forest in the island and adversely affected carbon sequestration process. Carbon sink depleted and conversely carbon source increased as the deforestation decomposes biomass into carbon which later released to the atmosphere [8, 9]. Further, this is also impacted to climate change mitigation program namely Reducing Emissions from Deforestation and Forest Degradation+ (REDD+), which aims to reduce carbon emissions by preventing deforestation and forest degradation [10].

Given the multiple benefits of ecosystem services provided by Tunda Island mangrove ecosystem, research is needed to support mangrove conservation program. Therefore, this study aims to analyze the
potency of carbon uptake and stock, identify mangrove species most able to sequestrate and store the carbon, and estimate the carbon price of Tunda Island mangrove ecosystem.

2. Materials and method

2.1. Research time and site
This research was conducted from April to June 2016. Field sampling was performed in Tunda Island mangrove ecosystem, Tirtayasa Subdistrict, Serang District, Banten Province, Indonesia. Identification of mangrove species and data analysis was performed at the Marine Biology Laboratory, Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Indonesia, Depok.

2.2. Materials and tool
Equipments used in this research are distinguished into field-work and laboratory equipment. The field-work tools are including roll meter as the transect gauge, small shovel to scope understory biomass vegetation, zip-lock plastic bags as the temporary storage for biomass sample, global positioning system to spot the station, rope to make plots, tape line to measure diameter at breast height (DBH), hanging tag to label species sample, digital single-lens reflex camera to digitalize the sample, scissors and knife as the cutting tool, and newspaper 40 % formalin, and glue to preserve the sample. The laboratory equipment includes digital scale to weight the sample and oven to drain the water from sample.

2.3. Field sampling
Sampling was conducted respectively at three stations of the southern and the eastern part of Tunda Island mangrove ecosystem. The distance of each station was 200 m. At each station, a 100 m transect was established perpendicular to the shoreline. The distance between plots were 35 m. To identify the mangrove trees in distinct growth stages, three different size plots were used. They were 2 m × 2 m plots to identify seedlings [11], 5 m × 5 m plots for saplings, and 10 m x 10 m plots for trees [12]. There were 18 sample plots in total.

Tree biomass was measured by identifying the tree species and calculating its DBH (stem diameter at a point 137 cm above the ground). Seedling biomass was measured using a destructive method meaning that all parts of the biomass which grow above the ground were taken for analysis. Afterwards, the seedling samples were weighed to obtain the total fresh weight in a plot area. Then at about ± 100 g of the samples were taken and dried at 150–200 °C using a laboratory oven until they reach constant weight [4].

2.4. Data analysis and allometric computations
Biomass and carbon stock values were calculated using allometric computations (1) retrieved from Komiyama et al. [13] as follows:

\[ W_{\text{top}} = 0.251 \rho (D)^{2.46} \]
\[ W_{\text{R}} = 0.199 \rho^{0.899} (D)^{2.22} \]

(W_{\text{top}}, aboveground biomass (kg); W_{\text{R}}, belowground biomass (kg); \rho, wood density (g/cm³); D, diameter (cm)).

Seedling biomass was calculated based on the following formulation [4]:

\[ \text{Total seedling biomass (g)} = \frac{\text{subplot dry weight}}{\text{subplot fresh weight}} \times \text{total fresh weight} \]
Analysis of carbon stock was calculated as follow [14]:

$$C = B \times \% C_{organic}$$  \hspace{1cm} (3)

C: carbon content from biomass (kg); B: total biomass (kg); \% C_{organic}: carbon content percentage, amounting to 0.464.

CO$_2$ uptake was estimated using the relative molecular mass ratio of O$_2$ (44) to C (12) as follow [4]:

$$CO_2 \text{ uptake} = 3.67 \times \text{carbon stock}$$  \hspace{1cm} (4)

Carbon stock per hectare for aboveground biomass was calculated as follows:

$$C_n = \frac{C_x}{1000} \times \frac{10000}{L_{plot}}$$  \hspace{1cm} (5)

C$_n$, carbon content per hectare in each carbon pool in each plot (ton/ha); C$_x$, carbon content of each carbon pool in each plot (kg); L$_{plot}$, area of plot in each pool (m$^2$).

