Carbon stock estimation in mangrove forest at Pitas, Sabah, Malaysia

Syahrir Mhd Hatta[1], Nurul Syakilah Suhaili[1], Ejria Salleh[2], Normah Awang Besar[1#]

1 Faculty of Tropical Forestry, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, MALAYSIA.
2 Borneo Marine Research Institute, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, MALAYSIA.
#Corresponding author. E-Mail: normabr@ums.edu.my; Tel: +6088-320000; Fax: +6088-320878.

ABSTRACT Mangrove forests play a significant role in reducing tropical carbon emissions and preventing climate change. The objectives of this study are to estimate the aboveground, belowground, and soil carbon storage in mangrove forests. This study was conducted in a mangrove forest in Pitas, Sabah. A transect method for sampling design was used with a total of 3 transects and 15 sub-transects. Forest inventory was done to get the diameter breast height of standing trees and soil sampling with four different depths (0 - 15 cm, 15 - 30 cm, 30 - 50 cm and 50 - 100 cm) were taken for soil analysis and bulk density. Allometric equation was used to calculate aboveground and belowground biomass then its carbon stock was estimated as 50% from its total biomass. CHNS elemental analyzer was used to determine the soil carbon content. A total of 223 individual trees were measured with DBH classification. The AGB and BGB on the study site were 204.53 Mg/ha and 68.18 Mg/ha and estimated the carbon is 50% of the biomass which is AGC 102.26 Mg/ha and BGC 34.09 Mg/ha. The bulk density of the soil ranges from 1.03 - 1.11 g/cm^3 and the soil carbon concentration from 15 - 30 cm depth shows the highest with 3.25%. The soil carbon shows the highest carbon storage in the total ecosystem carbon storage with 313.87 Mg/ha. this study reveals that the total carbon stock in mangrove forests at Pitas, Sabah, Malaysia, amounted to 450.22 Mg/ha which soil carbon contributes 69% of total carbon storage.

KEYWORDS: Mangrove, Carbon stock, Below ground biomass, Soil carbon, Above ground biomass
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Original Article

INTRODUCTION

Estimating carbon storage in mangrove forests is essential for understanding their role in mitigating climate change. Mangrove forests are not only vital habitats for numerous species, but they also play a crucial role in carbon sequestration and storage (Sumarga *et al*., 2022). These unique ecosystems have the ability to store large amounts of carbon, making them valuable in the efforts to combat climate change (Bandh *et al*., 2023). Over the last decade, scientists around the world have increasingly recognized the importance of mangrove and wetland ecosystems in stabilizing Earth's temperature. Robust studies have demonstrated that mangrove forests are critical for carbon sequestration and storage, rivalling other forest types in their ability to store high amounts of carbon (Nyanga, 2020).

Despite the growing interest in the role of mangroves, initiatives on climate change mitigation in some regions, such as Indonesia, have focused more on dryland and peatland ecosystems, neglecting the potential of mangrove ecosystems (Sidik *et al*., 2018). This study aims to fill the research gap by focusing on carbon storage estimation in disturbed mangrove forests in Pitas, Sabah, Malaysia. Objective of this research calculate the aboveground and belowground biomass in the study area and to estimate the soil carbon in the study area.

In recent years, there has been a surge of interest in the role of mangrove forests as carbon sinks and their potential contribution to climate change mitigation (Chatting *et al*., 2022). Mangrove have been recognized as important carbon sinks in coastal ecosystems due to their high carbon fixation capacity compared to terrestrial forests.

Malaysia encompasses an estimated 629,038 hectares of mangrove areas, with Sabah holding the majority at nearly 57%, while Sarawak and Peninsular account for 26% and 17%, respectively (Omar & Misman, 2020; Abdulaali *et al*., 2022). Historical data indicates a decline in Malaysia's mangrove coverage from 700,000 hectares in 1975 to 572,000 hectares in 2000, attributed to extensive harvesting of valuable mangrove trees and the impact of strong sea waves (Omar & Misman 2020). Notably, between 2000 and 2005, a reduction in the annual rate of mangrove loss is observed, amounting to 102,000 hectares compared to the previous figure of around 187,000 hectares. Presently, Malaysia has undertaken significant initiatives to conserve and restore its mangrove ecosystem, with the government demonstrating a commitment to bolstering protection efforts, particularly following the tsunami on December 26, 2004 (Omar *et al*., 2020). The preservation of the remaining mangrove forests is imperative, contributing to the reduction of global greenhouse gas emissions and supporting climate change mitigation endeavors.

