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Analysis of total biomass, carbon stock and carbon dioxide uptake in *Kandelia candel* stands

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ABSTRACT

Background: Mangrove ecosystems play a crucial role in mitigating climate change through carbon sequestration. This study aimed to quantify the biomass, carbon stock, and carbon dioxide uptake of *Kandelia candel* stands on Payung Island, South Sumatra, Indonesia. **Methods:** Non-destructive sampling was conducted at two stations using 10x10 m plots along 50 m transects. Tree diameter was measured and allometric equations were used to estimate biomass and carbon stocks. Environmental parameters were also recorded. **Finding:** The highest biomass (193.69 tosn/ha), carbon stock (89.11 tons C/ha), and CO_2 uptake (320.04 tons CO_2/ha) were found at Station II, correlating with larger average tree diameters. Environmental conditions, including salinity (0‰), pH (7.0), temperature (24-28°C), and humidity (90-91%), were favorable for *K. candel* growth. The substantial carbon storage demonstrates the importance of these stands for climate change mitigation. **Conclusion:** This study provides valuable data on the carbon sequestration potential of *K. candel* in a unique estuarine setting, contributing to our understanding of mangrove ecosystems' role in global carbon cycles and informing conservation strategies. **Novelty/Originality of this Study:** This study focuses on quantifying the biomass, carbon stocks, and CO_2 uptake of *Kandelia candel* stands within the unique estuarine ecosystem of Payung Island, South Sumatra. By providing species-specific data on *K. candel*—a mangrove species that has been relatively underexplored—this research addresses a significant knowledge gap and enhances our understanding of its role in carbon sequestration.

KEYWORDS: biomass, carbon dioxide uptake, carbon stock, kandelia candel, mangrove conservation

1. Introduction

Mangrove ecosystems play a pivotal role in mitigating global climate change through their exceptional capacity to sequester and store substantial quantities of carbon. These coastal forests function as significant carbon sinks, capturing atmospheric carbon dioxide and storing it in their biomass and sediments (Donato et al., 2011; Murdiyarso et al., 2015; Alongi, 2014; Kauffman & Donato, 2012). The carbon sequestration potential of mangroves surpasses that of numerous terrestrial forests, rendering them a crucial component in

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strategies aimed at reducing greenhouse gas emissions and combating global warming (Mcleod et al., 2011; Pendleton et al., 2012; Siikamäki et al., 2012; Twilley et al., 2017).

Global climate change, primarily driven by escalating atmospheric concentrations of greenhouse gases such as carbon dioxide (CO_2), poses significant threats to coastal ecosystems and communities. The impacts of climate change, including rising sea levels, increased frequency of extreme weather events, and alterations in temperature and precipitation patterns, are already evident (Nicholls & Cazenave, 2010). Mangrove forests exhibit particular vulnerability to these changes, yet simultaneously offer potential nature-based solutions for climate change mitigation and adaptation (Gilman et al., 2008; Ward et al., 2016; Friess et al., 2019).

Kandelia candel, a mangrove species indigenous to parts of Southeast Asia, represents a significant component of mangrove ecosystems in certain regions. This species, belonging to the Rhizophoraceae family, is renowned for its adaptability to diverse salinity levels and its potential for carbon sequestration (Duke et al., 2010; Wang et al., 2016). Elucidating the biomass accumulation, carbon storage, and CO_2 uptake capabilities of *K. candel* stands can provide invaluable insights into their role in climate change mitigation strategies (Peng et al., 2016).

Payung Island, located in Banyuasin Regency, South Sumatra, Indonesia, is an area with natural mangrove forests dominated by Kandelia candel (K. candel) populations. The location of the island, which is at the mouth of the Musi River, provides unique characteristics to the estuarine ecosystem that is influenced by a combination of freshwater inputs from rivers and seawater. This makes Payung Island an interesting example for the study of complex mangrove ecosystems (Sarno et al., 2020; Afriyani et al., 2017). The mangrove forests on this island not only function ecologically as habitats that support biodiversity, but also have significant potential as carbon sinks, contributing to climate change mitigation.

