Potential carbon storage of Indonesian mangroves

M I Maulana\(^1\), N L Auliah\(^1\) and Onrizal\(^{1,2,*}\)

\(^1\)Graduate Program of Forestry, Faculty of Forestry, Universitas Sumatera Utara, Medan, Indonesia.

\(^2\)Tropical Forest Ecology and Biodiversity Conservation Research Group, Universitas Sumatera Utara, Medan, Indonesia.

E-mail: *onrizal@usu.ac.id

Abstract. Even though it only covers 0.1% of the surface of the continent, mangrove forests recorded as carbon-rich forests on earth. Forest loss and degradation together, especially in the tropics contributes about 12% of the total annual anthropogenic CO\(_2\) emissions. Mangrove forests ecosystem have high carbon storage potential. The study results show that the ratio of carbon to area in mangrove ecosystems is almost 13 times greater than that of tropical rainforest ecosystems in Indonesia. This study has used published data recorded in Google Scholar and Science Direct. Indonesia's mangroves, with a total area of 3.1 million ha, store a total carbon of 5.2 Gt. The average stand biomass or aboveground biomass is around 407.15 tons ha\(^{-1}\), storing carbon as much as 191.36 tons ha\(^{-1}\) which is equivalent to the potential for CO\(_2\) absorption (CO\(_2\)e) by mangrove stands of 702.29 tons ha\(^{-1}\). Papua has the largest mangrove forest in Indonesia that has the potential for CO\(_2\)e. Assessment of carbon storage in soil needs to be done in estimating the total carbon stored in mangrove ecosystems, given the large potential for stored carbon that plays a role in climate change mitigation.

1. Introduction

Mangrove forests have a higher capacity than terrestrial forests to store large amounts of carbon in the soil over thousands of years. Mangroves with waterlogged soils, high sedimentation rates, and complex root structures that are free of fire risk, and anoxic soils result in greater levels of carbon storage and a thousand times slower rate of soil carbon turnover than in terrestrial forests. Mangrove ecosystems ability to reserve major amounts of soil carbon (5-10.4 Gt globally) over thousands of years makes this ecosystem important for carbon sequestration, and reduces or prevents greenhouse gas (GHG) emissions from losing soil carbon stocks [1]. This is an important option for mitigating climate change at a low cost.

Mangrove forests are well known for a series of ecosystem services, including fiber and fisheries production, protection from hurricane or tsunami, and sediment regulation, but its potential is decreasing rapidly as a consequent of aquaculture expansion, land clearing, excessive utilization, and development. The decline of 30-50% of the area during the last half century has prompted estimates that mangrove forests can be functionally disappearing only in 100 years. The 21st century's rapid sea level rise has also been cited as a major threat to mangrove forests, which have responded to past sea level changes by migrating to land or upward [2,3].

Mangroves cover only 0.1% of the continental surface of Earth (~81,485 km\(^2\)) [4], but have been confirmed as some of the highly carbon-rich (C) forests on earth. Indonesia itself is a country with the
largest mangroves in the world, around 28% of the world's mangroves in 2014 [4]. However, Indonesia was also recorded as the country with the largest loss of mangroves [4-6]. Indonesia's annual mangrove deforestation rate is about double the global average or nearly half of all global mangrove loss [4,6].

Forest loss and degradation result in carbon dioxide (CO\(_2\)) emissions that contributes to carbon sequestration capacity loss, climate change, and invaluable ecosystem services loss as well as biodiversity loss. Forest loss and degradation occurs mainly in the tropics; which accounts for approximately 12% of the total annual anthropogenic emissions of CO\(_2\) [7,8]. Therefore, this paper analyzes CO\(_2\) absorption based on carbon stocks of mangrove forests in several regions of Indonesia.

2. Materials and methods
This paper is the result of a review of various literature studies published in peer reviewed journals. Articles obtained from Google Scholar and Science Direct databases. CO\(_2\) sequestration analysis is calculated by converting the carbon content into CO\(_2\) using the following equation [9-11].

\[
CO_2e = \frac{Bm.CO_2}{Ba.C} \times C
\]  

(1)

Where \(CO_2e\) is the carbon dioxide equivalent (tons ha\(^{-1}\)), \(Bm.CO_2\) is the relative molecular weight of the CO\(_2\) (44), \(Ba.C\) is the relative atomic weight of C (12) and \(C\) is the carbon content (ton ha\(^{-1}\)) or following the equation of [12]:

\[
CO_2e = 3.67 \times C \text{ content}
\]  

(2)

3. Results and discussion
Net primary productivity and biomass of mangrove forests have been studied in a variety of mangrove forests around the world. The purpose of estimating the productivity and biomass of mangrove forests is important in ecosystem management and evaluating carbon stocks. However, production of biomass depends on the interaction between various factors, such as climate and topography and there are also some methodological differences in the estimation of net primary productivity [13].

