Original Article

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Carbon Dioxide (Co2) Sequestration in Mangrove Leaves at Tanjung Rejo Village

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Abstract:

The Paluh Getah Mangrove Beach in Tanjung Rejo Village is a highly potential mangrove ecotourism site for carbon sequestration. This study aimed to assess the biomass content, carbon sequestration level, and comparative CO_2 absorption in four mangrove leaf species (Avicennia marina, Excoecaria agallocha, Bruguiera gymnorhiza, and Ceriops tagal), as well as to analyze the effect of leaf thickness, width, and length on carbon uptake levels in Tanjung Rejo Village. Sampling was conducted at three stations determined using purposive sampling, each with three replications. Mangrove leaves were analyzed in the laboratory using the Walkley and Black method to determine carbon content. The results showed that Avicennia marina had the highest sequestration potential, followed by Bruguiera gymnorhiza, Ceriops tagal, and Excoecaria agallocha. Leaf length, width, and thickness measurements among the four species indicated variation in their CO_2 absorption capacity.

Keywords: Biomass, Mangrove, Tanjung Rejo, Carbon Sequestration

Introduction

Global warming is one of the major environmental issues facing the world today, marked by the increasing average surface temperature of the Earth due to greenhouse gas emissions, particularly carbon dioxide (CO_2), from various human activities (Azzahra et al., 2020). Mangrove ecosystems are recognized as effective carbon sinks that play a crucial role in climate change mitigation through the process of photosynthesis, storing carbon within plant tissues and sediments (Alongi, 2012; Donato et al., 2011; Kauffman et al., 2011). Numerous studies have demonstrated that mangrove forests possess a remarkably high carbon storage capacity, even exceeding that of many terrestrial ecosystems (Mcleod et al., 2011; Sanderman et al., 2018; Sillanpää et al., 2017).

However, most previous research has focused primarily on carbon storage in

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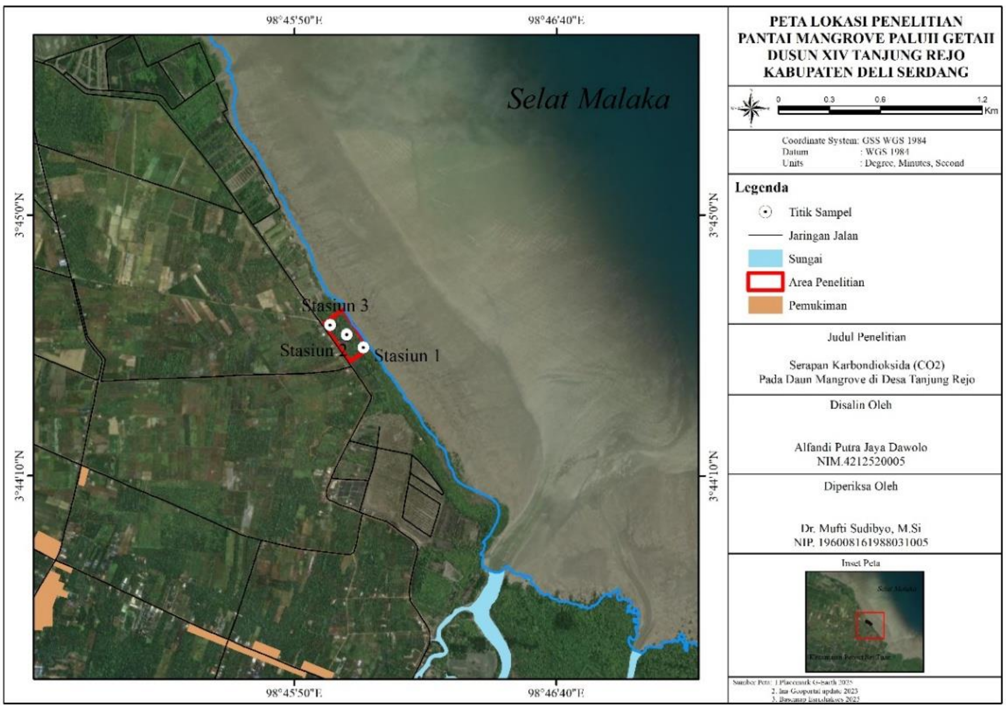
mangrove stand biomass and sediments, with relatively little attention given to leaf biomass as an important component in carbon estimation (Heriyanto et al., 2016; Murdiyarso et al., 2015). Moreover, there is a lack of studies specifically examining carbon uptake based on the morphological variations of mangrove leaves such as length, width, and thickness which may influence photosynthetic capacity and biomass accumulation. Research on differences in carbon uptake among various mangrove leaf types is also limited, particularly in the eastern coastal region of Sumatra, such as Tanjung Rejo Village, which holds significant potential for mangrove ecosystem conservation and management.

Therefore, this research is essential to address these knowledge gaps by examining the biomass and carbon dioxide uptake of four mangrove leaf species Avicennia marina, Excoecaria agallocha, Bruguiera gymnorhiza, and Ceriops tagal found in the mangrove forest of Tanjung Rejo Village. This study aims to: (1) determine the leaf biomass of the four mangrove species; (2) measure the CO_2 uptake level of each leaf type; (3) compare the carbon absorption capacity among the different mangrove leaves; and (4) analyze the influence of leaf morphological characteristics on carbon uptake. The findings of this research are expected to contribute scientifically to the understanding of the role of mangrove leaves in climate change mitigation and to serve as a foundation for sustainable coastal ecosystem management.