Measuring the carbon storage capacity of mangrove forests, especially in K. candel species, is essential to assess their contribution to regional and global carbon budgets. Recent studies have shown that mangrove forests can store up to five times more carbon per equivalent area than many terrestrial forests (Hermialingga et al., 2020; Ulqodry et al., 2010; Donato et al., 2011; Alongi, 2012). The uniqueness of mangrove ecosystems, including K. candel, lies in their ability to adapt to changing environments, including fluctuations in salinity and soil conditions. These adaptations include the development of strong roots and sturdy stem structures, allowing the species to survive and thrive in extreme conditions. These processes contribute not only to the resilience of the species but also to the capacity of the ecosystem to store carbon. However, specific data on carbon storage for less common species such as K. candel are still very limited in many regions. This knowledge gap hinders accurate assessment of the climate mitigation potential of different mangrove ecosystems (Kauffman et al., 2020). It is important to expand research on carbon stocks, especially in areas with under-studied mangrove forests. This can provide further insight into the role of mangrove species in the global carbon cycle and aid in conservation efforts.

To assess mangrove biomass and carbon stocks, non-destructive sampling methods are commonly used. This method relies on allometric equations to estimate aboveground (AGB) and belowground (BGB) biomass based on measurable tree parameters, such as diameter at breast height (DBH) (Komiyama et al., 2008; Chave et al., 2014). Using this methodology, carbon stocks can be quantified without the need for destructive harvesting, making it particularly suitable for conservation areas and long-term monitoring efforts. Furthermore, further research into the development of more specific allometric models for K. candel could improve the accuracy of biomass and carbon stock estimates, providing more comprehensive data on carbon storage potential.

Comprehending the carbon dynamics of *K. candel* stands holds particular importance given the species' limited distribution and potential vulnerability to environmental changes. *K. candel* is classified as Least Concern on the IUCN Red List, yet its populations face threats from habitat loss, pollution, and climate change impacts (Duke et al., 2010). Quantifying the carbon storage potential of *K. candel* can underscore its ecological importance and contribute to conservation efforts for this species and its habitats.

The carbon sequestration capacity of mangroves extends beyond their above-ground biomass. Mangrove sediments, often referred to as "blue carbon," represent a significant and long-term carbon sink (Mcleod et al., 2011). The anaerobic conditions prevalent in mangrove soils decelerate the decomposition of organic matter, leading to the accumulation of carbon over extended periods. Assessing both the above-ground and below-ground carbon stocks of *K. candel* stands can provide a more comprehensive understanding of their total carbon storage capacity (Macreadie et al., 2017).

Climate change mitigation strategies increasingly acknowledge the role of nature-based solutions, including the conservation and restoration of carbon-rich ecosystems such as mangroves. Quantifying the carbon stocks and sequestration potential of specific mangrove species and stands can inform policy decisions, guide conservation priorities, and support the development of carbon offset projects. The data derived from *K. candel* stands on Payung Island can contribute to these broader efforts by providing species-specific information from a relatively understudied area (Cohen-Shacham et al., 2016).

The potential for mangrove forests to contribute to climate change mitigation faces threats from ongoing deforestation and degradation. Despite their ecological and climate importance, mangroves continue to be lost at alarming rates in many parts of the world (Friess et al., 2019). Elucidating the carbon storage potential of specific mangrove species and stands can strengthen arguments for their conservation and highlight the climate-related consequences of their loss. This information holds particular relevance for areas like Payung Island, where natural mangrove forests persist but may face future development pressures.

Research on mangrove carbon stocks intersects with international climate policy frameworks, such as Reducing Emissions from Deforestation and Forest Degradation (REDD+) mechanisms (Alongi, 2011; Murdiyarso et al., 2013). Accurate quantification of carbon stocks in diverse mangrove ecosystems, including less common species like *K. candel*, is essential for the development and implementation of such programs. The data obtained from Payung Island can contribute to the growing body of knowledge supporting these international efforts to incentivize mangrove conservation and restoration.