Mangrove forests have an important role in managing the global climate and providing ecosystem products and other services [2,8,14-16]. Mangrove forests are recorded as the highly carbon-rich forests in the tropical areas and their carbon sequestration potential is counted to be up to 5 times that of tropical rain forests [2]. A recent valuation of carbon stored in various mangrove areas found that the Indo-Pacific is one of the highly carbon-rich forests in the tropics comprising, on average, 1,023 tC ha\(^{-1}\), most of which is deposit in soils with depth > 30 cm [2].

The total carbon potential of mangroves can be quantified by adding up the potential above-ground carbon (AGC), subsurface carbon or root system (BGC), and soil carbon (SOC). According to Rahadian [17], it is shown that in Indonesia, the ratio of carbon stock to mangrove forest area is almost 13 times greater than that of rainforest. He compared the total value of mangrove carbon storage with rainforest through reference to carbon stock by MoEF [18] of 125.02 t C ha\(^{-1}\), and then multiplied it by the area of remaining rainforest in Indonesia (93.95 million ha) [18], hence the total rainforest carbon storage is approximately 11.74 Gt C. Meanwhile, mangroves, which only cover a total area of 3.1 million ha, store carbon reaching 5.2 Gt C (Table 1). Thus, if the mangrove ecosystem is disturbed then the resulting emissions would also be higher than the terrestrial ecosystems in the same area.

Table 2 shows that mangroves in Indonesia have an average aboveground biomass (AGB) of around 407.15 tons ha\(^{-1}\), or carbon of 191.36 tons ha\(^{-1}\), so the potential for CO\(_2\) absorption by mangrove stands is 702.29 tons ha\(^{-1}\). Papua has a major contribution in carbon sequestration because it has the largest mangroves compared to other regions in Indonesia.
Table 1. Total carbon potential of mangrove ecosystems by region in Indonesia [17]

| Region     | Mangrove Area (ha) | Total AGC (Gt) | Total BGC (Gt) | Total SOC (Gt) | Total C stock (Gt) |
|------------|-------------------|----------------|----------------|----------------|--------------------|
| Papua      | 1,400,044.83      | 1.018          | 0.398          | 1.503          | 2.919              |
| Sumatra    | 638,319.48        | 0.318          | 0.124          | 0.470          | 0.912              |
| Kalimantan | 673,762.64        | 0.312          | 0.122          | 0.461          | 0.894              |
| Moluccas   | 234,558.95        | 0.115          | 0.045          | 0.170          | 0.329              |
| Sulawesi   | 129,790.77        | 0.042          | 0.016          | 0.062          | 0.120              |
| Java       | 46,019.44         | 0.008          | 0.003          | 0.012          | 0.023              |
| Bali-Nusra | 34,248.66         | 0.005          | 0.002          | 0.007          | 0.014              |
| Indonesia  | 3,156,744.77      | 1.818          | 0.710          | 2.684          | 5.213              |

Note: AGC = above-ground carbon; BGC = below-ground carbon; SOC = Soil Organic Carbon.

Table 2. Potential an average mangrove CO2e per unit area by region in Indonesia*

| Region     | Mangrove Area (ha) | µ AGB (ton ha⁻¹) | µ AGC (ton ha⁻¹) | µ CO2e (ton ha⁻¹) |
|------------|-------------------|-----------------|----------------|-----------------|
| Papua      | 1,400,044.83      | 496.50          | 233.35         | 856.39          |
| Sumatra    | 638,319.48        | 468.69          | 220.28         | 808.43          |
| Kalimantan | 673,762.64        | 466.88          | 219.43         | 805.31          |
| Moluccas   | 234,558.95        | 385.76          | 181.31         | 665.41          |
| Sulawesi   | 129,790.77        | 359.08          | 168.77         | 619.39          |
| Java       | 46,019.44         | 347.49          | 163.32         | 599.38          |
| Bali-Nusra | 34,248.66         | 325.65          | 153.05         | 561.69          |
| Indonesia  | 3,156,744.77      | 407.15          | 191.36         | 702.29          |

Note: *based on this study

Due to the absorption of CO2 and carbon storage of mangroves is much greater than rainforests, mangroves are very important in mitigating climate change and becoming an asset in reducing GHG emissions. When mangroves are part of Nationally Determined Contributions (NDC), it will provide an opportunity to fill the gap in emission reduction programs. The mangrove area, which is still considered very small compared to the rainforest, has neglected the mangrove ecosystem role in climate change mitigation. This is because the value of mangrove soil carbon storage is not included, causing an underestimate of the total carbon value in the mangrove ecosystem [17]. Most of the carbon storage of mangrove ecosystems is stored in the soil [2,19-21].

