Soil carbon stock in different of mangrove ecosystem in Mahakam Delta, East Kalimantan, Indonesia

Rita Diana[1*], *Kiswanto* Kiswanto[1], *Esti Handayani* Hardi[2], *Nurul Puspita* Palupi[3], *Retno Haris* Susmiyati[4], *Jaslin* Jaslin[1], *Paulus* Matius[1], *Syahrinudin* Syahrinudin[1], and *Karyati* Karyati[1]

[1]Mulawarman University, Forestry Faculty, Kampus Gunung Kelua, Samarinda, Indonesia
[2]Mulawarman University, Fishery and Marine Faculty, Samarinda, Indonesia
[3]Mulawarman University, Agriculture Faculty, Samarinda, Indonesia
[4]Mulawarman University, Faculty of Law, Samarinda, Indonesia

Abstract. Mangrove forests serve as a buffer against sedimentation from the mainland into the sea, protect the area from coastal erosion, and prevent seawater intrusion in some ecological types of coastal environments. Additionally, because soil and below-ground biomass retain a significant quantity of carbon, they are essential for carbon sequestration. The current study seeks to estimate the soil organic carbon stock of mangroves associated with natural regeneration, mangrove rehabilitation areas and abandoned shrimp ponds, in Mahakam Delta, East Kalimantan, Indonesia. A 125-meter-long transect line was used to collect data, with three sampling points representing the length of the transect line. Each soil sample was taken at three different depths: 0-50 cm, 50-100 cm, and 100-150 cm. After that, the samples were taken to the laboratory for carbon analysis. The mangrove rehabilitation area had the highest bulk density at 8.64 gr/cm3, followed by natural mangroves along the river border at 7.67 gr/cm3, and abandoned ponds had the lowest at 7.16 gr/cm3. The rehabilitation area had the highest soil carbon stock at 1120 tons/ha, followed by natural mangroves along the riverside at 686 tons/ha and abandoned ponds at 383 tons/ha. In accordance with the study, mangrove rehabilitation regions had larger soil carbon stocks than natural regeneration along the riverside and abandoned ponds. In order to protect the ecologically significant mangrove ecosystem and minimize the effects of climate change, mangrove restoration and rehabilitation are necessary.

1 Introduction

Mangroves are an ecologically and economically significant environment. According to Giri et al. [1] 22.6% of the global mangrove area is located in Indonesia. The mangrove ecosystem in the Mahakam Delta region is comprised of numerous forest stand zones that grow on

* Corresponding author: ritadiana@fahutan.unmul.ac.id

alluvial mud soils in coastal locations around the Mahakam Delta, which is affected by sea tides [2]. *Avicennia, Sonneratia, Rhizophora, Bruguiera, Ceriops,* and *Lumnitzera* form the dominant zones, which are accompanied by numerous lesser species of mangrove forests: *Excoecaria, Xylocarpus, Aegiceras, Scyphyceras,* and Nypa spp. stands [3].

Mangroves typically develop in coastal regions, but many also inhabit river border regions, which act as a buffer between aquatic ecosystems (such as rivers) and the land. Because of the resilience of the soil structure and the ease with which it may be prevented from erosion and erosion brought on by water currents, mangroves that grow along riverbanks can withstand erosion. The neighborhood makes use of this benefit to construct ponds since, if the river border is functioning well, it can make river valleys more stable and pond embankments prevent protracted cliff scouring [4]. The majority of pond aquaculture operations take place in mangrove-covered coastal areas. On the river bank of the Salo Sumbala, Muara Badak, in the Mahakam Delta, the secondary mangrove ecosystem is still in great condition [5].

Continuous exploitation of mangrove regions can diminish the diversity of plant species that play a leading role and function ecologically and could be used for socioeconomic purposes [6]. Mangrove ecosystems serve a crucial role in mitigating global climate change, also known as blue carbon, by boosting carbon absorption [1]. According to Kauffman et al. [7], mangrove forest ecosystems can perform better in terms of overall ecosystem carbon pools than dry plain forest ecosystems, especially tropical forest ecosystems. Mangrove forest ecosystems have the capacity to store more than 1000 tons of carbon per hectare; this carbon is primarily found in the soil's subsurface layer. This number determines the value of soil carbon deposits [6]. The bulk density of the soil is closely correlated with the soil's own density. The bulk density increases with soil density. In order to lessen global warming and climate change, the carbon contained in soil, such as soil organic carbon (SOC), can be removed from the atmosphere [8]. Carbon stock research in natural mangroves and ponds has been widely conducted in the Mahakam Delta [3, 5]. Meanwhile, more information on carbon soil stocks in rehabilitated areas, particularly where ponds once existed, is required. Thus, the purpose of this study is to determine the soil bulk density and the difference in carbon deposits in the soil in natural mangroves, abandoned ponds, and former ponds that have been rehabilitated in the Mahakam Delta.

