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Organic Carbon Dynamics In Mangrove Sediments Of North Minahasa, Indonesia

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Abstract

This study aimed to investigate the carbon content in mangrove sediments within the North Minahasa District Marine Conservation Area and to understand the factors affecting organic carbon dynamics. It is revealed that the carbon content is significantly varied. Carbon content ranged from 13.874 to 132.65 Mg C ha-1 across different sampling locations, with an overall stored carbon content estimated at approximately 645.19 Mg C ha-1. Soil density and depth were identified as key factors influencing carbon storage, with thicker soil density associated with higher carbon reserves. These findings highlight the importance of understanding local sediment characteristics for effective blue carbon ecosystem management and conservation strategies.

Keywords: carbon, sediment, mangrove, North Minahasa

INTRODUCTION

The mangrove ecosystem is a blue carbon ecosystem, which involves capturing and storing organic carbon in oceanic and coastal environments. Blue carbon ecosystems include vegetative coastal ecosystems such as seagrass, tidal marshes, and mangrove forests (Macreadie et al. 2019; Bulmer et al. 2020). This carbon comprises soil surface living biomass (leaves, branches, trunks), underground living biomass (root and rhizome), and nonliving biomass (litter and dead woods) (Howard et al. 2014). The blue carbon ecosystem is important in aquatic carbon dynamics and significantly reduces global climatic change's impact (Bulmer et al. 2020; Stankovic et al. 2023). Indonesia can sequester carbon amounting to 3.4 gigatons, equivalent to roughly 17% of the blue carbon produced worldwide (Alongi et al. 2016).

Mangrove ecosystems, situated at the interface of land and sea, serve as crucial carbon sinks, especially in coastal regions. These unique habitats play a significant role in carbon sequestration, primarily through the storage of organic carbon in their sediments, thereby contributing to climate change mitigation and coastal resilience. Mangrove forests are recognized as the most effective carbon storage forests, with a substantial portion of their carbon stored underground (Alongi, 2012). Organic carbon in mangrove sediments is derived from various sources, including mangrove litter (leaves, roots, and wood), microalgae, and terrestrial runoff. Studies have underscored the dominant role of mangrove-derived detritus in enriching the sedimentary organic carbon pool. For example, Bouillon et al. (2008) demonstrated that mangrove leaves and roots significantly contribute to the organic carbon content in sediments, often distinguished using δ13C isotopic analysis to differentiate between marine and terrestrial sources.

Several factors influence the dynamics of organic carbon in mangrove sediments, such as sedimentation rates, microbial activity, and tidal flushing. High sedimentation rates can enhance organic carbon burial and long-term storage. Microbial decomposition is pivotal in transforming and mineralizing organic carbon, with variations in microbial activity influenced by sediment depth and oxygen availability (Kristensen et al., 2008). Tidal dynamics also play a critical role; tidal flushing transports organic material in and out of mangrove ecosystems, affecting the spatial distribution and retention of organic carbon. Frequent tidal inundation promotes the deposition of fine particles and associated organic matter, thereby boosting organic carbon accumulation in mangrove sediments (Chen et al., 2017).

This research examines the carbon content in mangrove sediments within the North Minahasa District Marine Conservation Area, aiming to understand the factors influencing organic carbon dynamics to enhance understanding of carbon sequestration processes. Encompassing 4,542 hectares, the North Minahasa District constitutes the largest government-protected mangrove region in North Sulawesi Province, Indonesia. Due to the limited studies on carbon content in this area, this investigation addresses a critical knowledge gap.