Methods

This study is a descriptive quantitative research aimed at calculating biomass and estimating carbon dioxide (CO_2) uptake from several mangrove leaf species based on their morphological characteristics. The research was conducted from March to April 2025 in the Mangrove Coastal Area of Paluh Getah, Hamlet XIV, Tanjung Rejo Village, Deli Serdang Regency, North Sumatra. Species identification and laboratory analyses were carried out at the UPTD Laboratorium Lingkungan, Dinas Lingkungan Hidup dan Kehutanan of North Sumatra Province.

Figure 1.
RESEARCH LOCATION. SOURCE: ALFANDI (2025).



The population in this study consisted of leaves from four mangrove species: *Avicennia marina*, *Excoecaria agallocha*, *Bruguiera gymnorhiza*, and *Ceriops tagal*. The samples used were mature leaves collected through purposive sampling during two time intervals morning (08:00–12:00 WIB) and afternoon (16:00–17:00 WIB). Data collection involved several stages, including leaf sampling, measurement of light intensity using a lux meter, leaf color assessment using a Leaf Color Chart (LCC), leaf drying in an oven at 104°C for 9 hours, and weighing of dry mass using an analytical balance. Organic carbon analysis was conducted using the *Walkley and Black* method, employing reagents such as 1 N $K_2Cr_2O_7$, H_2SO_4, $(NH_4)_2Fe(SO_4)_2$, diphenylamine, and distilled water, along with standard laboratory equipment such as burettes, Erlenmeyer flasks, droppers, and stands.

Leaf biomass was determined from the dry weight, calculated by converting from moisture content. The organic carbon content was then determined using the Schumacher formula and converted into biomass carbon content. The final analysis, which estimated CO_2 sequestration, was performed by multiplying the biomass carbon content by the molecular mass conversion factor of CO_2 to carbon atoms, following the formula from Heriyanto and Subiandono (2012). The data were analyzed descriptively to identify differences in CO_2 uptake capacity among the mangrove leaf species and to assess the influence of leaf morphology on this capacity.

Result and Discussion

1. Light Intensity

The differences in light intensity are closely related to the position of the sun and the canopy density at each station. Sunlight plays a vital role in the photosynthesis process, which in turn influences the ability of leaves to absorb carbon dioxide. In the morning, optimal sunlight allows photosynthesis to proceed at maximum efficiency, potentially contributing to increased carbon uptake by leaves during this period (Hermansyah, 2023). Additionally, variations in light intensity among mangrove species suggest that crown structure and leaf density can significantly affect the amount of light received directly by each species.

Table 1.
LIGHT INTENSITY (LUX)

Light Intensity (×100) at Each Station	Time	Leaf Type *Avicennia marina*	 *Excoecaria agallocha*	 *Bruguiera gymnorhiza*	 *Ceriops tagal*
I	Morning	624,3 3	728,0 0	229,67 189,33	576 ,33
		181,6	95,33	241,33	126,
II	After noon	7 443,0	705,33 102,33	180,33 236,67	33 551,

	Morn	0	732,0	196,67	00
III	ing	299,0	0		130
	After	0	97,33		,67
	noon	645,6			578
	Morn	7			,33
	ing	152,6			130
	Sore	7			,67

Avicennia marina and *Excoecaria agallocha* consistently exhibited higher light intensity values compared to *Bruguiera gymnorhiza* and *Ceriops tagal*, which is likely due to their leaf morphology and branch positioning that are more exposed to sunlight.

2. Moisture Content in Mangrove Leaves

Water content in leaves is a crucial parameter for determining a plant's physiological capacity, including its efficiency in photosynthesis, respiration, and transpiration. The water content data for four mangrove species across three different stations and two observation times (morning and afternoon) revealed considerable variation. *Bruguiera gymnorhiza* recorded the highest water content at 67.53% in Station III during the morning, followed by *Ceriops tagal* (64.75% in Station I, afternoon), and *Avicennia marina* (64.38% in Station II, morning). In contrast, the lowest water content was found in *Excoecaria agallocha* at Station III in the morning, measuring only 59.25%.

Tabel 2.
MOISTURE CONTENT OF FOUR MANGROVE LEAF SPECIES (%)

Station	**Time**	**Leaf Type**			
		Avicennia marina	*Excoecaria agallocha*	*Bruguiera gymnorhiza*	*Ceriops tagal*
I	Morni	61,91	60,92	62,38	64,
	ng	60,69	60,34	63,85	60
	After	64,38	61,15	61,55	64,7
	noon	63,87	61,46	66,87	5
II	Morni	63,79	59,25	67,53	62,6
	ng	65,41	60,40	62,09	6
	After				64,1
III	noon				6
	Morni				63,7
	ng				3
	After				64,
	noon				01

The high water content observed in *Bruguiera gymnorhiza* can be attributed to its leaf morphology, which tends to be broader and thicker, allowing it to retain water for longer periods within its mesophyll tissue. Leaves with higher water content typically exhibit good turgidity, enabling the stomata to remain open for optimal gas exchange and photosynthesis. This condition aligns with the previously presented CO_2 uptake data, where *Bruguiera gymnorhiza* also showed high absorption values, particularly at Station III. On the other hand, the low water content in *Excoecaria agallocha* may indicate a limited capacity for water storage, potentially due to its thinner leaf structure and higher cuticle content, which can increase the rate of transpiration. This low water content is also correlated with the lower CO_2 uptake observed in this species, as discussed earlier.