The study of *K. candel* stands on Payung Island presents opportunities to examine how local environmental conditions influence carbon storage in mangrove ecosystems. Factors such as tidal regime, salinity, nutrient availability, and sedimentation rates can significantly affect mangrove productivity and carbon sequestration (Twilley et al., 2019). Elucidating these relationships can aid in predicting how mangrove carbon stocks might respond to future environmental changes and inform adaptive management strategies. In addition to their carbon storage capacity, mangroves provide numerous other ecosystem services, including coastal protection, fisheries support, and biodiversity conservation (Carugati et al., 2018). Quantifying the carbon stocks of *K. candel* stands can complement assessments of these other services, providing a more comprehensive valuation of mangrove ecosystems. This holistic approach can strengthen arguments for mangrove conservation and sustainable management, highlighting their multifaceted importance in coastal landscapes.

The present study aims to address these knowledge gaps by quantifying the biomass, carbon stocks, and CO_2 uptake of *K. candel* stands on Payung Island, Banyuasin Regency, South Sumatra. By focusing on this specific mangrove species in a unique estuarine setting, the research will contribute valuable data to our understanding of mangrove carbon dynamics and their potential role in climate change mitigation strategies. The results of this study can inform local and regional conservation efforts, support policy decisions related to coastal management and climate action, and contribute to the broader scientific understanding of mangrove ecosystems in the face of global environmental change.

2. Methods

The research was conducted from January to April 2022 on Payung Island, Banyuasin II Sub-district, Banyuasin Regency, South Sumatra, Indonesia (Figure 1). Payung Island is a protected forest area covering approximately 490 hectares, located at the mouth of the Musi River (Hermialingga et al., 2020). The island is characterized by low-lying terrain with muddy substrates influenced by tidal fluctuations, creating ideal conditions for mangrove ecosystems (Afriani et al., 2017).

Sampling Design Sampling stations were selected using purposive sampling based on the presence of *Kandelia candel* trees with stem diameters ≥5 cm (Komiyama et al., 2008). Two sampling stations were designated as Station I and Station II with the following coordinates: Station I is located at S 02°21'52.41" E 104°55'34.41" and Station II at S 02°21'33.26" E 104°55'04.69". At each station, three 50-meter transects were designated perpendicular to the coastline with a minimum distance between transects of 10 meters (Figure 1). Along each transect, five plots measuring 10 m x 10 m were drawn at 10-meter intervals, so that the total sampling plots at both stations reached 30 plots (Sutaryo, 2009).

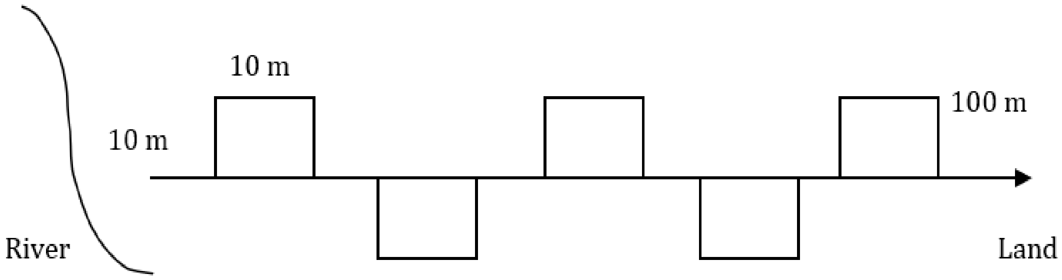

Fig. 1. Schematic diagram of transect and plot layout

2.1 Data Collection

The data on Kandelia candel stands were obtained through non-destructive sampling methods (Sutaryo, 2009). Within each plot, the following measurements and observations were recorded: the stem circumference was measured at breast height (1.3 m above ground or highest prop root) using a flexible measuring tape (Komiyama et al., 2008), the total number of *K. candel* individuals with stem diameters ≥5 cm was counted, and the presence and abundance of other mangrove species within the plots were noted. Additionally, the following environmental parameters were measured at each station using appropriate instruments: water salinity (‰) using a hand refractometer, sediment pH using a pH meter, air temperature (°C) and humidity (%) using a multifunction environment meter, light intensity (lux) using a multifunction environment meter, and the substrate type, for which sediment samples were collected for laboratory analysis.

2.2 Data Analysis

The data analysis of the stem diameter calculation was carried out by measuring the circumference of the stem which was then converted into a diameter using Equation 1. In this process, the diameter (D) is expressed in centimeters, while the circumference (C) is also measured in the same units. The pi (π) value used in the calculation is 3.14.