4. Conclusions and recommendations
Indonesia has a ratio of carbon stock to area in mangrove forests nearly 13 times greater than rainforests. Indonesia's mangroves with a total area of 3.1 million ha store a total carbon of up to 5.2 Gt C with an average AGB of around 407.15 tons ha⁻¹, storing carbon of 191.36 tons ha⁻¹, and the potential for CO2 absorption by mangrove stands amounting to 702.29 tons ha⁻¹. Papua has a biggest contribution with the largest mangroves and has the potential for high CO2 absorption. Soil carbon storage needs to be included in estimating the total carbon value in mangrove ecosystems, given the large potential for stored carbon and CO2 absorption which plays an important role in mitigating climate change.

References
[1] Atwood T B, Connolly R M, Almahasheer H et al. 2017 Nature Climate Change 7(7) pp 523-528
[2] Donato D C, Kauffman J B, Murdiyarso D et al. 2011 Nature geoscience 4(5) pp 293-297
[3] Sahu S C, Suresh H S, Murthy I K et al. 2015 *Journal of Earth Science & Climatic Change* **6**(5) p 1

[4] Hamilton S E and Casey D 2016 *Global Ecology and Biogeography* **25**(6) 729-738

[5] Giri C, Ochieng E, Tieszen L L, et al. 2011 *Global Ecology and Biogeography*, **20**(1) 154-159.

[6] Onrizal, Thoha A, Ahmad A et al. 2018 *Proceedings of the International Conference of Science, Technology, Engineering, and Ramification Researches* DOI: 10.5220/0010098501020105

[7] Van der Werf G R, Morton D C, DeFries R S et al. 2009 *Nature geoscience* **2**(11) pp 737-738

[8] Njana M A, Zahabu E and Malimbwi R E 2018 *Southern Forests: a Journal of Forest Science* **80**(3) pp 217-232

[9] Dharmawan I W S and Siregar C A 2008. *Karbon Tanah dan Pendugaan Karbon Tegakan Avicennia marina (Forsk.) Vierh di Ciasem Purwakarta* [Soil Carbon and Estimation Carbon Density Avicennia marina (Forsk.) Vierh in Ciasem Purwakarta] *Jurnal Penelitian Hutan dan Konservasi Alam* **5**(4) 317-328.

[10] Heriuyanto N M and Subiandono E. 2012. *Komposisi dan Struktur Tegakan, Biomassa, dan Potensi Kandungan Karbon Hutan Mangrove di Taman Nasional Alas Purwo* [Composition and Density Structure, Biomass and Potention of Mangrove Forest Content in National Park Alas Purwo] *Jurnal Penelitian Hutan dan Konservasi Alam* **9**(1) 23-32

[11] Prakoso T B, Afati N and Suprapto D. 2018. *Biomassa Kandungan Karbon dan Serapan CO2 Pada Tegakan Mangrove di Kawasan Konservasi Mangrove Bedono, Demak* [Biomass Carbon Content and CO2 Absorbtion on Mangrove Density in Mangrove Conservation Area Bedono, Demak] *Management of Aquatic Resources Journal* **6**(2) 156-163

[12] Onrizal 2018 *Proceedings of the International Conference of Science, Technology, Engineering, and Ramification Researches* doi: 10.5220/0010089600780082

[13] Kamruzaman M, Osawa A, Deshar R et al. 2017 *Regional Studies in Marine Science* **12** pp 19-27

[14] Nagelkerken I, Blaber S J M, Bouillon S et al. 2008 *Aquatic botany* **89**(2) 155-185

[15] Zhang K, Liu H, Li Y, Xu H et al. 2012 *Estuarine, Coastal and Shelf Science* **102** pp 11-23

[16] Komiyama A 2014 *Reviews in Agricultural Science* **2** 11-20

[17] Rahadian A 2019 *Spatial Model of Biomass and Mangrove Carbon Estimation in Indonesia* Graduate School of IPB University, Bogor.

[18] MoEF 2016 *National Forest Reference Emission Level for Deforestation and Forest Degradation: In the Context of Decision 1/CP.16 para 70 UNFCCC 69* (Encourages developing country Parties to contribute to mitigation actions in the forest sector) Directorate General of Climate Change, The Ministry of Environment and Forestry Indonesia

[19] Murdiyarso D, Purbopuspito J, Kauffman J B, Warren M W, Sasmito S D, Donato D C, Manuri S, Krisnawati H, Taberima S and Kurnianto S 2015 *Nature Clim Change* **5** pp 1089-1092

[20] Sanders C J, Maher D T, Tait D R et al. 2016 *Journal of Geophysical Research: Biogeosciences* **121**(10) pp 2600-2609

[21] Sanderman J, Hengl T, Fiske G et al. 2018 *Environmental Research Letters* **13**(5) p 055002

Acknowledgements

Thank goes to Ministry of Research and Technology/BRIN for funding this research through the 2020 PDUPT research scheme (27/E1/KPT/2020 and 11/AMD/E1/KP.PTNBH/2020).