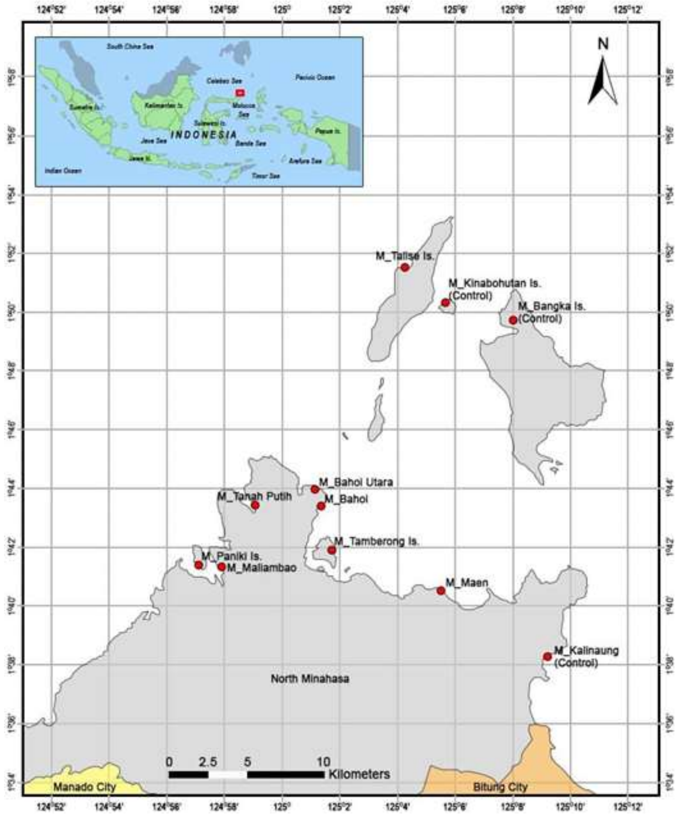

Figure 1. Study site

METHODOLOGY

The sediments were sampled using a sediment core from eleven locations at two subdistricts in North Minahasa Districts of North Sulawesi Province. The following tables list all villages and their subdistricts.

Data collection.

The percentage of organic carbon in the soil is soil sample depth, sampling intervals, and soil density (bulk density). The sample sediment is collected by putting the sediment core into the substrate through the maximum limit. The sample collected is divided by 5 cm and kept in a sample plastic for laboratory analysis. The sediment samples were initially dried in porcelain dishes at 60˚C for 48 hours. Once dried, they were ground to achieve homogeneity using a mortar, after which they were returned to their respective sample bags. Subsequently, 3 grams of each sample were carefully weighed using a small spoon and transferred into porcelain crucibles. The samples underwent combustion in a muffle furnace at 450˚C for 4 hours. Following combustion, the samples were re-weighed, and the recorded results were documented.

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The obtained samples are analyzed in the laboratory using the loss on ignition (LOI) method (Howard, J et al., 2014). The analysis steps are as follows: dry sediment samples in porcelain dishes at 60˚C for 48 hours, and then, ground them to achieve homogeneity using a mortar, and after that return them to their respective sample bags. Subsequently, 3 grams of each sample were carefully weighed using a small spoon and transferred into porcelain crucibles. The samples underwent combustion in a muffle furnace at 450˚C for 4 hours. Following combustion, the samples were re-weighed, and the recorded results were documented.

Sampling locations, subdistricts, and coordinates.

Locations		**Coordinates**	
Names	**Subdistricts**	**Latitute**	**Longitude**
Paniki Island	West Likupang	1,690222	125,9517
Tamberong Island	West Likupang	2,698556	125,0286
Maen	East Likupang	1,675111	125,0921
Kalinaung	East Likupang	1,637917	125,1531
Tanah Putih	West Likupang	1,723417	125,9838
Bangka Island	East Likupang	1,828639	125,1337
Kinabuhutan Island	West Likupang	1,8385	125,0943
Talise Island	West Likupang	1,858444	125,0709
Bahoi Utara	West Likupang	1,732627	125,018874
Bahoi	West Likupang	1,723105	125,022358
Maliambao	West Likupang	1,689041	125,965168

Data Analysis. The parameters computed encompass sediment sample depth, soil density, carbon density, estimated carbon content, and the percentage of organic carbon within the sediment. The analytical calculations employed are based on the methodologies described by Howard et al. (2014) as follows:

1. Soil density is the weight of soil particles per unit volume, including its pores. The formula used to calculate soil density (BD) is presented in Equation 1, as follows:

Soil Density (g/cm3)

$$= \frac{oven-dry\ mass\ (\mathrm{g})}{sample\ volume\ (\mathrm{cm}^3)} \ldots\ldots\ldots\ldots\ldots(1)$$

2. The loss on ignition (LOI) is calculated using Equation 2, as follows:

$$\%\ \mathrm{BO} = \left(\frac{\mathrm{Wo}-\mathrm{Wt}}{\mathrm{Wo}}\ \mathrm{X}\ 100\right) \ldots\ldots\ldots\ldots(2)$$