Aboveground biomass (AGB) and belowground biomass (BGB) were estimated using allometric equations specifically developed for the Kandelia candel species by Komiyama et al. (2008), as presented in Table 1. In this study, AGB is defined as aboveground biomass, measured in kilograms, while BGB is belowground biomass, also measured in kilograms. This measurement process aims to obtain accurate data on both biomass components, which are very important in understanding the carbon storage capacity in the ecosystem.

$$D\frac{C}{\pi} \quad \text{(Eq. 1)}$$

The wood density (ρ) used in the calculation has a value of 0.527 g/cm^3 for the K. candel species, based on information available in the WAC 2021 Database. Stem diameter (D), measured in centimeters, is also an important variable in this biomass estimation. By utilizing the appropriate allometric equations, the estimation of AGB and BGB biomass becomes more accurate, thus providing a clearer picture of the carbon storage potential in the K. candel ecosystem. Accuracy in biomass estimation is critical as it can impact carbon stock assessments as well as understanding the role of this species in climate change mitigation and sustainable natural resource management.

Table 1. Allometric equations for calculating *Kandelia candel* biomass

Species	Biomass (gr/cm^2)	Allometric Model
Kandelia candel	Above-ground Biomass (AGB)	$B= 0,251 \times \rho \times D^{2,46}$
	Root Biomass (RB)	$B=0,199 \times \rho^{0,899} \times D^{2,22}$
	Total Biomass (X)	B= SB+RB (ton/ha)

Menawhile, conversion of biomass values from grams per square centimeter to tons per hectare was done by calculating the total biomass per tree as the sum of aboveground biomass (AGB) and belowground biomass (BGB). The biomass at the plot level was then scaled to a per hectare basis using Equation 2. Where Bn is the biomass per unit area in tons per hectare, Bx is the total biomass of all individuals in the plot in kilograms, and A is the plot area in square meters.

$$Bn\frac{Bx}{1.000.000}\ x\ \frac{1.000.000}{luas\ lokasi} \quad \text{(Eq. 2)}$$

This study also estimated carbon stocks by multiplying the total biomass by a conversion factor of 0.46, which is based on the assumption that about 46% of plant biomass consists of carbon according to the Intergovernmental Panel on Climate Change in 2006. Where C is the carbon stock in tons of carbon/hectare, and B is the total biomass in tons/hectare (Equation 3).

$$C = B \times 0.46 \quad \text{(Eq. 3)}$$

Conversion of biomass value from grams per square centimeter to tons per hectare is done by calculating the biomass value in tons per hectare referring to the National Standardization Agency in 2011, namely Bn is equal to the total biomass of all individuals in one location multiplied by 10 to the power of negative one (Equation 4). Where Bn is the biomass per unit area of the location in tons/hectare, and Bx is the biomass of all individuals in one location (g/cm^2).

$$Bn = (\Sigma\ Bx) \times 10^{-1} \quad \text{(Eq. 4)}$$

Next, the conversion of biomass value to carbon stock is done using the formula C equals B multiplied by 46 percent (Equation 5). Where C is carbon stock in tons of carbon/hectare, and B is biomass in tons/hectare. Finally, the conversion of carbon stock value to carbon dioxide absorption uses the formula CO_2 Absorption equals C multiplied by 3.67 (Equation 6). Where CO_2 Absorption is carbon dioxide absorption in tons of carbon dioxide/hectare, and C is carbon stock in tons of carbon/hectare.

$$C = B \times 46\% \quad \text{(Eq. 5)}$$

$$CO_2\ \text{Sequestration} = C \times 3.67 \quad \text{(Eq. 6)}$$

2.2.4 Measurement of Environmental Parameters of Kandelia candel habitat on Payung Island

This study aims to calculate the value of carbon stock and carbon dioxide sequestration on Payung Island. Various environmental parameters affecting the mangrove forest ecosystem were observed to gain a comprehensive understanding of the factors contributing to the potential for carbon storage. Salinity parameters were measured to determine the level of salt content in water, which is an important factor in the growth of mangrove plants. Salinity can affect the ability of plants to absorb air and nutrients, as well as affect the biodiversity in the ecosystem.