2 Material and methods

2.1 Study area

This research was conducted in the Mahakam Delta in Muara Badak District on riverside natural mangroves in Muara Badak Ulu Village, Abandoned Pond Mangroves and Mangrove Rehabilitation Areas in Salo Palai Village, Kutai Kartanegara Regency as shown in Figure 1.

 https://doi.org/10.1051/e3sconf/202337302003

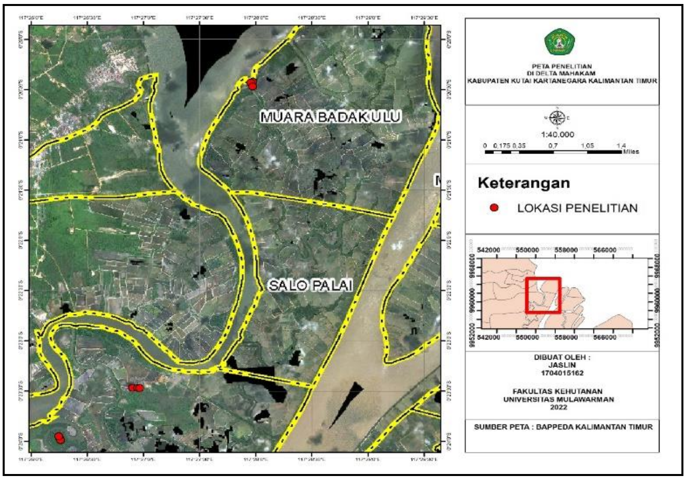

Fig. 1. Research area in Mahakam Delta.

2.2 Sampling and data analysis

A peat drill, GPS, drone, scales, sample ring, and compass were used in the study. The study data was collected using a 125-meter-long transect path, with three sampling location points representing the length of the transect path. Each soil sample point was collected at three depths: 0-50 cm, 50-100 cm, and 100-150 cm (Figure 2a, 2b). The sample is placed in a ring sample and weighed at its wet weight (Figure 2c), and the sample is transported to the laboratory for carbon soil analysis.

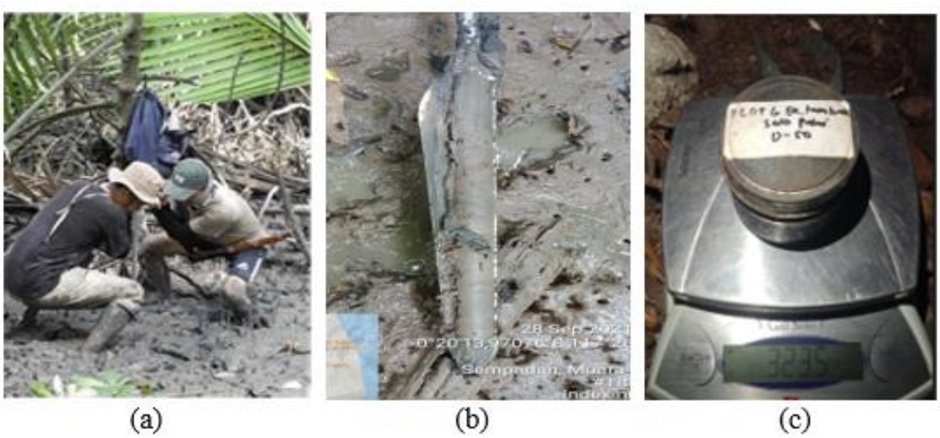

Fig. 2. Soil sampling: (a) soil sampling using peat drills (b) Soil samples on peat drill bits (c) soil samples are put in ring samples and weighed.

Three sampling points are used, each with a depth interval of 50 cm (0-50 cm, 50-100 cm, and 100-150 cm), to sample the soil's carbon content. Use the following formula to calculate the amount of soil carbon:

$$Ct = Kd \times \rho \times \%\, C\ organic \qquad (1)$$

 https://doi.org/10.1051/e3sconf/202337302003

Where:
Ct = soil carbon content (grams per centimeter squared ~g/cm2)
Kd = depth of soil sample (centimeters ~ cm)
ρ = bulk density (g/cm3)
% C organic = percentage value of carbon content

3 Result and discussion

3.1 Bulk density

The data analysis revealed that the rehabilitated mangrove area had the highest bulk density. This finding demonstrates that the area of former ponds rehabilitated with mangrove plants has an effect on increasing soil bulk density when compared to natural mangroves on river banks and abandoned pond areas.