MATERIAL AND METHODS

Study area

The study was undertaken in the mangrove forest of Pitas, Sabah, Malaysia. Pitas Mangrove Forest is a component of Tun Mustapha Park, Sabah, Malaysia (Figure 1). This region was officially designated on May 19, 2016, and boasts distinctive biodiversity that sustains a network of interconnected habitats. The total area covers 13,980 hectares, predominantly comprised of mangrove forest.

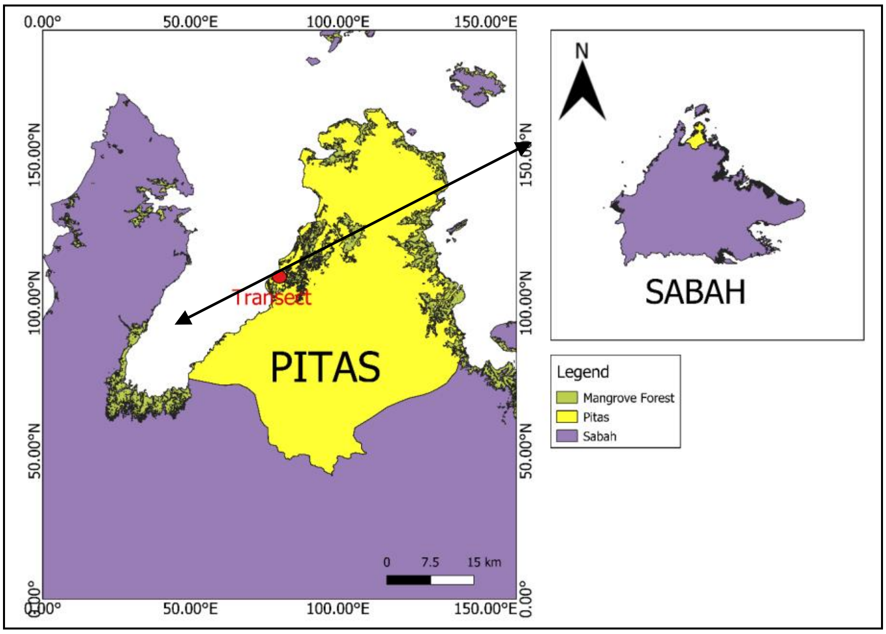

Figure 1. Location of the study area mangrove forest which located at the northern part of Sabah, Malaysia.

Procedures

The entire carbon storage examined in this study are the carbon stored in standing, live trees both above and below ground, as well as in the soil. Using a random transect method, three transect lines with five subplots each were set up throughout the study region. The transect line length was 125 meters, and the subplots were built with a radius of 7 meters and a spacing of 25 meters between each subplot. While soil data were collected by soil sampling using the *ring* for bulk density, aboveground and belowground data were approximated using a non-destructive method. Using the transect line approach, our investigation adhered to the guidelines provided in a published protocol book (Kauffman *et al*., 2014). Fieldwork data collecting took place between January 2020 and September 2019.

The diameter breast height (DBH) and tree height of standing trees with a DBH larger than 5 cm were measured during a forest inventory. A TruPulse 360 rangefinder and a DBH meter were used to take the measurements. The DBH of every tree that was larger than 5 cm was measured within a 7 m radius using the methods described in the publications of Kauffman and Donato (2012) and Komiyama *et al*. (2005). At each subplot, soil samples were taken at four distinct depths: 0–15 cm, 15–30 cm, 30–50 cm, and 50–100 cm. Each transect yielded twenty samples, for a total of sixty samples for this investigation. For the purpose of analyzing soil bulk density, undisturbed soil samples were collected using a bulk density ring (98.125 cm^3). Soils sample were analyzed in the laboratory using CHNS Elemental analyzer for carbon content.

Aboveground and belowground biomass analysis

Several equations have been developed to quantify mangrove tree biomass; however, a lack of data on species distribution at the study site constrains the options for available allometric equations (Wong *et al*., 2020; Suhaili *et al*., 2020; Hatta *et al*., 2022). To calculate the aboveground biomass for the primary mangrove zone in Sabah, an allometric equation specific to *Rhizophora* spp., formulated by Komiyama *et al.* (2005), was utilized. The sole parameter employed in the equation, W=0.128DBH^2.60, represents the diameter of the tree at breast height. In comparison to other equations such as Clough and Scott (1989), which exhibits a relative error range of -9.84% to +10.3%, and Ong *et al*. (2004) with a relative error range of +6.81% to 10.8%, the selected allometric equation yields a relative error ranging from -8.44% to +6.81% (Komiyama *et al*., 2008).