Sediment pH was also described to provide information about the acidity or alkalinity of the soil. The appropriate pH is very important for the health of plants and soil microorganisms, because it can affect the availability of nutrients. The ideal pH range for mangrove growth is usually between 6.0 and 9.0, so this measurement provides an overview of the soil conditions that support the life of the Kandelia candel species on Payung Island. The measured air temperature serves to determine the temperature conditions that can affect ecosystem processes in the ecosystem. The ideal temperature not only supports the process of photosynthesis but also contributes to the activity of microorganisms in the soil, which is important for the nutrient cycle. In addition, air humidity was also recorded, because the level of air vapor in the atmosphere can affect the growth of plants and microorganisms. Optimal humidity supports the transpiration process of plants, which is important for the absorption of carbon dioxide through photosynthesis. The types of substrates described include various types of soil on Payung Island, which play an important role in supporting plant life and storing carbon in the soil. Soil composition, such as texture and organic content, can affect the capacity of the soil to store carbon. Soils rich in organic matter tend to have a higher carbon storage capacity, making it an important factor in assessing carbon stocks.

2.3. Data collection and data processing

Data collection at the research location was conducted using a Non-Destructive sampling method, which involves measuring the circumference of *K. candel* stems using a measuring tape at a height of 1.3 m from the ground surface, which is then converted to stem diameter, with a qualifying diameter range of ≥ 5 cm. The number of *K. candel* individuals within the plot along the transect line was counted, followed by recording other species present in the plot. Environmental parameters for each observation station were measured (water salinity, sediment pH, air temperature, air humidity, and light intensity) using prepared instruments (handheld refractometer, envirometer, and soil tester). The results of environmental parameters were then recorded.

The circumference values of *K. candel* stems were converted to diameter values (Equation 1). The *K. candel* stem diameter data were then input into the allometric model (Equation 2) to estimate root biomass. Biomass values were converted from g/cm^2 to ton/ha (Equation 3). The biomass values were multiplied by a conversion factor of 46% (Equation 4) to estimate the carbon stock stored in *K. candel* stands. Carbon dioxide sequestration values were determined by multiplying the carbon stock values by a conversion factor of 3.67 (Equation 5). Data processing was performed using MS Excel application, followed by determining the comparison of *Kandelia candel* carbon stock values between the two research stations.

3. Results and Discussion

3.1. Biomass, Carbon Stock, and Carbon Dioxide Absorption of Kandelia candel (L.) Druce on Payung Island, Banyuasin II District, South Sumatra

Based on research conducted to estimate biomass, carbon stock, and carbon dioxide absorption of Kandelia candel (L.) Druce on Payung Island, Banyuasin II Regency, South

Sumatra, significant results were obtained as shown in Table 2. The Kandelia candel species showed a prominent presence at observation stations I and II on Payung Island, with greater abundance observed at this location. Research conducted by Sarno et al. (2020) showed the natural dominance and optimal growth of Kandelia candel in the Payung Island area, especially at these stations, with an important value index report of 30.59%.

The prevalence of this species is associated with peat soil conditions rich in organic matter and freshwater swamp environments, as well as the adaptability of the species to brackish water zones that often have salinity fluctuations. Analysis of the data presented in Table 2 reveals that the highest biomass value for Kandelia candel on Payung Island was recorded at observation station II, which was 193.69 tons per hectare, while station I produced a biomass value of 149.01 tons per hectare. The biomass value of a plant species is largely determined by its stem diameter, where stem diameter plays an important role as a factor that influences the calculation of overall biomass. Suwardi et al. in 2017 reported that stem diameter covers 97.1% of the variation in tree biomass, indicating a strong positive correlation between stem size and biomass accumulation.

The highest number of individual trees was documented at station I, yet the maximum biomass value was obtained at station II. This apparent discrepancy is elucidated by the larger average stem diameter of specimens found at station II compared to those at station I. This phenomenon aligns with the findings of Mandari et al. (2016), who observed that despite plot III having the highest tree density, plot II exhibited the greatest biomass value due to larger average stem diameters. Specifically, plot II yielded a biomass value of 47.55 ton/ha, surpassing plot III's 40.87 ton/ha despite the latter's higher tree density.