Where:
BO is percentage of organic matter in the sediment lost during the combustion process.
Wo is the initial weight (gram)
Wt is the final weight after combustion (gram)

3. The conversion of the percentage of organic matter to the percentage of carbon is calculated using Equation 3, as follows:

% C= (1/1.724) X % BO …….(3)

Where:
%C is the carbon content of organic sedimentary material
1.724 is a constant for converting % organic matter to % organic carbon (C)

4. The carbon (C) density is calculated using Equation 4, as follows:

Soil C density (g C cm^{-3}) = %C x BD.........(4)

Where:
BD is soil density

5. The carbon content in the soil is estimated using Equation 5, as follows:

Soil C ($mgCha^{-1}$) = BD x SDI (*Soil Depth Interval*) x % C ....(5)

Where:
Soil C ($mgCha^{-1}$) is the Carbon Storage Estimation
*S*DI is Depth Sample Interval (cm)

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Total sediment carbon of one core is determined by summing up all sediment carbons in each interval, then converted, and uniformed through the depth of 1 meter.

RESULTS AND DISCUSSIONS

Soil density.

The results showed that the soil density at all sites varied a little bit from 0.414 to 401 g/cm^3. Tamberong Island has the highest soil density at 0.414 g/cm^3 followed by Kinabuhutan Island at 0.412 g/cm^3. while the lowest is on Talise Island at only 0.401 g/cm3. The result of soil density analysis is presented in Figure 2.

Compared to the soil density values of terrestrial forests, the soil density values of coastal and small islands are smaller. This is because the components of mangrove soil particles are predominantly muddy sand, resulting in very low water retention capability and low soil density. Edwin (2016) reported that soil density in rubber and pepper plantations was 1.26 g/cm3. According to Milliman and Syvitski (1992), geological processes and environmental factors influence sediment discharge to the ocean, which can differ between coastal and small island environments. Bird (2008) reported that coastal sediments are subject to erosion from wave action and coastal processes, which can lead to constant reshaping and redistribution. Sediment on small islands may experience less dynamic erosion but can still be affected by local weather patterns and sea level changes.

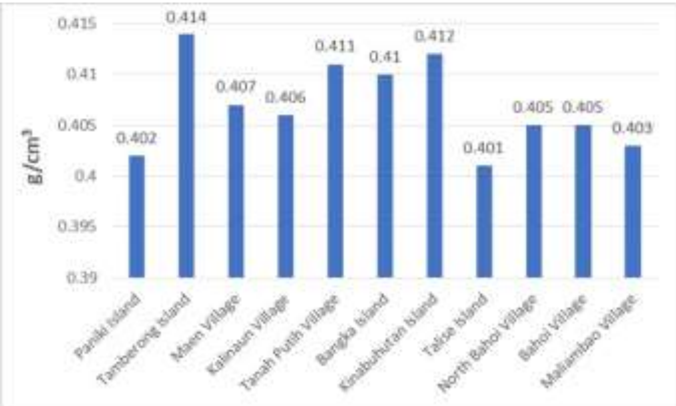

Figure 2. Average soil density at each location

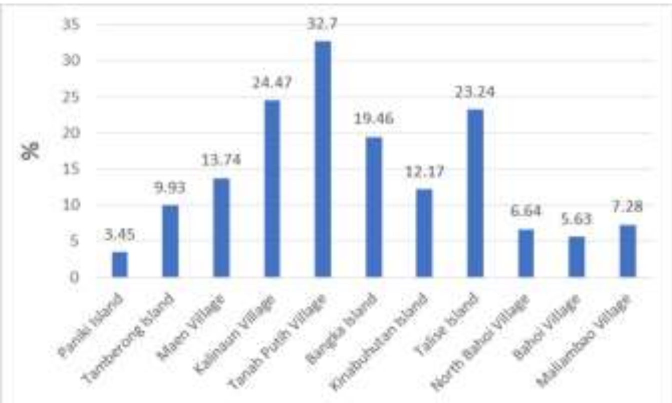

Figure 3. Average percentage of organic carbon at each location.

Percentage of Carbon (%C).