The resulting aboveground biomass was subsequently converted into aboveground carbon, employing a conversion factor of 0.5, based on the assumption that the carbon stock of standing trees is equivalent to 50% of their biomass (Houghton & Hackler, 2001). Utilizing the biomass comparison ratio of 3:1 (AGB:BGB) established by Kusmana *et al*. (2018), the biomass of roots was calculated, and the carbon content was estimated to be 50% of the biomass.

Soil Carbon stock

Four distinct depths were used to calculate the bulk density of the undisturbed soil samples and the carbon content of all the mix-soil samples. The numbers were then used as the inputs to compute the soil carbon stock. This equation (Mg/ha) was used to calculate the soil carbon stock for each sampled depth interval (Kauffman & Donato, 2012; Suhaili *et al*., 2020). Next, the carbon stock for each soil depth was added to estimate the overall soil carbon stock:

$$\text{Soil Carbon (Mg/ha)} = \text{Bulk density (g/cm}^3\text{)} \times \text{Soil Depth Interval (cm)} \times \text{Carbon content (\%C)}$$

The total ecosystem carbon stock in the area can be calculated by adding up all of the primary carbon stock that have been measured, such as the above-ground (living plants), below-ground (roots), and soil carbon stock.

RESULT AND DISCUSSION

Standing living tree

For the distribution of the tree stand in the sampling study area (Figure 2), there is a total of 223 trees which are dominated by the *Rizhopora apiculate* species. The tree has six separate classes: 5 to 10 cm to, 10 to 20 cm, 20-30 cm, 30-40 to 40-50 cm, and 50-60 cm. While the least number of trees were located in the 50 to 60 cm DBH class, the majority of trees fell into the 10 to 20 cm DBH category followed by the 5 to 10 cm DBH class.

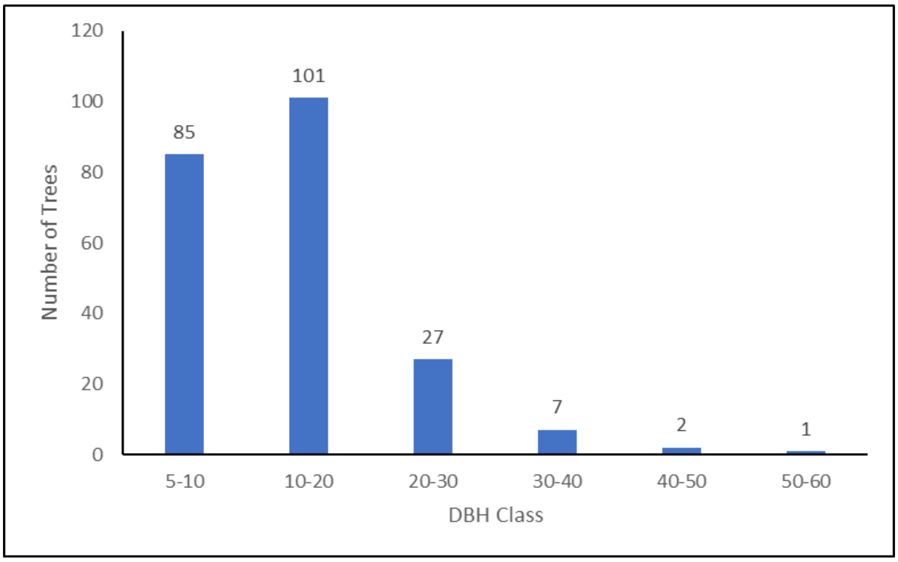

Figure 2. The standing living tree based on their diameter (DBH) classification.

Aboveground carbon storage, belowground carbon storage, soil carbon and total carbon stock

Figure 3 illustrates the biomass of both aboveground and belowground components for living trees and root systems in the mangrove forest of Pitas, Sabah. Due to the constant exposure of roots to the challenging mangrove conditions, characterized by high salinity and an elevated water table, the aboveground tree biomass exhibits a higher value than the belowground biomass (Kusmana *et al.,* 2018). The findings indicate that the standing trees in the mangrove forest of Pitas have an aboveground biomass of 204.53 Mg/ha and a belowground biomass of 68.18 Mg/ha.