Table 2. Biomass, Carbon Stock, and Carbon Dioxide Absorption of Kandelia candel (L.) Druce on Payung Island, Banyuasin II District, South Sumatra.

Observation Station	Number of Individuals	Average Tree Diameter (cm)	Biomass (ton/ha)	Carbon Stock (ton C/ha)	CO_2 Absorption (ton CO_2/ha)
Station I	58	9,81	149,01	68,54	251,28
Station II	51	11,04	342,70	157,65	320,04
Total	109	-	342,70	157,65	571,32

A positive correlation was found between stem diameter and biomass values, where a larger diameter corresponds to a larger biomass accumulation, while a smaller diameter results in a reduced biomass value. Agustin et al. (2014) noted that increasing tree diameter and height correlated with increasing biomass values, emphasizing that stem diameter was also positively correlated with root diameter. This means that root biomass can be estimated through stem diameter measurements, making it easier to estimate overall biomass.

The results of the current study corroborate the results of Mandari et al. (2016), which showed that station I, with 58 individual trees, produced a biomass value of 149.01 tons per hectare, which was lower than the 193.69 tons per hectare recorded at station II with 51 individual trees. This discrepancy was caused by the larger average tree diameter at station II compared to station I. This finding suggests that stem diameter has a greater influence on biomass values than the number of individual trees at the study site. This is important to consider in ecosystem management and conservation, where tree size can be a key indicator to determine the potential for carbon storage in an area. Thus, trunk diameter is not only a physical measure, but also reflects the capacity of the ecosystem to store carbon and support environmental sustainability.

Examination of Table 2 reveals that the highest carbon stock value for Kandelia candel was recorded at observation station II, measuring 89.11 ton C/ha, while station I yielded a carbon stock value of 68.54 ton C/ha. This trend aligns with the DBH (Diameter at Breast Height) values, reinforcing the direct relationship between DBH and plant biomass. Stem diameter is directly proportional to biomass value, with higher DBH indicating older trees and consequently greater carbon stock. Forest biomass and carbon stock accumulation are heavily dependent on plant physiological processes, primarily photosynthesis. The magnitude of stand photosynthesis rate is influenced by factors such as chlorophyll content, stomatal density, tree age, canopy structure, and canopy cover. Lukito & Rohmatiah (2013) assert that larger leaf area per unit area corresponds to increased CO_2 absorption by the stand. Greater leaf abundance, typically associated with older trees, results in higher potential biomass and enhanced carbon storage capacity. Thus, tree age emerges as a significant factor affecting both biomass and carbon stock values in a given stand.

The observed differences in carbon stock values between observation stations can be attributed to variations in stem diameters of Kandelia candel across locations. Hairiah et al. (2011) further suggest that disparities in carbon stock between observation stations are influenced by plant density and substrate type. Carbon storage capacity in a given area is enhanced by favorable soil fertility conditions, which promote increased tree biomass. In other words, above-ground carbon stock (plant biomass) is determined by soil carbon stock (soil organic matter), underscoring the necessity of quantifying carbon storage across various components of the ecosystem.

The stem component showed the highest carbon stock value because its composition consists of 40 to 46% cellulose. The carbon-rich nature of cellulose in the stem contributes to the increase in carbon content, forming a positive relationship between cellulose concentration and carbon stock, as stated by Manafe et al. (2016). Cellulose functions as the main structural component of plant cell walls, contributes to plant strength and stability, and plays a role in the photosynthesis process that supports growth. In addition, higher cellulose content is associated with larger stem diameters, indicating that larger plants can store more carbon. This suggests that stem diameter, as an indicator of growth, is very important in determining the potential for carbon storage in Kandelia candel species.

The analysis carried out on Table 2 shows a carbon dioxide absorption value of 251.28 tons of CO_2/ha at observation station I and 320.04 tons of CO_2/ha at observation station II. The high carbon dioxide absorption value at station II is closely correlated with higher biomass and carbon stock values at that location. The data shows that the more biomass there is, the greater the capacity of the ecosystem to absorb carbon dioxide from the atmosphere. This finding is in line with the statement of Heriyanto & Subiandono (2012) who stated that carbon dioxide absorption is intrinsically related to standing biomass. In the context of mangrove ecosystems, biomass can be accumulated through production and density, which are measured through several parameters, such as tree diameter, height, wood density, and soil fertility. These parameters are important to provide a clearer picture of the dynamics of growth and health of mangrove ecosystems, and how these factors interact to affect carbon dioxide absorption values.