The differences in water content between morning and afternoon also reflect changes in environmental conditions such as temperature, humidity, and light intensity. In general, leaf water content tends to decrease slightly in the afternoon, as seen in *Avicennia marina* at Station I (morning: 61.91% → afternoon: 60.69%) and *Ceriops tagal* at Station III (morning: 63.73% → afternoon: 64.01%). However, not all species followed this downward trend, indicating that each species exhibits a distinct physiological response to diurnal environmental changes. Overall, leaf water content serves as an important indicator of plant physiological health and environmental adaptation, particularly within the dynamic conditions of mangrove ecosystems. Species with higher water content generally have a greater CO_2 uptake capacity, as it supports more efficient photosynthetic activity.

3. Leaf Dimensions

Leaf size exhibited a relatively consistent pattern, with *Avicennia marina* generally having the largest dimensions, particularly in terms of leaf thickness and width. The highest recorded thickness was observed in *Avicennia marina* at Station III in the afternoon (1.05 mm), while the lowest thickness was found in *Excoecaria agallocha* at Station I in the morning (0.48 mm). Similarly, the longest leaf was also recorded in *Avicennia marina* at the same location (9.13 cm). The greatest leaf width was observed in *Avicennia marina* at Station III in the morning (5.40 cm), whereas the smallest leaf width was found in *Excoecaria agallocha* at Station II in the morning (3.27 cm).

Table 3.
THICKNESS (MM), LENGTH (CM), AND WIDTH (CM)

Station	**Time**	**Leaf Size**	**Leaf Type**			
			Avicennia marina	*Excoecaria agallocha*	*Bruguiera gymnorhiza*	*Ceriops tagal*
I	Morning	Thickness	1,00	0,48	0,90	0,77
		Length	8,97	8,50	7,30	8,50
		Width	4,50	3,40	3,57	3,87
	Afternoon	Thickness	0,91	0,45	0,81	0,74
		Length	8,43	8,13	7,50	7,50
		Width	4,43	3,27	3,97	4,13

II	Morning	Thickness	0,94	0,44	0,90	0,78
		Length	7,93	8,13	7,97	7,40
		Width	4,30	3,00	4,50	4,00
	Afternoon	Thickness	1,00	0,46	0,77	0,77
		Length	8,83	8,13	7,83	8,00
		Width	4,37	3,40	4,00	3,63
III	Morning	Thickness	1,01	0,51	0,88	0,79
		Length	8,83	7,23	7,90	7,23
		Width	4,70	3,17	3,90	4,27
	Afternoon	Thickness	0,85	0,44	0,86	0,67
		Length	9,37	8,10	7,80	8,23
		Width	4,53	3,33	3,80	3,83

This indicates that *Avicennia marina* is morphologically better adapted to capturing sunlight and conducting photosynthesis efficiently, particularly in environments with high light intensity. The variation in leaf size also reflects differing adaptive strategies among species. Broader and thicker leaves allow for greater photosynthetic efficiency, while smaller and thinner leaves tend to reduce water loss through transpiration and are more suited to environments with higher water stress (Zheng et al., 2019).

4. Carbon Dioxide (CO_2) Uptake

The potential for carbon dioxide (CO_2) uptake by mangrove leaves showed significant variation across species, sampling times, and station locations. This measurement was conducted by considering total leaf biomass, organic carbon content, and the conversion of carbon into CO_2.

Table 4.
CO_2 UPTAKE POTENTIAL OF *AVICENNIA MARINA* LEAVES

Station	Time	Total Biomass (g)	Organic Carbon (%)	Organic Carbon from Biomass (g)	CO_2 Uptake Potential (mg)
I	Morning	22,61	39,0 ± 1,03	886,31 ± 20,72	3251,01 ±76,20
	Afternoon	19,22			
II	Morning	24,99	38,4 ± 0,91	734,2 ±	2690,91 ±

III	Afternoon Morning Afternoon	24,72 25,84 23,77	40,2 ± 1,24 40,0 ± 0,91 42,2 ± 0,34 42,4 ± 0,91	17,61 1004,41 ± 26,13 988,797 ± 22,65 1089,33 ± 9,91 1006,88 ± 23,37	63,95 3677,66 ± 99,78 3626,35 ± 84,28 3992,72 ± 33,80 3690,44 ± 87,18

