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POTENTIAL OF CARBON SINK IN MANGROVE SUBSTRATES IN LEMBAR BAY, WEST LOMBOK, INDONESIA

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ABSTRACT

Mangroves are one of the coastal vegetation that can mitigate carbon (carbon sink and carbon storage). This study aimed to determine the potential for soil carbon stock found under stands of mangroves in Lembar Bay, West Lombok, and West Nusa Tenggara. The research began with the identification of the species and then proceeded toa sampling of the soil, which was then analyzed using the Walkley and Black method. The results showed that there were ten species of mangroves, namely, *Rhizophora stylosa, Avicennia lanata, Avicennia marina, Bruguiera gymnorrhiza, Ceriops decandra, Excoecaria agallocha, Lumnitzera racemosa, Scyphiphora hydrophyllacea, Thespesia populnea,* and *Xylocarpus maluccensis*. The highest soil carbon content percentage was found in the lower soil of the *A. lanata* (1.43 %C) mangrove, and the lowest was found in the lower-stand soil of *E. agallocha* (0.21 %C). Meanwhile, the carbon sinks per meter were 0.002-0.066 gC/m², with an average of 0.020±0.020 gC/m². The estimated total soil carbon sink in 10 mangrove stands was 0.20-6.60 tons C/ha, with an average of 2.18±2.010 tons C/ha. The average total estimated soil carbon stock found in 20.49 ha of the mangrove area studied was 44.67 tonsC, which is equivalent to 263.69 tonsC in a mangrove area of 120.96 ha in Lembar Bay.

Keywords: carbon stock, c-organic, mangroves, soil

INTRODUCTION

Mangroves are one of the plants in coastal areas that play a role in disaster mitigation (abrasion, breakwater, sea wind barrier, and tsunami), biota habitats, and germplasms. The environmental benefits of mangrove ecosystems that have not been widely studied include their potential as carbon sinks and carbon storage, especially in mangrove ecosystem soil (Brath *et al.* 2015; Lovelock & Duarte 2019; Macreadie *et al.* 2019). Based on Murray *et al.*(2011), the average annual carbon sequestration potential of mangrove ecosystems is between 6 and 8 Mg CO_2 e/ha (tonnes CO_2 equivalent per hectare) and is two to four times greater than the carbon sink potential of tropical forests (Nellemann *et al.* 2009).

One of the coasts in the Mangrove Corridor Essential Ecosystem Area is Lembar Bay, West Lombok, which is directly affected by the activities of the Lembar harbor. Lembar harbor is an inter-island sea and goods transportation route that continues to be developed as a port area (reclamation) covering 22 ha. It has a direct impact on the degradation of mangrove

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ecosystems, resulting in a decrease in the mangrove ecosystem area, which currently only has an area of ±120.96 ha (Saraswati 2019).

The ecological potential of mangrove ecosystems as carbon sinks and carbon storage has been widely studied. The following data are some of those previous findings. The soil carbon stock of the Tanjung Lesung Banten mangrove ecosystem of 27.92 tons C/ha; the mangrove carbon stock in Dukuh Tapak, Tugurejo Village, Semarang amounted to 708.2 tons C/ha; mangroves in Timbulsloko Village, Demak, Central Java had carbon stock of 1,307.77 tons/ha; Perancak mangroves in Jembrana, Baliretain carbon stock of 119.75 tons C/ha; mangroves of the Batang Apar Estuary of West Sumatra had carbon stock of 2,561.90 tons C/ha (Handoyo *et al.* 2020); mangroves in Sungai Sembilan, Dumai had carbon stock of 1,819.31 tons C/ha (Handoyo *et al.* 2020); mangroves in Tambakbulusan Village, Demak, Central Java carbon stock of 57.74 tons C/ha; and Gili Meno mangroves, North Lombok had carbon stock of 154.62±99.78 tons C/ha, equivalent to a total soil carbon stock of 1,020.50 tonsC in a total 6.6 ha of the mangrove ecosystem area (Hilyana & Rahman 2022).