The magnitude of carbon absorption in mangrove species is closely related to the height and diameter of the tree. In this case, larger trees tend to show greater carbon absorption potential. The process of absorption of atmospheric carbon dioxide by trees takes place through leaves, twigs, stems, and roots, where the carbon dioxide is converted into organic carbon through photosynthesis that occurs in the leaves. The carbon bound in organic form is then stored as biomass in various plant components, including stems, leaves, roots, branches, and twigs, which contribute to the carbon balance in the ecosystem.

The value of carbon dioxide absorption is directly influenced by the value of the carbon stock in the stand, where a larger carbon stock in the stand is in line with a higher carbon absorption capacity. Yaqin et al. in 2022 emphasized that the carbon dioxide absorption capacity of mangrove stands is regulated by the estimated carbon stock contained in the stand. Variations in mangrove composition can be associated with various environmental conditions that apply in different mangrove areas. Ulqodry et al. (2014) classified mangroves as C3 plants, which show different sensitivity and photosynthetic capacity to different environmental conditions and between species.

These environmental factors, such as light intensity, salinity, temperature, and tidal regime, contribute to the observed variation in the structure and function of mangrove ecosystems. For example, different light intensities will affect the rate of photosynthesis, while salinity can affect root health and growth. Extreme temperatures can also disrupt plant metabolism, and changes in tidal regimes can affect water and nutrient availability. Thus, the interaction between environmental factors and mangrove species is crucial to understanding the dynamics of carbon sequestration in these ecosystems, as well as their implications for natural resource management and climate change mitigation strategies. Good management of mangrove ecosystems will not only increase carbon sequestration capacity but also support sustainability and biodiversity in the area.

3.2. Environmental Parameters

Based on the research that has been conducted to determine the biomass value, carbon stock, and carbon dioxide absorption of Kandelia candel plants on Payung Island, Banyuasin II Regency, South Sumatra, the results of environmental parameters were obtained that showed conditions that support the growth of this species. The data presented in Table 3 show that at observation station I, salinity was recorded at 0‰ with an air temperature of 25 °C. Meanwhile, at observation station II, the same salinity was also recorded at 0‰, but with a higher air temperature, namely 28 °C. The existence of consistent salinity at both observation stations shows that the environment on Payung Island is very suitable for mangrove growth, which in its pair provides a positive contribution to the observed biomass, carbon stock, and carbon dioxide absorption values.

Temperature is a crucial factor that affects the photosynthesis process in plants. In the context of mangroves, optimal temperature is very important to ensure efficient photosynthesis. Research by Hutasoit et al. (2017) showed that the optimal temperature range for photosynthesis in mangroves is between 20 and 30 °C. With air temperatures recorded on Payung Island ranging from 25 to 28 °C, this places these conditions within the ideal range for the photosynthesis process. Appropriate temperatures not only support photosynthesis efficiency but also play a role in increasing the biological productivity of mangrove forests, which has direct implications for biomass growth.

These optimal environmental conditions allow the mangrove forests on Payung Island to obtain sufficient sunlight, which is essential for efficient photosynthesis. With effective photosynthesis, Kandelia candel plants can produce greater biomass, which contributes to increasing carbon stocks and carbon dioxide absorption capacity in the area. Higher biomass is not only important for the mangrove ecosystem, but also has an impact on the health and overall mangrove ecosystem. In addition to temperature and salinity, other environmental variables also need to be considered for a deeper understanding of the growth dynamics of K. candel. Factors such as humidity, light intensity, and soil conditions also play a role in influencing the health and productivity of mangrove ecosystems.

Table 3. Environmental Parameters of Kandelia candel (L.) Druce on Payung Island, Banyuasin II District, South Sumatra.