Table 5.
CO_2 UPTAKE POTENTIAL OF *EXCOECARIA AGALLOCHA* LEAVES

Station	**Time**	**Total Biomass (g)**	**Organic Carbon (%)**	**Organic Carbon from Biomass (g)**	**CO_2 Uptake Potential (mg)**
I	Morning	7,55	19,2 ± 1,03	144,96 ± 7,84	531,57 ± 29,76
	Afternoon	7,88	20,4 ± 0,6	158,573 ± 8,21	581,37 ± 29,57
II	Morning	7,75	25,2 ± 0,6	195,3 ± 4,65	715,7 ± 17,52
	Afternoon	7,79	25,8 ± 1,03	200,977 ± 8,09	786,44 ± 104,81
III	Morning	7,58	33,0 ± 1,03	250,133	916,63 ±
	Afternoon	7,78	33,6		

			± 0,6	± 7,87	29,04
				261,40 ± 4,66	957,05 ± 16,41

Table 6.
CO_2 UPTAKE POTENTIAL OF *BRUGUIERA GYMNORHIZA* LEAVES

Station	Time	Total Biomass (g)	Organic Carbon (%)	Organic Carbon from Biomass (g)	CO_2 Uptake Potential (mg)
I	Morning	19,25	44,6 ± 0,91	858,55 ± 17,64	3147,75 ± 63,88
	Afternoon	16,52	44,2 ± 0,91	718,25 ±14,89	2634,05 ± 55,67
II	Morning	20,81	44,8 ± 0,69	932,28 ±14,41	3416,32 ± 55,57
	Afternoon	18,10	45,0 ± 0,6	814,5 ± 10,86	2984,71 ± 41,87
III	Morning	17,59	45,1 ± 0,75	793.30 ± 13,28	2907,59 ± 48,11
	Afternoon	21,96	45,0 ± 0,6	988.19 ± 13,17	3623,21 ± 48,33

Table 7.
CO_2 UPTAKE POTENTIAL OF *CERIOPS TAGAL* LEAVES

Statio	Time	Total Bio	Organic	Organic Car	CO_2 Uptake

n		mass (g)	Carbon (%)	bon from Biomass (g)	Potential (mg)
I	Morning	12,75	37,2 ± 1,03	474,3 ± 13,25	1737,98 ± 49,56
	Afternoon	12,48	37,8 ± 0,6	471,74 ± 7,49	1726,83 ± 27,96
II	Morning	13,48	39,8 ± 0,34	536.49 ± 4,67	1965,37 ± 17,08
	Afternoon	12,60	40,2 ± 0	506,62 ± 6,96	1857,80 ± 0
III	Morning	13,27	41,6 ± 0,34	552,02 ± 4,60	2024,72 ± 16,53
	Afternoon	12,92	42,2 ± 0,69	545.22 ± 4,47	1993,01 ± 20,03

Table 8.
CO_2 UPTAKE POTENTIAL OF LEAVES IN THE PALUH GETAH MANGROVE COAST

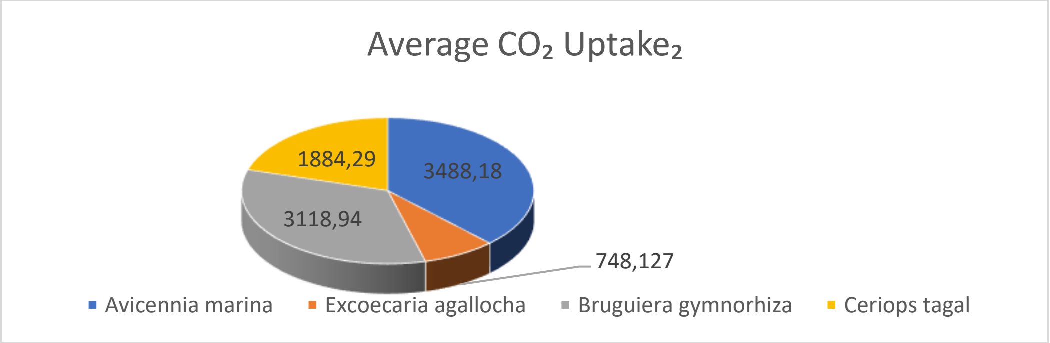
Station	Time	Mangrove Species			
		Avicennia marina	*Excoecaria agallocha*	*Brugera gymrhiz*	*Ceriops tagal*
I	Morning	3251,01 ±76,20	531,57 ± 29,76	3147,75 ± 63,88	1737,98 ± 49,56
	Afternoon	2690,91 ± 63,95	581,37 ± 29,57	2634,05 ± 55,6	1726,83 ± 27,
II	Morning	3677	715,7 ± 17,52		
III					

	ning	,66 ±	786,4	7	96
	After	99,7	4 ±	341	196
	noon	8	104,8	6,32	5,3
		3626	1	±	7 ±
		,35 ±	916,6	55,5	17,
		84,2	3 ±	7	08
		8	29,04	298	185
		3992	957,0	4,71	7,8
		,72 ±	5 ±	±	0 ±
		33,8	16,41	41,8	0
		0		7	20
		3690		290	24,
		,44 ±		7,59	72
		87,1		±	±
		8		48,1	16,
				1	53
				362	199
				3,21	3,0
				±	1 ±
				48,	20,
				33	03

The highest CO_2 uptake potential was recorded in Avicennia marina at Station III in the morning, with a value of 3992.72 ± 33.80 mg. This value was significantly higher than those of the other species, indicating that Avicennia marina has an optimal capacity for CO_2 absorption. This result is consistent with its larger and thicker leaf morphology, as previously discussed. In contrast, the lowest CO_2 uptake potential was observed in Excoecaria agallocha at Station I in the morning, amounting to 531.57 ± 29.76 mg. This species demonstrated a low carbon uptake capacity, which aligns with its smaller leaf size and lower organic carbon content.