In general, research on carbon sinks in mangrove ecosystems is still related to the potential for carbon sinks in certain locations, and not specifically related to the potential for soil carbon stock under mangroves. This is in line with the opinion of Mcleod *et al.* (2011) and Howard *et al.*(2017) that in-depth analysis related to the potential of mangroves as carbon sinks and carbon storage in different species and habitats is very important. Due to this, this study can be a source of information on the potential for soil carbon storage found under ten types of mangroves in the harbor area of Lembar Bay, West Lombok, Indonesia.

MATERIALS AND METHODS

The study was carried out in the mangrove ecosystem located in Lembar Bay, Lembar, West Lombok, in February-March 2023 with a research site encompassing an area of 20.49 ha (located at 116°3'-116°4' E and 8°43'-8°44' S) (Fig 1). This was a quantitative descriptive study that began with the identification of mangroves and sampling of soil found under mangrove stands. Soil samples were collected fromunder ten mangrove standsat the research site. These stands represented various species, including *Avicennia lanata, Avicennia marina, Bruguiera gymnorrhiza, Ceriops decandra, Excoecaria agallocha, Lumnitzera racemosa, Rhizophora stylosa, Scyphiphora hydrophyllacea, Thespesia populcarapus,* and *Xylocarpus maluccensis*.

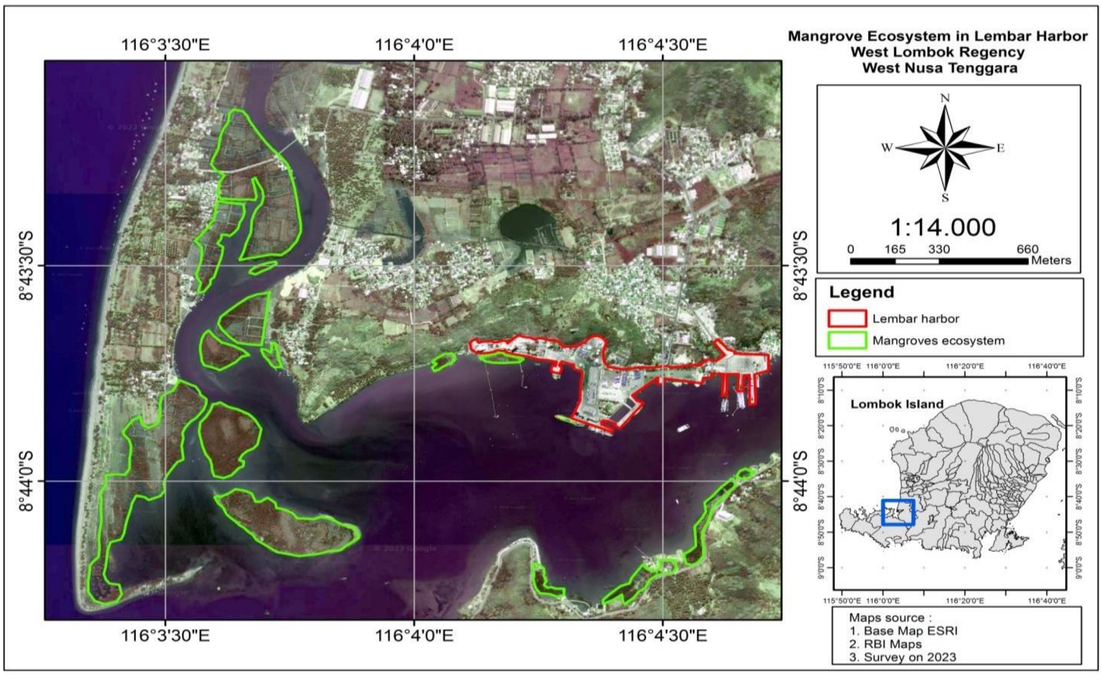

Figure 1 Mangrove ecosystem of Lembar Bay, West Lombok, Indonesia

Mangrove Identification

Mangroves were identified in situ based on morphological characteristics by referring to the introductory guide to Mangroves in Indonesia (Noor *et al.* 2006).