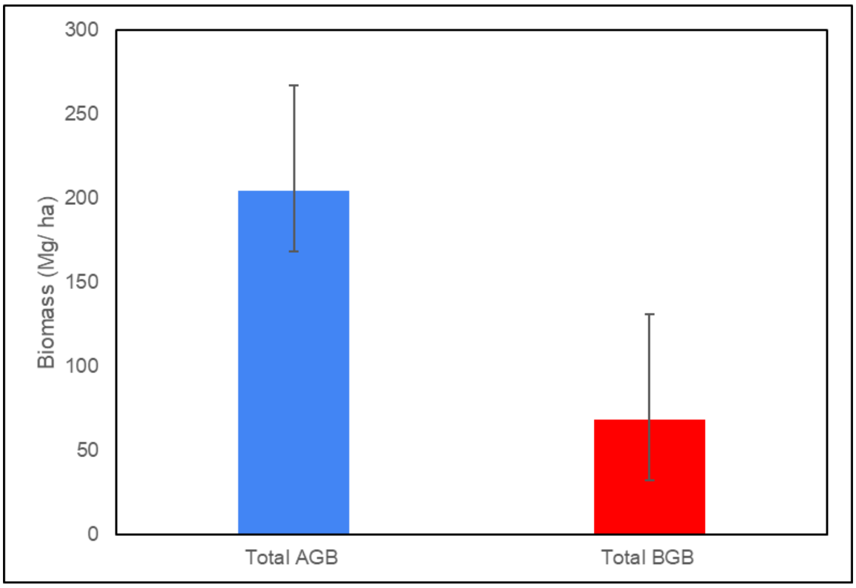

Figure 3. Aboveground (AGB) and belowground biomass (BGB) for standing living and root trees in mangroves Forest at Pitas, Sabah, Malaysia.

Furthermore, this aboveground biomass value is somewhat greater than the recorded aboveground biomass of the predominant species (*Rhizophora apiculata*) in the mangrove forest of Sulaman Lake Forest Reserve, Sabah, as reported by Suhaili *et al*. (2020), which is 134.59 Mg/ha. However, it is lower than the aboveground biomass reported by Hatta *et al*. (2022) in the Kudat mangrove forest, Sabah, and the study conducted by Hemati *et al*. (2014) in an undisturbed mangrove forest at Kuala Selangor Nature Park, Peninsular Malaysia, where the recorded aboveground biomass in these locations is comparatively lower.

The results of this study reveal a marginally higher above-ground tree biomass compared to the research conducted in Sulaman Lake Forest Reserve, where Suhaili *et al*. (2020) reported 134.59 Mg/ha. This finding is slightly more than the 116.79 Mg/ha of above-ground biomass documented in the dominant species, *Rhizophora apiculate*, in the Awat-Awat mangrove forest, Sarawak, Malaysia, as reported by Arianto *et al*. (2015). The study also observed that a forest dominated by a specific species tends to exhibit greater aboveground biomass values than a mixed-species mangrove forest, which recorded 115.56 Mg/ha (comprising *Rhizophora apiculata, Rhizophora mucronata, and Ceriops tagal*).

Based on Figure 4 the AGC is slightly higher which is 102.26 Mg/ha more than Sulaman Lake Forest Reserve recorded a lower range of above ground carbon with estimated value 67.30 Mg/ha. This value represents the amount of carbon stored in the aboveground biomass of the mangrove trees (Suhaili *et al*., 2020). In the State of Yap, Micronesia, the aboveground carbon stock was reported to be 116.7 Mg/ha (Kauffman *et al*., 2011), which is higher than the value found in Sulaman Lake Forest Reserve and in range with the above ground carbon found in Pitas.