3. Results and discussion

3.1. Analysis of biomass, carbon stock, and carbon uptake

Carbon content analysis at six stations in Tunda Island mangrove ecosystem showed that the biomass was 196.76 ton/ha; the carbon stock was 91.48 ton/ha, and carbon uptake was 335.06 ton/ha. These values represented the carbon content of trees, saplings, and seedling of the mangrove. The ability of mangroves to absorb CO$_2$ from the atmosphere indicated the role of mangrove ecosystems as a carbon sink and could be an option to mitigate climate change. The average biomass, carbon stock values, and carbon uptake of Tunda Island mangrove ecosystem are presented in table 1.

Measurement of carbon stock in a certain area can provide information about the amount of atmospheric CO$_2$ that can be absorbed by the vegetation [15]. The lowest amount of carbon stock and uptake in this study was obtained from station 2 with the value of 3.87 ton/ha and 14.21 ton/ha, respectively. Conversely, the highest value was found in station 3 with 218.14 ton/ha of carbon stock and 796.22 ton/ha of carbon uptake. Accordingly, carbon stock value of seedling was 0.41 ton/ha and the uptake was 1.53 ton/ha. The different amount of carbon stock and uptake between station 2 and 3 are due to the environmental factor including the proximity of mangrove area to human settlement. Station 3 is located far away from settlements, cottage, and ship dock. Meanwhile, station 2 is close to a cottage and ship dock.

Ecological factors such as tree density and diameter are amongst the factors influencing the carbon stock value [15, 16]. Carbon absorbed by mangrove vegetation will be stored in the tree biomass [3, 17], therefore the value of tree biomass is equal to carbon storage. Tree biomass can be estimated based on measurements of stem diameter. The larger the diameter, the more CO$_2$ have been absorbed. Tree diameter increases in a radial direction through continued cell division in cambium and progressively slows down after the tree reached a certain age [15].

This can be seen from carbon stock calculations based on tree trunk diameter. Station 1, which was dominated by *Avicennia marina* with average diameter 25.8 cm, had the highest carbon stock value (34.66 ton/ha; see table 2 below). Station 2 was dominated by *Sonneratia caseolaris* and *Excoecaria agallocha*, with the diameter less than 10 cm on average. The largest diameter recorded at station 2 was 4.84 cm for *E. agallocha* with a carbon stock value of 0.4 ton/ha. The largest diameter of mangrove tree recorded at station 3 was 38.2 cm in *E. agallocha* with a carbon stock value of 55.57 ton/ha. In addition,
*E. agallocha* with the average diameter > 10 cm and has low species density had larger carbon stock values than *E. agallocha* with average diameter < 10 cm and has high density. *Rhizophora stylosa* species at station 4 had the highest average diameter and carbon stock value (22.29 cm and 34.44 ton/ha, respectively). *R. mucronata* at station 5 had average diameter < 10 cm and high tree density. Albeit had high density, the biomass and carbon stock value of the trees were lower than *R. mucronata* with an average diameter > 10 cm and had low tree density. Thus, it confirms that beside the diameter, carbon stock value was also affected by tree density [18].

To corroborate the above hypothesis, spearman correlation statistical analysis was performed in this study. It aims to determine the relationship between tree diameter, density, and carbon stock. According to the spearman test, diameter and carbon stock had a significance value (2-tailed) of 0.000. Thus, indicating that there was a significant correlation between diameter and carbon stock. The correlation coefficient was 0.990, which signifies a high correlation between diameter and carbon stock. The relationship was positive, meaning the larger the tree diameter, the greater the carbon stock value.

There was also a significant correlation between density and carbon stock. The correlation coefficient was −0.567, which indicates a moderate, negative relationship. Signifying that the greater the tree density, the lower the carbon stock value. This result reveals that trees with high densities yet have small diameters do not necessarily have high carbon stock values. On the other hand, trees with large diameters will certainly have high carbon stock values.