For Bruguiera gymnorhiza, the highest uptake was found at Station II in the morning, reaching 3416.32 ± 55.57 mg, while the lowest was recorded at Station I in the afternoon. This indicates that the sampling time influences uptake capacity, with morning conditions generally resulting in higher values compared to the afternoon (Nugroho, 2021). Meanwhile, Ceriops tagal exhibited its highest CO_2 uptake at Station III in the morning, at 2024.72 ± 16.53 mg, and the lowest at Station I in the afternoon, at 1726.83 ± 27.96 mg. Although its values were lower than those of Avicennia marina and Bruguiera gymnorhiza, Ceriops tagal still showed a consistent trend of increasing carbon uptake from Station I to Station III.

Figure 2.
AVERAGE CO_2 UPTAKE

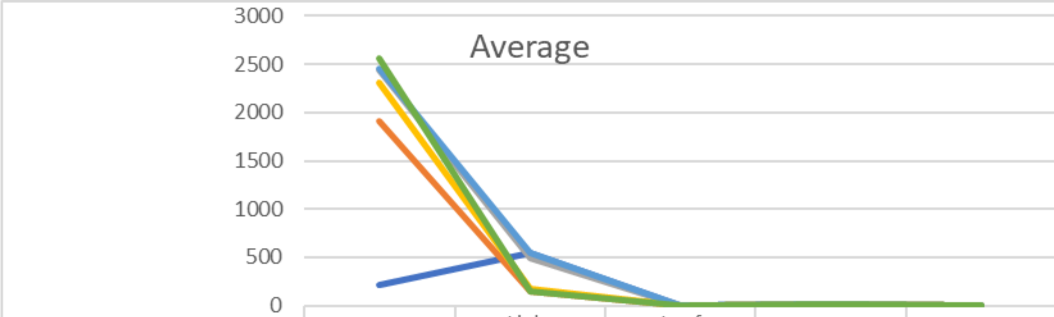


When compared across stations, Station III generally exhibited the highest carbon uptake, particularly in the morning, with *Avicennia marina* showing dominant performance. This may be influenced by the environmental conditions at Station III, which are more favorable for leaf development and biomass accumulation such as higher light intensity, humidity, and salinity. Overall, the results of the study indicate that species type, leaf size, and growth location significantly affect the CO_2 uptake potential (*Zheng et al., 2019*). *Avicennia marina* proved to be the most efficient species in absorbing CO_2, reinforcing its vital role in climate change mitigation within mangrove ecosystems.

5. CO_2 Uptake, Light Intensity, Leaf Thickness, Leaf Length, and Leaf Width

CO_2 uptake capacity is not influenced by a single factor alone, but rather results from the interaction of multiple variables, including leaf morphological traits and surrounding environmental conditions. Light intensity exhibited a fluctuating pattern, with the highest value recorded at Station III in the morning (548.16 lx) and the lowest at Station I in the afternoon (148.16 lx). This pattern appears to align with the CO_2 uptake values, where higher light intensity is generally associated with increased CO_2 absorption. This relationship can be explained by the process of photosynthesis, which directly depends on the availability of light as an energy source.

Figure 3.
COMPARISON OF AVERAGE CO_2, LIGHT INTENSITY (LX), LEAF THICKNESS (MM), LEAF LENGTH (CM), AND LEAF WIDTH (CM) UPTAKE OF FOUR MANGROVE SPECIES ACROSS THREE STATIONS AND TWO DIFFERENT TIMES.



	CO_2 Uptake	Light Intensity X100 (Lx)	Leaf Thickness (mm)	Leaf Length (cm)	Leaf Width (cm)
Station I Morning	216,07	539,58	0,78	8,31	3,83
Station I Aternoon	1908,29	148,16	0,72	7,89	3,95
Station II Morning	2443,76	485,16	0,76	7,85	3,95
Station II Afternoon	2313,82	178,08	0,75	8,19	3,85
Station III Morning	2460,415	548,16	0,79	7,79	4,01
Station III Afternoon	2565,928	144,33	0,7	8,37	3,87