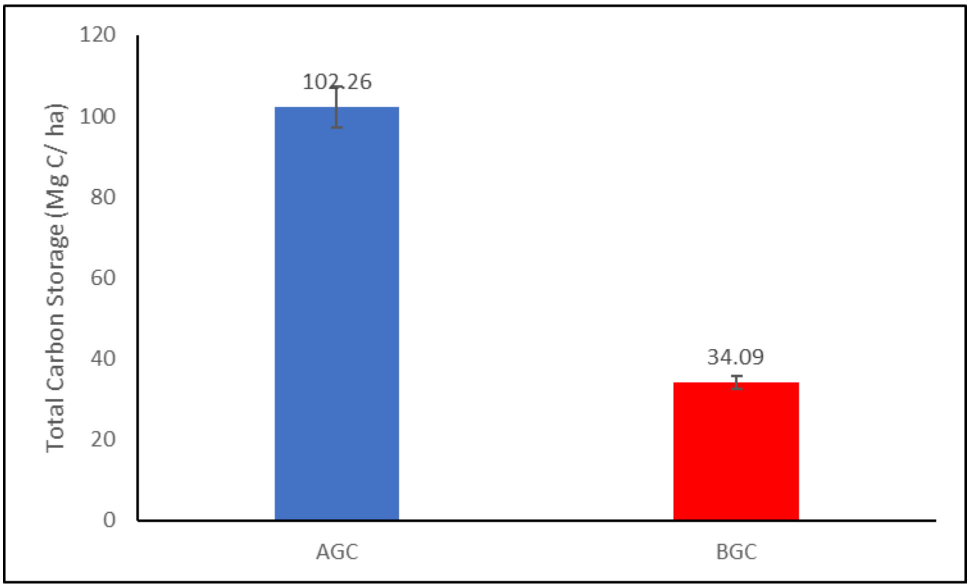

Figure 4. Above (AGC) and Below (BGC) ground carbon storage in mangrove forest at Pitas, Sabah.

The amount of carbon sequestered increases with the amount of biomass generated to be expected since trees physiologically continue to build more biomass as they age, albeit the rate varies by species. The study also discovered that almost all the mangrove forest's total carbon stock was stored in aboveground biomass.

Bulk Density and Carbon Content

The bulk density and carbon content at mangrove forest at Pitas Sabah showed at Table 1. The mangrove soil, which was distinguished by its high moisture content, low solid content, and the bulk of its pores being filled with liquid and gas, played a crucial part in the mangrove's biogeochemical process (Matsui *et al*., 2015). According to Adame and Lovelock (2011), high annual temperatures (>29°C) and low annual rainfall (>200 mm) were study sites that had a significant impact on the amount of carbon in the sediments because they had higher carbon contents than low annual temperatures (>15°C) and high annual rainfall (4000 mm). Tun Mustapha Park had a high soil carbon content because it was a reserve with an annual temperature of 29°C and 350mm of annual rainfall.

Table 1. The soil bulk density and carbon content at mangrove forest at Pitas Sabah.

Depth (cm)	Bulk Density (g/cm³)	Carbon content (%)
0-15	1.11 ± 0.05**a**	2.77 ± 0.24**a**
15-30	1.06 ± 0.05**a**	3.25 ± 0.34**a**
30-50	1.03 ± 0.06**a**	3.15 ± 0.30**a**
50-100	1.08 ± 0.03**a**	2.89 ± 0.20**a**

A prior study by Crnobrna *et al*. (2022) found a substantial association between carbon contents and bulk density, but no statistically significant link, meaning the relationship is negative. Even though the soil had a high bulk density, the carbon content was low because the clay composition in the soil had the natural ability to store carbon, in addition to having an impact on bulk density.

Soil Carbon Stock

Figure 5 shows the soil carbon stock at four deferent depths of soils. Soil carbon stock at 50-100cm depth is the highest compared to other soil depth.

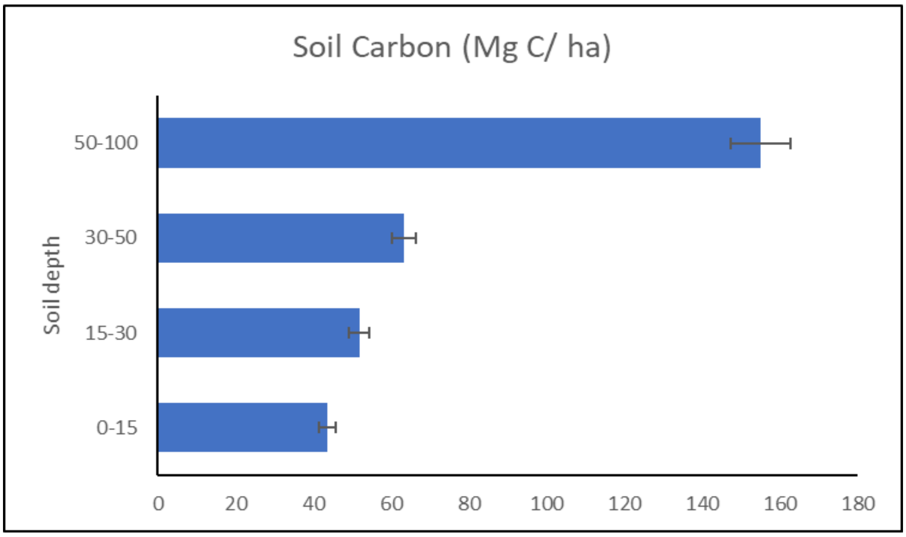

Figure 5. Soil carbon stock by sampling depth in Mangroves Forest at Pitas, Sabah, Malaysia