### 3.2. Analysis of Biomass, carbon stock, and carbon uptake by species and families of trees

Table 2 shows the biomass, carbon stock, and carbon uptake value of Tunda island mangrove ecosystem according to the tree family and species. *Excoecaria agallocha* was the mangrove species with the greatest total biomass, carbon stock, and carbon uptake (230.33 ton/ha, 107.47 ton/ha, and 392.23 ton/ha, correspondingly). A lot of saplings and seedlings of *E. agallocha* have been found around the plot which signifying a good regeneration condition of the species. *Sonneratia caseolaris* was the species with the lowest total biomass, carbon stock, and carbon uptake value (3.43 ton/ha, 1.59 tons/ha, and 5.84 ton/ha, respectively).

Maintaining vegetation cover and protecting the ecological function of forests are essential to mitigate climate change. One of the international initiatives which aims to protect forest and maintain carbon sink is REDD+. The program mainly targets developing countries and helps them conserving the forest with carbon trading mechanism as the tool [19].

Prior to the trade, the estimation of carbon stock and uptake is required. The value is multiplied by global carbon price which is projected to be between 20–50 USD per ton CO₂ in 2020–2030 [20]. It is equivalent to Rp. 276,140–Rp. 690,350 per ton CO₂ (1 USD = Rp. 13,807). If this value is multiplied

**Table 1.** The average potency of biomass, carbon stock, and carbon uptake at each station in Tunda Island mangrove ecosystem.

| Location | Biomass (ton/ha) | C stock (ton/ha) | C uptake (ton/ha) |
|----------|-----------------|-----------------|------------------|
| Station 1 | 106.32          | 49.33           | 181.05           |
| Station 2 | 8.35            | 3.87            | 14.21            |
| Station 3 | 467.57          | 218.14          | 796.22           |
| Station 4 | 220.64          | 102.38          | 375.73           |
| Station 5 | 84.64           | 39.27           | 144.14           |
| Station 6 | 287.64          | 133.46          | 489.83           |
| Mean      | 195.86          | 91.07           | 333.53           |
| Seedlings | 0.9             | 0.41            | 1.53             |
| Mean total| 196.76          | 91.48           | 335.06           |
Table 2. Total biomass, carbon stock, and carbon uptake in Tunda Island mangrove ecosystem according to tree family and species.

| Family               | Species                  | Biomass (ton/ha) | C stock (ton/ha) | C uptake (ton/ha) |
|----------------------|--------------------------|------------------|------------------|-------------------|
| Rhizophoraceae       | Rhizophora mucronata     | 86.82            | 20.14            | 73.92             |
|                      | Rhizophora stylosa       | 193.18           | 89.63            | 328.97            |
| Total                |                          | 280              | 109.77           | 402.89            |
| Sterculiaceae        | Heritiera globosa        | 29.43            | 13.65            | 50.12             |
| Sonneratiaceae       | Sonneratia caseolaris    | 3.43             | 1.59             | 5.84              |
|                      | Sonneratia alba          | 121.92           | 56.57            | 207.62            |
| Total                |                          | 125.35           | 58.16            | 213.46            |
| Euphorbiaceae        | Excoecaria agallocha     | 230.33           | 107.47           | 392.23            |
| Combretaceae         | Lumnitzera littorea      | 11.82            | 5.48             | 20.13             |
| Avicenniaceae        | Avicennia marina         | 74.70            | 34.66            | 127.21            |

by the ability of Tunda Island mangrove ecosystem to uptake CO₂ which was 335.06 ton/ha, the estimated carbon price would be Rp. 92,523,468–Rp. 231,308,671 per hectare. The carbon price potency of 30 hectare mangrove vegetation in Tunda Island will be Rp. 2,775,704,040–Rp. 6,939,260,130.

4. Conclusion
Tunda Island mangrove ecosystem has the biomass value 196.76 ton/ha, carbon stock 91.48 ton/ha, and carbon uptake 335.06 ton/ha. At the level of tree and sapling, _Excoecaria Agallocha_ is recorded as the species with the greatest value of carbon stock (107.47 ton/ha) and uptake (392.23 ton/ha). Tunda Island mangrove ecosystem has an estimated carbon price of Rp 88,690,382–Rp 221,725,955 per hectare.

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