Analysis of Soil Organic Carbon Content

Soil sampling was carried out to a depth of 30 cm around the roots and a slope of 30º using pipes with a diameter of 5 cm and a length of 35 cm. The soil's carbon organic content was analyzed using the Walkley and Black method (Walkley & Black 1934). A soil sample weighing 0.5 g with a size of less than 0.5 mm was placed in a 100 ml volumetric flask. Then, 5 ml of 1 N $K_2Cr_2O_7$ was added, and the mixture was shaken. Following that, 7.5 ml of concentrated H_2SO_4 was added, and the mixture was shaken and left to stand for 30 minutes. It was then diluted with ion-free waterand the clear solution sample's absorbance was measured using a spectrophotometer at a wavelength of 561 nm. As a comparison, 0 and 250 ppm standards were made by pipetting 0 and 5 ml of the 5.000 ppm standard solution into a 100 ml volumetric flask with the same treatment as the sample procedure.

Data Analysis

Soil Carbon Content

The soil's carbon content was calculated using the following formula (Sulaeman *et al.* 2005):

$$\text{Soil c – organic content} = \frac{\text{Ppm curve}}{500 \text{ x correction factor}}$$

where:

ppm curve	=	The sample content obtained from the curve of therelationship between the standard series contentand its reading after corrected for blanks
Correction factor	=	100/(100 - % water content)

Soil Carbon Stock

The soil's carbon stockwas calculated using the following formula (Badan Standarisasi Nasional, 2011):

$$Ct = Kd \text{ x } \varrho \text{ x \% c-organic}$$

where:

Ct	=	Soil carbon stock (g/cm^2)
Kd	=	Soil sample depth or soil depth (cm)
ϱ	=	Bulk density is the ratio of the soil's dry weight to its volume (g/cm^3)
% c-organic	=	Value of carbon content percentage (0.47)

Soil Carbon Stock in Hectare Area

The soil's organic carbon content in hectare area was calculated using the following formula (Badan Standarisasi Nasional 2011):

$$\text{C soil (ton C/ha)} = Ct \text{ x } 100$$

where:

C_{soil}	=	Soil carbon stock (tons C/ha)
Ct	=	Soil organic carbon (g/cm^2)
100	=	Conversion factor from g/cm^2 to tons C/ha

Total Carbon Stock Area

The total carbon stock area was calculated using the following formula (Lugina *et al.* 2017):

$$C_{totals} = C_n + C_{soil}$$

Description:

C_{totals}	=	Total carbon stock (tons C/ha)
C_n	=	Carbon stocks per hectare in each carbon pool in each plot (tons C)
C_{soil}	=	Soil carbon stock (tons/ha)

RESULTS AND DISCUSSION

Mangrove Species

A total of 10 mangrove stands were identified in Lembar Bay, namely, *Avicennia lanata, Avicennia marina, Bruguiera gymnorrhiza, Ceriops decandra, Excoecaria agallocha*, *Lumnitzera racemosa, Rhizophora stylosa, Scyphiphora hydrophyllacea, Thespesia populnea,* and *Xylocarpus maluccensis*. There were more strands discovered in this study than that of Syarifuddin & Zulhamran (2012), which found five species, namely, *Avicennia marina, Rhizophora stylosa, Rhizophora mucronata, Rhizophora apiculata,* and *Sonneratia alba*. On the other hand, Sukuryadi *et al.*(2021) found 12 species in a Lembar Bay mangrove area of 168.9 ha, those species being *Avicennia alba, Avicennia marina, Bruguiera cylindrica, Ceriop decandra, Ceriop tagal, Lumnitzera littorea, Lumnitzera racemosa, Phemphis acidula, Rhizhopora* *stylosa, Rhizophora apiculata, Rhizophora mucronata,* and *Sonneratia alba*. These different findings may have occurred due to differences in research areas in the port. This has the potential to disrupt the mangroves' growth and development due to potential contamination from port activities and the loading and unloading of goods. Besides that, the research methodology utilized quadrant points, which limited the collection area of species composition data.