Table 1. Bulk density value in three Mangrove Forest Conditions.

Location	Sample	Depth			Total (gr/cm^3)	Average
		0-50 cm	50-100 cm	100-150 cm		
Abandoned Pond Mangroves	1	0.85	0.92	0.88	7.16	0.80
	3	0.73	0.95	0.73		
	6	0.61	0.77	0.72		
Mangrove along riverside	1	0.98	0.74	0.90	7.67	0.85
	3	0.88	0.83	0.85		
	6	0.82	0.83	0.84		
Mangrove Rehabilitation Areas	1	0.91	0.89	0.82	8.64	0.96
	3	1.10	1.05	0.95		
	6	0.89	0.96	1.07		

According to Donato et al. [9], the relationship between infiltration rate and stand density is unaffected because the nature of the soil, if it has a lot of pore space, can increase infiltration rate. The greater the density of the stand, the less pore space there is in the soil, and the more weight there is in the soil, the greater its bulk density. According to the Table 1, the soil sample has a different bulk density value at each excavation point due to the structure of the soil layer at different depths. According to Hardjowigeno [6], bulk density can vary from layer to layer depending on the pore space or soil structure.

3.2 Soil carbon stock in three different mangrove ecosystems

The results of the laboratory carbon percentage analysis are then computed to determine the value of soil carbon storage in each mangrove forest condition.

Table 2. Soil carbon stock in three different locations.

Site location	Bulk Density (gr/cm^3)	C Organik (%)	C Organik	C Total (ton/ha)
Natural regeneration mangrove	0,80	9,529	0,095	383
Rehabilitation mangrove area	0,96	23,3	0,233	1120
Mangrove along riverside	0,85	16,3	0,163	686

According to Table 2, the Mangrove Rehabilitation Area has the highest total carbon storage at 1120 tons/ha, followed by riverside natural mangroves at 686 tons/ha and abandoned ponds at 383 tons/ha. The density of mangroves at each of the three study sites can cause a difference in carbon storage. However according to Richards and Friess [10], the different carbon analysis results can be influenced by the number and density of trees, tree species, and environmental factors such as solar irradiation, moisture content, temperature, and soil fertility, all of which affect the rate of photosynthesis. According to the findings of this study, the rehabilitation area has a higher carbon value than the area overgrown with mangroves along the riverbank and the area of mangroves that grow naturally in abandoned ponds. Furthermore, the density of trees in natural mangroves along the river and in abandoned pond areas is lower than in mangrove rehabilitation areas. Moreover, due to the type that causes type differences in the three locations, tidal conditions can affect the amount of carbon stored.

The soil's total carbon source includes not only mangrove vegetation but also solid deposits in estuary waters [11] and algae [12]. Tides and sedimentary deposits can also have an impact on soil carbon stocks. Erratic tidal conditions also reduce soil carbon sedimentation. The constituents of soil particles are washed at any time due to the ups and downs that occur. As a result, the carbon stored in it can be carried away by tidal currents [7, 9].

Mangrove soil particles are dominated by sandy mud and numerous macro-pores. Because the soil has a low water retention capacity, the soil density is low [13]. Furthermore, such soil is susceptible to leaching. As a result, mangrove roots play an important role. Mangrove roots serve as a good sediment trap in addition to supporting the growth of mangrove tree stands. The *Rhizophora mucronata* stands dominate the Mangrove Rehabilitation Area, which have supporting roots that can help maintain the organic joints of the soil and withstand the impact of waves. Mangrove stands surrounding the mangrove rehabilitation area help reduce river flow directly to the rehabilitation site. Because the location of natural mangroves on the riverbank can be directly affected by river currents, tides cause soil particle leaching. As a result, the soil carbon stock along the river has a lower value than in the rehabilitation area. The Natural Mangrove Riverside has a wide variety of vegetation. Other species with bristly roots, such as *Avicennia sp.* and *Sonneratia alba*, are the dominant species under *Rhizophora apiculata* with supporting roots.