Parameter	Research Locations	
	Station I	Station II
Water salinity (°/◦◦)	0	0
Sediment pH	7,0	7,0
Air temperature (˚C)	24˚ C	28˚ C
Air humidity (%)	90,0	91,1
Light intensity (lux)	0,25	0,28
Substrate type	Clay	Sandy clay

The salinity values of the measurement results recorded in Table 3 show a salinity of 0‰, indicating that the waters on Payung Island tend to be freshwater. According to Matatula et al. (2019), salinity is a crucial factor that influences the growth, resilience, and zonation of mangroves, which generally grow better in saline or brackish areas. The low salinity levels are most likely influenced by the influx of fresh water from rivers, which mixes with seawater, creating environmental conditions that are favorable for the growth of mangrove species such as Kandelia candel. Several types of mangroves have different adaptation strategies to overcome salinity levels, as explained by Noor et al. (2006), where some species can selectively avoid salt absorption or even excrete salt through special glands in their leaves, indicating the flexibility and ability of mangrove species to adapt to varying environmental conditions.

The measured air humidity levels at observation stations I and II were recorded at 90.0% and 91.1%, respectively, indicating a positive correlation with biomass, carbon stock, and carbon dioxide absorption values. High air humidity supports the process of photosynthesis by facilitating the evaporation of water from the leaves, which is an important step in the absorption of carbon dioxide by plants. In addition, measurements of light intensity at both stations showed a value of 0.25 lux at station I and 0.28 lux at station II. Light intensity is very important in the process of photosynthesis, because it allows plants to absorb carbon dioxide and convert it into organic carbon stored in the form of biomass. Sutaryo (2009) explained that this photosynthesis process not only provides the energy needed for plant growth, but also contributes to an increase in the size of the diameter and height of plants, which in turn will affect the capacity of the ecosystem to absorb carbon dioxide from the atmosphere. Thus, the combination of low salinity, high air humidity, and adequate light intensity creates optimal conditions for the growth and productivity of the mangrove ecosystem on Payung Island.

Both observation stations I and II also have consistent soil pH, which is 7.0. According to research conducted by Ariani et al. (2016), mangroves can thrive in waters with a pH range of 6.0 to 9.0. This indicates that the pH levels measured at observation stations I and II provide suitable habitat and support the growth of mangrove plant species, including Kandelia candel. With optimal pH, mangrove plants can more efficiently absorb nutrients needed for their growth. These optimal environmental conditions contribute to the health of the mangrove ecosystem and the potential for higher carbon stocks, which in turn can support the process of absorbing carbon dioxide more effectively.

4. Conclusions

This study aimed to quantify the biomass, carbon stock, and carbon dioxide uptake of Kandelia candel (L.) Druce stands on Payung Island, Banyuasin II Sub-district, Banyuasin Regency, South Sumatra. Kandelia candel, a mangrove species belonging to the Rhizophoraceae family, plays a crucial role in the region's coastal ecosystem and its ability to sequester and store carbon. The results demonstrate the significant carbon storage potential of the Kandelia candel stands on Payung Island. The highest biomass value was observed in Station II, reaching 193.69 ton/ha, while the carbon stock was 89.11 ton C/ha. These findings highlight the substantial contribution of this mangrove species to the local and regional carbon budgets. Furthermore, the carbon dioxide uptake capacity of the Kandelia candel stands was estimated to be as high as 320.04 ton CO_2/ha, underscoring their pivotal role in climate change mitigation.

The environmental parameters measured, including salinity, sediment pH, air temperature, air humidity, and light intensity, were found to be within the optimal range for Kandelia candel growth and development. These favorable conditions likely contribute to the robust biomass accumulation and carbon sequestration potential observed in the study area. The data collected from this research can inform local and regional conservation efforts, support policy decisions related to coastal management and climate action, and contribute to the broader scientific understanding of mangrove ecosystems and their role in addressing global environmental challenges.

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Author Contribution

Conceptualization, S.R., & S.; Methodology, S.R., & S.; Software, S.R., & S.; Validation, S.R., & S.; Formal Analysis, S.R.; Investigations, S.R.; Resources, S.R., & S.; Data Curation, S.R., & R.N.A.S.; Writing – Original Draft Preparation, S S.R., S., & R.N.A.S.; Writing – Review & Editing, S.R., & R.N.A.S.; Visualization, S.R., & S.

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