Soil of C-Organic Content

The largest percentage of soil carbon content was found in the bottom soil of *Avicennia lanata* (1.43% C) when compared to nine other species (Table 1). Meanwhile, the lowest percentage soil carbon content was found under *Excoecaria agallocha*st ands at 0.21% C. The soil carbon content percentage found in Lembar Bay waslower than that of the soil carbon in the Gili Meno at the range of 4.85-20.00 %C (Rahman & Hadi 2021; Hilyana & Rahman 2022). The high and low soil carbon content found under the Lembar Bay mangrove stands could generally be caused by the soil fraction size. This is in line with the research results of Lee *et al.* 2014, Ati *et al.*(2015); Sidik *et al.*(2016); and Lestariningsih *et al.*(2018). Another supporting factor is the large amount of organic matter sourced from litter weathering mixed with the soil (Rahman *et al.* 2023). In addition, it could be influenced by species density, species age, soil fraction, and each mangrove's growing zoning position (Schwarzer *et al.* 2016; Hilmi 2018; Bomer *et al.* 2020; Wang *et al.* 2020; Jannah *et al.* 2021). This is confirmed by the results reported by (Susilowati *et al.* 2020) that species density can affect litter production, which is one of the main sources of organic material for soil mangrove ecosystems.

Another factor is the water's condition, one of which is its pH, which can cause low weathering activity for organic matter by organisms (Abdelhakeem *et al.* 2016; Barreto *et al.* 2016; Hilmi *et al.* 2017; Hilmi *et al.* 2019). The physical factors that affect the waters of Lembar Bay are wind speed, temperature, and humidity. This is related to the amount of litter production in each mangrove species in Lembar Bay. Another factor is mangrove vegetation zoning, which is always flooded. This causes litter, fruit, and flowers, as the main sources of organic matter, to be affected by currents and carried to the open sea. This contributes to the organic sinking process in Lembar Bay. Greater attention should be directed towards the activities at the Lembar portas they have the potential to exacerbate environmental pollution through the changes in the water conditions. This is in line with several other studies on factors that affect carbon conservation in mangrove ecosystems, such as Matsui *et al.* (2015), Jones *et al.* (2016), Weiss *et al.* (2016), Martuti *et al.* (2017), Suhendra *et al.* (2018), Asadi *et al.* (2018), Pérez *et al.* (2018), Gao *et al.* (2019), and Kida & Fujitake (2020).

Table 1 Soil carbon content under mangrove stands in Lembar Bay

No.	Mangroves	Soil Carbon Content Under Mangrove Stands						
		Gross Weight	Dry Weight	Moisture Level	Correction Factor	Absorbance	Ppm curve	% C
1	*Avicennia lanata*	8.00	6.91	15.77	1.16	0.10	61.63	1.43
2	*Avicennia marina*	22.30	21.08	5.78	1.06	0.05	26.91	0.57
3	*Bruguiera gymnorrhiza*	20.00	19.35	3.36	1.03	0.04	20.71	0.43
4	*Ceriops decandra*	17.74	17.09	3.84	1.04	0.02	10.17	0.21
5	*Excoecaria agallocha*	15.57	15.21	2.30	1.02	0.01	5.83	0.12
6	*Lumnitzera racemosa*	17.31	16.53	4.51	1.05	0.03	16.06	0.34
7	*Rhizophora stylosa*	26.14	24.74	5.67	1.06	0.04	23.81	0.50
8	*Scyphiphora hydrophyllacea*	11.34	10.38	9.30	1.09	0.08	47.37	1.04
9	*Thespesia populnea*	16.70	16.15	3.43	1.03	0.02	9.55	0.20
10	*Xylocarpus maluccensis*	14.03	13.15	6.67	1.07	0.04	20.71	0.44
Average		16.91	16.06	6.06	1.06	0.04	24.28	0.53
Standard Deviation		5.220	5.141	3.959	0.041	0.028	17.591	0.409