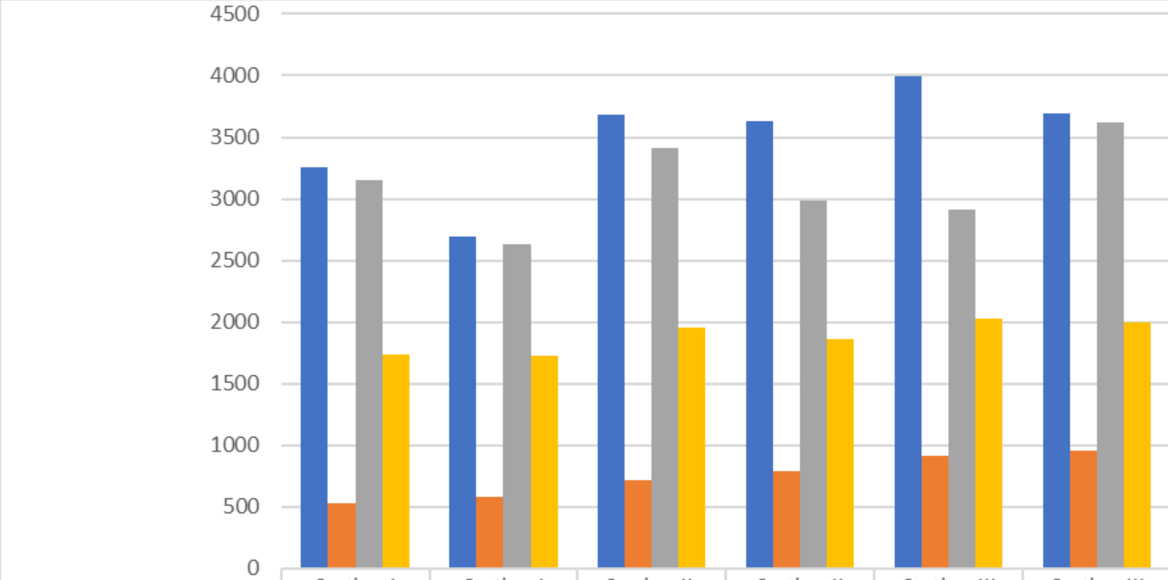
However, anomalies such as the observation at Station II in the morning where light intensity was 485.16 lx, yet CO_2 uptake reached 2443.76 mg suggest that, in addition to light, leaf morphological factors also play a crucial role. At this point, the leaf thickness was 0.76 mm, length 7.85 cm, and width 3.95 cm, which are relatively optimal compared to other sites. Leaves with appropriate thickness and size provide sufficient surface area for light capture and efficient gas exchange, thereby supporting maximum photosynthetic activity. Leaf length and width also contribute to CO_2 uptake capacity. For instance, although light intensity at Station III in the afternoon was lower than in the morning, its CO_2 uptake was higher. This is likely supported by the longer (8.37 cm) and wider (3.87 cm) leaves, which increase the absorption surface and enable efficient light capture and gas exchange to continue optimally. In general, a positive relationship can be observed between light intensity and leaf morphological dimensions with CO_2 uptake. This aligns with fundamental principles of plant physiology, which state that optimal photosynthesis is achieved through sufficient light availability and leaf structures that support efficient gas diffusion (Nugroho, 2021).

6. Correlation of Carbon Dioxide (CO_2) Uptake with Leaf Type

Analysis of the four mangrove leaf species revealed significant differences in their ability to absorb carbon dioxide. *Avicennia marina* recorded the highest average CO_2 uptake at 3488.18 mg, followed by *Bruguiera gymnorhiza* (3118.94 mg), *Ceriops tagal* (1884.29 mg), and the lowest in *Excoecaria agallocha* (748.13 mg). These differences are closely related to the distinct physiological and morphological characteristics of each species. *Avicennia marina*, for instance, is well known for its strong adaptive capacity to high salinity and intense light conditions, as well as for its leaf structure that is highly efficient in conducting photosynthesis. Its leaves are typically thicker and possess stomata that are more responsive to changes in humidity and temperature. These traits support high photosynthetic activity and elevated CO_2 uptake. *Bruguiera gymnorhiza* also demonstrated high uptake potential, likely due to its broader leaves, which enhance gas exchange capacity. In contrast, *Excoecaria agallocha* exhibited the lowest CO_2

uptake, possibly due to its relatively small and thin leaf structure, along with limited adaptability to high light intensity.

Figure 4.
COMPARISON OF AVERAGE CO_2 UPTAKE OF FOUR MANGROVE SPECIES ACROSS THREE STATIONS AND TWO DIFFERENT TIMES.



	Station I Morning	Station I Aternoon	Station II Morning	Station II Afternoon	Station III Morning	Station III Afternoon
Avicennia marina	3251,01	2690,91	3677,66	3626,35	3992,72	3690,44
Excoecaria agallocha	531,57	581,37	715,7	786,44	916,63	957,05
Bruguiera gymnorhiza	3147,75	2634,05	3416,32	2984,71	2907,59	3623,21
Ceriops tagal	1737,98	1726,83	1956,37	1857,8	2024,72	1993,01

When analyzed in relation to location and time, all species generally exhibited higher CO_2 uptake in the morning compared to the afternoon, although this trend is not absolute. For example, at Station III, *Avicennia marina* consistently maintained high uptake levels both in the morning (3992.72 mg) and afternoon (3690.44 mg), demonstrating its stable physiological efficiency. This correlation suggests that certain mangrove species have greater potential in their role as carbon sinks *(Sutaryo, 2009).* Therefore, this information can be utilized in mangrove conservation and rehabilitation strategies that prioritize carbon sequestration capacity focusing on species proven to be the most efficient, such as *Avicennia marina* and *Bruguiera gymnorhiza*.