The soil carbon stock (Table 4) constituted approximately 55% of the total carbon stock, a proportion that closely aligns with findings from the study conducted by Suhaili *et al*. (2020) at Sulaman Lake Forest Reserve, Sabah, and Alongi *et al*. (2015) in the mangrove forest of Sumatra, Indonesia. These results differ from those reported by Hong *et al*. (2017) in a degraded mangrove forest in Peninsular Malaysia and Hatta *et al*. (2022) in the Kudat Mangrove Forest, Sabah, where soil accounted for only 60% of the ecosystem's total carbon stock, with living trees contributing to 32%.

Contrastingly, Kida *et al*. (2021) documented a higher soil carbon stock at Trat mangrove forest, Thailand, amounting to 961.7 Mg/ha (87%) of the total carbon stock in mangrove ecosystems. This finding is in line with other research indicating that mangrove soils store a greater amount of carbon compared to trees and roots, contrasting with other major forest domains globally, such as tropical forests, boreal forests, and temperate forests (Besar *et al*., 2020; Donato *et al*., 2011; Kauffman *et al*., 2011; Dimalen & Rojo, 2019).

The value of the soil organic carbon stock in an area can be influenced by a variety of factors, including sampling depth, soil type, topography, climate, and type of land use (Besar *et al*., 2020; Suhaili *et al*., 2021). According to Kauffman and Donato (2012) other types of forest also reported to have lower carbon storage compared to a mangrove forest which temperate forest with 210 Mg/ha and boreal forest is 380 Mg/ha.

TOTAL CARBON STOCK

The overall carbon stock in the mangrove ecosystem at Pitas indicates that soil holds the highest value, with a carbon stock of 313.87 Mg/ha, followed by aboveground carbon for living trees at 102.26 Mg/ha and belowground carbon at 34.09 Mg/ha (Table 2).

Table 2. The comparison of total carbon storage with different study site

Study site	Aboveground Carbon (Mg/ha)	Belowground Carbon (Mg/ha)	Soil Carbon (Mg/ha)	Total ecosystem carbon stock (Mg/ha)	Reference
Sumatra, Sulawesi, Java, Kalimantan, Papua, Bali, Indonesia	191.2 (20%)	21.1 (2%)	761.3 (78%)	973.6	Alongi *et al*. (2016)
Selangor, Malaysia	48.17 (32%)	13.12 (8%)	90.11 (60%)	151.4	Hong *et al*. (2017)
Tuaran, Sabah, Malaysia	67.30 (15%)	22.44 (5%)	351.98 (80%)	441.72	Suhaili *et al*. (2020)
Kudat, Sabah, Malaysia	136.58 (30%)	45.53 (10%)	273.76 (60%)	455.87	Hatta *et al*. (2022)
Central Java, Indonesia	30.27 (4%)	10.99 (2%)	671.87 (94%)	713.13	Sugiatmo *et al*. (2023)
Pitas Sabah, Malaysia	102.26 (22%)	34.09 (9%)	313.87 (69%)	450.22	Present study

The total carbon stock value closely resembles the total carbon stock observed in the mangrove forest at Sulaman Lake Forest Reserve, Sabah, which is 441.91 Mg C ha^{-1} (Suhaili *et al*., 2020) but surpasses the findings from the study conducted by Hong *et al*. (2017) in Peninsular Malaysia. The overall carbon stock in the mangrove ecosystem is influenced by factors such as historical disturbances, human activities, the age of the mangrove, tree species, soil texture, and the depth of soil samples.

Kida *et al*. (2021), in their study discovered that lower amounts of carbon were stored in woody debris (0.1–0.3%), belowground biomass (3%–6%), and aboveground biomass (7%–11%). These results underline the significance of considering the previously understudied deep soil carbon storage in mangrove ecosystems. Mangrove ecosystems have the capacity to capture significant amounts of carbon from the atmosphere and store it in their soils, which has critical implications for mitigating climate change.

CONCLUSION

This study reveals that the total carbon stock in mangrove forests at Pitas, Sabah, Malaysia, amounted to 450.22 Mg/ha. The major contributor to the total ecosystem carbon storage is the soil in the mangrove forest, followed by the aboveground (living trees) and the belowground (roots).

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TRANSACTIONS ON SCIENCE AND TECHNOLOGY