The soil carbon content percentage (%C) can affect the total accumulation of potential carbon sinks in the research area. This study's results indicate that the soil carbon content stored 0.002-0.066 gC/m^2 with an average of 0.020±0.020 gC/m^2 (Table 2). The soil carbon content in each area is determined by its bulk density and percentage value. The soil carbon content under the *Avicennia lanata* mangrove stands had the largest amount of storage compared to the other nine species. However, it was lower than the results from another study which observed five mangrove stands (*Avecennia marina, Bruguera cylindrica, Rhizophora apiculata, Lumnitzera racemosa*, and *Excoecaria agallocha*) in Gili Meno, North Lombok. That study found an average of 0.57-3.08 gC/m^2 with an average of 1.55±1.000 gC/m^2 (Hilyana & Rahman 2022).

Several factors can determine the level of total accumulated soil carbon storage. These factors can be influenced by the percentage of soil carbon content, soil specific gravity, sampling depth, bulk density, litter, and topography of the area (Mahasani *et al.* 2015; Stringer *et al.* 2016; Rahman *et al.* 2019; Gao *et al.* 2019; Susilowati *et al.* 2020; Dencer-Brown *et al.* 2020). In addition, it has been reinforced by Leopold *et al.* (2013) and Pham *et al.*(2019) stating that species dominance correlates with an uptake of carbon, oxygen, and nutrients from soil and air, and species relationships develop patterns of grouping and species association.

It is estimated that the total soil carbon stock of Lembar Bay found in 10 mangrove stands was 0.20-6.60 tons C/ha with an average of 2.18±2.010 tons C/ha (Table 3). This value is smaller than that in some previous research results. The soil carbon stock of the Tanjung Lesung Banten mangrove was discovered to be 27.92 tons C/ha (Ati *et al.* 2015); the mangrove soil carbon stock in Dusun Pandan Sari Brebes, Central Java amounted to 326.46 tons C/ha;

Table 2 Carbon content under each mangrove stand in Lembar Bay

No.	Mangroves	Soil Carbon Content Under Mangrove Stands					
		Gross Weight (g)	Dry Weight (g)	Biomass	Bulk Density	Soil Carbon Content (% C)	Soil Carbon (gC/m²)
1	*Avicennia lanata*	8.00	6.91	1.09	0.002	1.43	0.066
2	*Avicennia marina*	22.30	21.08	1.22	0.002	0.57	0.029
3	*Bruguiera gymnorrhiza*	20.00	19.35	0.65	0.001	0.43	0.012
4	*Ceriops decandra*	17.74	17.09	0.65	0.001	0.21	0.006
5	*Excoecaria agallocha*	15.57	15.21	0.36	0.001	0.12	0.002
6	*Lumnitzera racemosa*	17.31	16.53	0.78	0.001	0.34	0.011
7	*Rhizophora stylosa*	26.14	24.74	1.40	0.002	0.50	0.029
8	*Scyphiphora hydrophyllacea*	11.34	10.38	0.96	0.001	1.04	0.042
9	*Thespesia populnea*	16.70	16.15	0.55	0.001	0.20	0.005
10	*Xylocarpus maluccensis*	14.03	13.15	0.88	0.001	0.44	0.016
Average		16.91	16.06	0.85	0.001	0.53	0.02
Standard Deviation		5.220	5.141	0.321	0.000	0.409	0.020

Table 3 Soil carbon stock of mangrove ecosystem in Lembar Bay

No.	Mangroves	SoilOrganic Carbon StockUnder Mangrove Stands		
		Soil Carbon (% C)	Soil Carbon (g C/m²)	Soil Carbon (tons C/ha)
1	*Avicennia lanata*	1.43	0.066	6.60
2	*Avicennia marina*	0.57	0.029	2.90
3	*Bruguiera gymnorrhiza*	0.43	0.012	1.20
4	*Ceriops decandra*	0.21	0.006	0.60
5	*Excoecaria agallocha*	0.12	0.002	0.20
6	*Lumnitzera racemosa*	0.34	0.011	1.10
7	*Rhizophora stylosa*	0.50	0.029	2.90
8	*Scyphiphora hydrophyllacea*	1.04	0.042	4.20
9	*Thespesia populnea*	0.20	0.005	0.50
10	*Xylocarpus maluccensis*	0.44	0.016	1.60
Average		0.53	0.02	2.18
Standard Deviation		0.409	0.020	2.010