Conclusion

The amount of biomass in the four mangrove leaf species varied across stations and sampling times. The highest biomass was recorded in Avicennia marina leaves at Station III in the morning, with a total of 25.84 grams, while the lowest was found in Excoecaria agallocha leaves at Station I in the morning, totaling 7.55 grams. The highest carbon dioxide (CO_2) uptake was also observed in Avicennia marina, with a maximum value of 3992.72 ± 33.80 mg at Station III in the morning. In contrast, the lowest uptake was recorded in Excoecaria agallocha at Station I in the morning, with a value of 531.57 ± 29.76 mg.

References

Abdullah, T., & Rahmat, B. (2019). Perhitungan ruang terbuka hijau berdasarkan emisi karbon dioksida. *Jurnal Pijar MIPA,* 14(1), 95–99. https://doi.org/10.29303/jpm.v14i1.997

Agustina, L., Simanjuntak, P. P., & Khoir, A. N. U. (2019). Pengaruh parameter meteorologi terhadap konsentrasi CO_2 dan CH_4 di DKI Jakarta. *Jurnal Meteorologi Klimatologi dan Geofisika,* 6(2), 30–38. https://jurnal.stmkg.ac.id/index.php/jmkg/article/view/121

Alfisyahri, N., Syafruddin, K., & Endrizal, R. (2020). Hubungan kausalitas konsumsi energi hydropower, emisi karbon dioksida dan pertumbuhan ekonomi pada negara-negara G20. *Jurnal Ilmiah Manajemen, Ekonomi, & Akuntansi (MEA),* 4(1), 114–127. https://doi.org/10.31955/mea.v4i1.273

Azzahra, M. S., Suryanti, S., & Sigit, F. (2020). Estimasi serapan karbon pada hutan mangrove Desa Bedono, Demak, Jawa Tengah. *Journal of Fisheries and Marine Research,* 4(2), 308–315.

Badan Standarisasi Nasional. (2011). Pengukuran dan perhitungan cadangan karbon: Pengukuran lapangan untuk penaksiran cadangan karbon hutan (Ground based forest carbon accounting) (SNI 7724, pp. 28–55). Jakarta, Indonesia: Badan Standarisasi Nasional.

Daud, M., Latifah, H., Hikmah, & Sarman. (2014). Potensi biomassa, cadangan karbon, dan serapan karbon dioksida pada Kebun Raya Massenrempulu Enrekang. Proceedings of Seminar Nasional (pp. 1–9). ResearchGate. https://www.researchgate.net/publication/327559283

Devano, M. H., & Padian, A. S. S. (2024). Pengaturan prinsip kehati-hatian dalam pengelolaan emisi karbon di Indonesia. *Jaksa: Jurnal Kajian Ilmu Hukum dan Politik*, 2(1), 112–125. https://doi.org/10.51903/jaksa.v2i1.1509

Djamaluddin, R. (2018). Mangrove: Biologi, ekologi, rehabilitasi, dan konservasi. Manado, Indonesia: Unsrat Press. Fitria, A., & Ghesang, D. (2021). Ekosistem mangrove dan mitigasi pemanasan global. *Jurnal Ekologi, Masyarakat dan Sains,* 2(1), 29–34.

Gani, A. (2013). *Bagan warna daun* (BWD). Balai Besar Penelitian Tanaman Padi.

Hamzi, I. B. A., Mulyanto, & Diana, A. (2017). Penyerapan karbon dioksida (CO_2) pada daun, serasah daun, dan sedimen mangrove Sonneratia caseolaris (L.) Engler kategori tiang di kawasan mangrove Tlocor, Kabupaten Sidoarjo. Prosiding Seminar Nasional Kelautan dan Perikanan, 33–38.

Heriyanto, N. M., & Subiandono, E. (2012). Komposisi dan struktur tegakan, biomasa, dan potensi kandungan karbon hutan mangrove di Taman Nasional Alas Purwo. *Jurnal Penelitian Hutan dan Konservasi Alam*, 9(1), 23–32.

Hermansyah, B. (2023). Studi emisi karbon dari kendaraan bermotor dan daya serap karbon dari pohon di PT Komatsu Undercarriage Indonesia. *Journal of Comprehensive Science,* 2(9), 1572–1585. https://jcs.greenpublisher.id/index.php/jcs/article/view/510 Integrated Taxonomic Information System. (2025).

Ceriops tagal (Perr.) C.B. Rob. https://www.itis.gov Iqbal, M., Hermawan, R., & Dahlan, E. N. (2015). Potential carbon dioxide sequestration of several plant leaves in green belt of Pajajaran Street, Bogor. *Jurnal Penelitian Sosial dan Ekonomi Kehutanan,* 12(1), 67–76. https://doi.org/10.20886/jpsek.2015.12.1.67-76

Ismail, A. (2020). Potensi penurunan emisi gas rumah kaca (GRK) dalam kegiatan belajar di rumah secara online: Analisis jejak karbon (carbon footprint analysis). *Jukung: Jurnal Teknik Lingkungan,* 6(2), 195–203. https://doi.org/10.20527/jukung.v6i2.9262

Kindangen, G., Sondak, C., & Kumampung, D. R. H. (2021). Estimasi kandungan karbon biomasa pneumatofor Avicennia marina. *Jurnal Pesisir dan Laut Tropis*, 9(3), 141. https://doi.org/10.35800/jplt.9.3.2021.38167

Kristanti, L. M. (2019). Analisis simpanan CO_2 pada akar, daun dan sedimen sekitar mangrove Avicenna marina di kawasan mangrove Desa Tambaan, Kecamatan Panggungrejo, Pasuruan, Jawa Timur (Skripsi, Universitas Brawijaya).