Differences in stand roots can also affect the ability of soil organic sediments to be retained. Because the breath root is shaped like a pencil or cone that protrudes upwards and is brownish, it has many gaps in places for air to enter [14]. Because there is enough vacant land in the middle of the area, an abandoned pond has a lower carbon storage value. Although *Rhizophora mucronata* stands with supporting roots dominate this location, the low vegetation density can reduce the value of soil carbon stock.

The data analysis using ANOVA results revealed that the depth of the soil did not differ significantly. Meanwhile, differences in location have a significant impact on soil carbon storage. The difference in the density of mangrove stands that comprise each location is thought to account for the soil carbon stock. Meanwhile, the carbon content of biomass and CO2 absorption in mangrove stands show that mangrove ecosystems have a significant impact on CO2 concentrations in the atmosphere [15]. Because the density of mangroves affects the amount of biomass produced by mangroves, the greater the number of mangroves stands, the better it is to absorb CO2. Meanwhile, differences in soil depth have no effect on carbon storage because the soil layer in each location is relatively the same [16]. According to the National Land Agency's 2010 soil type map data for East Kalimantan Province, there is only one soil type in this area, which is the Wet Entisol soil type. According to Rahman et al. [2] the mangrove ecosystem in the Mahakam Delta area is mainly composed of several forest stand zones that grow on alluvial mud soils near the mouths of the Mahakam river, which are influenced by tides.

4 Conclusion

The rehabilitation area has the highest bulk density value, followed by natural mangroves along the riverside, and abandoned ponds have the lowest. At 383 tons/ha, abandoned ponds used to have the lowest carbon stock value. Similarly, the mangrove rehabilitation area has the most extensive soil carbon storage at 1120 tons/ha, followed by natural mangroves on the river's edge at 686 tons/ha. As a result, rehabilitation is required in the area of the abandoned pond.

This reaearch is part of a collaboration between Mulawarman University and BRGM under Maching Fund Kedaireka Program.

References

1. C. Giri, E. Ochieng, L. L. Tieszen, Z. Zhu, A. Singh, T. Loveland, N. Duke, Global Ecology and Biogeography **20**, 1 154–159 (2011)
2. A. F. Rahman, D. Dragoni, A. B. Munoz, J. A. Hutabarat, Remote sens. Environ. 130, 96-107 (2012)
3. V. Arifanti, J. Kauffman, D. Hadriyanto, D. Murdiyarso, R. Diana, Forest Ecology and Management 432, 17-29 (2019)
4. R. N. A. Ati, A. Rustam, T. L. Kepel, N. Sudirman, M. Astrid, A. Daulat, A. A. Hutahaean, Jurnal Segara **10**, 2 119-127 (2014)
5. R. Diana, P. Matius, M. Hendra, R. Melsitiara, *Species diversity and estimation of carbon stock in abandoned shrimp pond of mangrove ecosystem in East Kalimantan* (IOP Conf.Series: Earth and Enviromental Science 800 2021)
6. S. Hardjowigeno, Klasifikasi Tanah dan Pedogenesis (Akademika Pressindo, Jakarta, 2003)
7. J. B. Kauffman, D. C. Donato, Protocols for the measurement, monitoring and reporting of structure, biomass and carbon stocks in mangrove forests (Working Paper 86. CIFOR, Bogor, Indonesia, 2012)
8. Y. Chan, Primefact 735, 1-5 (2008)
9. D. C. Donato, J. B. Kauffman, D. Murdiyarso, S. Kurnianto, M. Stidham, M. Kanninen, Nature Geoscience **4**, 5 (2011)
10. D. R. Richards, D. A. Friess, *Rates and drivers of mangrove deforestation in Southeast Asia, 2000–2012* in Proceedings of the National Academy of Sciences, 113(2): 344–9 (2016)

11. Y. Yong, P. Baipeng, C. Guangcheng, C. Yan, Acta Ecologica Sinica. **31**, 3 (2011)
12. G. Wang, D. Guan, M. R. Peart, Y. Chen, Y. Peng, Forest Ecology and Management 310 (2013)
13. A. Widyastuti, Y. E. Nasution, E. Rochmatino, Biodiversitas **19**, 1 (2018)
14. R. Wiarta, Y. Indrayani, F. Mulia, D. Astiani, Biodiversitas **20**, 2 (2019)
15. T. B. Prakoso, N. Afiati, D. Suprapto, Management of Aquatic Resources Journal (MAQUARES) **6**, 2 (2018)
16. A. Ayma-Romay, H. Bown, Forest Ecosystems **6**, 1 (2019)