the mangrove soil carbon stock of the Perancak mangrove forest, Jembrana, Bali totaled 119.75 tons C/ha; the mangrove soil carbon stock in Sungai Sembilan, Dumai was calculated to be 1,819.31 tons C/ha (Handoyo *et al.* 2020); the mangrove soil carbon stock in Tambakbulusan Village, Demak, Central Javawas 57.74 tons C/ha (Susilowati *et al.* 2020); and the soil carbon stock in the mangrove ecosystem of Gili Meno, North Lombok was found to be 154.62±99.78 tons C/ha (Hilyana & Rahman 2022).

Based on the potential value of carbon sinks and storage in mangrove ecosystems calculated in several places in Indonesia, there is a greater potential for mangrove ecosystems to store carbon than tropical forests. This can be seen in the results of studies by Daud *et al.* (2015), Raynaldo *et al.* (2022), and Yaqin *et al.* (2022). A report by Alongi (2020) also supports this finding, stating that, globally, mangrove ecosystems have a total carbon stock of 738 ± 27.9 MgC/ha. It has also been reported that the largest potential carbon sink is in the soil, and it is equivalent to 77% of the total carbon stock although mangrove forests only make up 0.2% of this stock compared to forestson land (Hamilton & Casey 2016).

The soil carbon content found under 10 mangrove stands in Lembar Bay was lower than the soil carbon stock under five mangrove stands on Gili Meno. The mangroves include *Rizophora apiculata* (307.96 tons C/ha), *Avicennia marina* (197.16 tons C/ha), *Excoecaria agallocha* (114.31 tons C/ha), *Lumnitzera racemosa* (59.90 tons C/ha), and *Bruguiera cylindrica* (57.17 tons C/ha). The average estimated total of soil carbon stock found in 20.49 ha of the mangrove area studied was 44.67 tonsC, which is equivalent to 263.69 tonsC in a 120.96 ha area of mangroves in Lembar Bay (Table 4). If the entire 20.49 ha area wascovered by *Avicennia lanata*, it could contribute 135.23 tonsC of carbon storage. The lowest soil carbon stock capacity was found from *Excoecaria agallocha* at 4.10 tonsC in a mangrove area of 20.49 ha.

Table 4 Carbon pool in mangrove soil in Lembar Bay

No.	Mangroves	Carbon Pool in Mangrove Soil in Lembar Bay		
		Soil Carbon (tons C/ha)	**ResearchArea (ha)**	**Carbon Pool (tonsC)**
1	*Avicennia lanata*	6.60	20.49	135.23
2	*Avicennia marina*	2.90	20.49	59.42
3	*Bruguiera gymnorrhiza*	1.20	20.49	24.59
4	*Ceriops decandra*	0.60	20.49	12.29
5	*Excoecaria agallocha*	0.20	20.49	4.10
6	*Lumnitzera racemosa*	1.10	20.49	22.54
7	*Rhizophora stylosa*	2.90	20.49	59.42
8	*Scyphiphora hydrophyllacea*	4.20	20.49	86.06
9	*Thespesia populnea*	0.50	20.49	10.25
10	*Xylocarpus maluccensis*	1.60	20.49	32.78
Average		0.53	20.49	44.67
Standard Deviation		0.409	0.000	41.182

CONCLUSION

The highest soil carbon stock in the mangrove ecosystem of the Lembar harbor was found in the subsoil of *Avicennia lanata* stands, while the lowest was found in the subsoil of *Excoecaria agallocha*. The total carbon absorption potential of the mangrove ecosystem soil in the study area was 44.67 tonsC. This is equivalent to 263.69 tonsC in the mangrove forest in Lembar Bay, covering an area of 120.96 ha.

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