Lestari, K. W., & Nilasari, D. (2023). Potensi simpanan karbon pada beberapa tipe agroforestri berbasis kopi robusta di Desa Rowosari, Jember. *Journal of Tropical Silviculture*, 14(2), 150–157. https://doi.org/10.29244/j-siltrop.14.02.150-157

Luwuk, K., & Banggai, K. (2022). Inventarisasi mangrove di kawasan hutan mangrove Cagar Alam Pulau Dua. *JBB: Jurnal Biologi Babasal*, 1(1), 1–5.

Meiviana, A., Diah, R. S., & Moekti, H. S. (2004). Bumi makin panas: Ancaman perubahan iklim di Indonesia. Kementerian Lingkungan Hidup Republik Indonesia.

Nugroho, S. (2021). Suara Bukit Kototabang. Bukit Kototabang, Indonesia: Badan Meteorologi, Klimatologi, dan Geofisika. Nuryoto, N., Nia, M., Alya, S. C., & Suripno. (2021). Pemanfaatan karbon dioksida untuk sintesis precipitated calcium carbonate (PCC) dengan metode karbonasi. *Jurnal Integrasi Proses,* 10(2), 90–95. http://jurnal.untirta.ac.id/index.php/jip

Nurruhwati, I., Purwita, S. D., Sunarto, & Zahidah. (2017). Blue carbon content of mangrove vegetation in Subang District. Proceedings of the ASEAN-FEE International Fisheries Symposium, 1–6. Prasetyo, A. B., & Jaka, W. (2022). Pemanfaatan teknologi carbon capture and storage (CCS) dalam upaya mendukung produksi energi yang berkelanjutan. *Jurnal Energi Baru & Terbarukan*, 3(3), 231–238.

Pratama, R., & Parinduri, L. (2019). Penanggulangan pemanasan global. *Buletin Utama Teknik*, 15(1), 91–95. https://jurnal.uisu.ac.id/index.php/but/article/view/1879

Purnobasuki, H. (2006). Peranan mangrove dalam mitigasi iklim. Buletin PSL *Universitas Surabaya*, 9(1), 9–10.

Purnobasuki, H. (2012). Pemanfaatan hutan mangrove sebagai penyimpan karbon. *Buletin PSL Universitas Surabaya*, 3(1), 3–5.

Safitri, I., Kushadiwijayanto, A. A., Nurdiansyah, S. I., Sofiana, M. S. J., & Andreani, A. (2023). Inventarisasi jenis mangrove di wilayah pesisir Desa Sungai Nibung, Kalimantan Barat. *Jurnal Ilmu Lingkungan*, 22(1), 109–124. https://doi.org/10.14710/jil.22.1.109-124

Schumacher, B. A. (2002). Methods for the determination of total organic carbon (TOC) in soils and sediments. Washington, DC: US Environmental Protection Agency, Office of Research and Development.

Sidik, A. K., Hartono, M., & Ilyas, H. (2020). Potensi struktur vegetasi mangrove dan nilai serapan biomassa karbon. Gorontalo, Indonesia: Ideas Publishing.

Sondak, C. F. A. (2015). Estimasi potensi penyerapan karbon biru (blue carbon) oleh hutan mangrove Sulawesi Utara. *Journal of ASEAN Maritime Issues,* 1(1), 24–28. Sutaryo, D. (2009). Penghitungan biomassa. Bogor, Indonesia: Wetlands International Indonesia Programme.

Syamiyah, N., & Sri, W. (2021). Pencemaran udara dalam ruangan (karbon dioksida dan total senyawa organik volatile) serta gangguan paru pada siswa SD di Depok. *Journal of Baja Health Science,* 1(2), 126–140. https://doi.org/10.47080/joubahs.v1i02.1485

Thalib, M., Baderan, D. W. K., & Katili, A. S. (2021). Produksi dan laju dekomposisi serasah Ceriops tagal di Cagar Alam Tanjung Panjang. *Jurnal Sylva Lestari*, 9(1), 151–160. https://doi.org/10.23960/jsl19151-160

Wahyuni, I., Amalia, R., Octoviani, R., Eliyana, S., & Biologi, P. (2024). Inventarisasi mangrove di kawasan hutan mangrove Cagar Alam Pulau Dua. *JB&P: Jurnal Biologi dan Pembelajarannya,* 11(1), 64–80. https://ojs.unpkediri.ac.id/index.php/biologi

Zheng, Y., Li, F., Hao, L., Yu, J., Guo, L., Zhou, H., Ma, C., Zhang, X., & Xu, M.

(2019). Elevated CO_2 concentration induces photosynthetic down-regulation with changes in leaf structure, non-structural carbohydrates and nitrogen content of soybean. BMC Plant Biology, 19(1), 1–18. https://doi.org/10.1186/s12870-019-1788-9