This study revealed that sediment collected from Tanah Putih Village has a percentage of carbon at 32.7%, followed by Kalinaun Village (24.47%), Talise Island (23.24%), and Bangka Island (19.46%). In contrast, Paniki Island has the lowest percentage at 3.45%. Other locations such as Maen Village, Kinabuhutan Island, North Bahoi Village, Bahoi Village, and Malamabo Village have moderate to low carbon percentages, ranging from 5.63% to 13.74%. This variation indicates significant differences in carbon storage and flux among the different areas. The details are presented in Figure 3.

Carbon Content.

This study revealed the carbon content across the islands and villages, demonstrating a broad range of values. Tanah Putih Village exhibits the highest total carbon concentration at 132.65 mgCh^{-1}, followed by Kalinaun Village at 99.26 mgCh^{-1}, Talise Island at 93.18 mgCh$^{-1,}$ and Bangka Island at 80.57 mgCh^{-1}. Kinabuhutan Island and Talise Island also have relatively high carbon concentrations, with 80.57 mgCh^{-1} and 49.98 mgCh^{-1}, respectively. Maen Village, Kinabuhutan Island, and Tamberong Island show moderate values at 55.83 mgCh^{-1} 49.98mgCh$^{-1,}$ and 40.73 mgCh^{-1}. Lower concentrations are observed in Malalmbao Village (29.35 mgCh^{-1}), North Bahoi Village (27.04 mgCh^{-1}) Bahoi Village (22.72 mgCh^{-1}), and Paniki Island, which has the lowest at 13.87 mgCh^{-1}. This data highlights significant variability in carbon storage across different locations, with Bangka Island showing notably higher carbon levels compared to other areas.

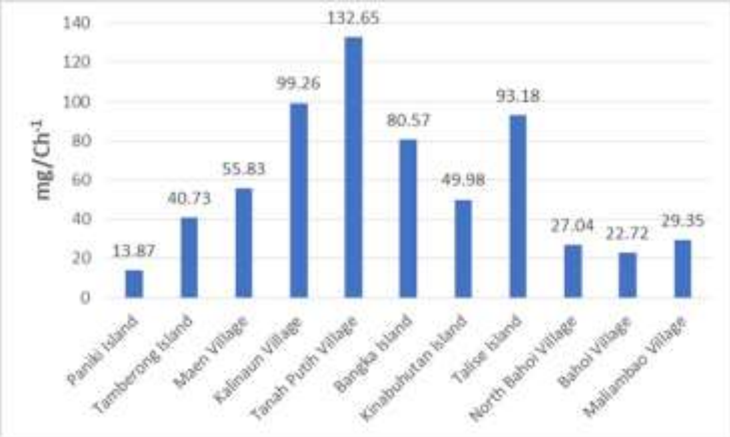

Figure 4. The carbon content at each location.

This indicates that soil density significantly influences carbon content at each location. The study's findings are notably higher than those reported by Mahasani et al. (2016) in the Ngurah Rai Forest Mangrove Park, Bali, which ranged from 83.046 to 216.168 Mg ha-1. Conversely, these results exceed the carbon content found by Suryono et al. (2018) in the Perancak Mangrove Forest, Bali, which recorded 57.699 mg ha-1.

The variability in carbon content across different locations underscores the critical role of sediment soil density and depth in carbon sequestration. Denser soils, typically with greater depth, tend to store higher carbon stocks, as suggested by Prayitno et al., 2013. This correlation implies that regions with compact, dense soils are more efficient at storing carbon, thereby contributing more significantly to carbon sequestration. These findings could inform future conservation strategies, emphasizing the preservation and restoration of areas with high soil density to maximize carbon storage.

Conflict of interest.

The authors declare that there is no conflict of interest.

CONCLUSION

The carbon analysis across various islands and villages reveals significant variability, highlighting the influence of soil density and depth on carbon content. Tanah Putih Village exhibits the highest carbon concentration, while Paniki Island has the lowest. Comparatively, the findings surpass those of previous studies in similar environments, indicating higher carbon storage potential in the sampled locations. The data suggest that denser, deeper soils are more effective in sequestering carbon. These insights emphasize the importance of preserving and managing areas with high soil density to enhance carbon sequestration, which is crucial for mitigating climate change and informing conservation strategies.

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