ESTIMATING CARBON SEQUESTRATION OF CASUARINACEAE IN DIFFERENT PLANTING AGED AT PANTAI SENOK, BACHOK

by

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DECLARATION

I declare that this thesis entitled "Estimating Carbon Sequestration of Casuarinaceae in Different Planting Aged at Pantai Senok, Bachok" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Estimating Carbon Sequestration of Casuarinaceae in Different Planting Aged at Pantai Senok, Bachok

ABSTRACT

Climate change, caused by the increase in atmospheric carbon dioxide (CO2) levels, is a major global problem. Forests play a crucial role in mitigating climate change through carbon sequestration, the process of absorbing and storing atmospheric CO2 through photosynthesis and biomass accumulation. The aim of this study was to estimate the carbon sequestration potential of Casuarinaceae of different ages in Pantai Senok, Bachok, Kelantan. This study involved 3 plots of casuarina trees with different planting ages at 15, 14 and 2 years old with including diameter at breast height (DBH) in cm and total tree height in cm. 440 trees of Casuarinaceae were measured in this study. The results showed a significant increase in carbon stock with increasing age of the planting. The 15 years old Casuarinaceae had the highest carbon storage capacity with 12.82 t/ha. In contrast, the 2 years old planting had the lowest carbon stock of 2.22 t/ha. Followed with carbon sequestration are 47.06 t/ha for 15 years old and 8.16 for 2 years old trees. This study highlights the importance of Casuarinaceae for carbon sequestration which can leads to mitigation of climate change at Pantai Senok, Bachok, Kelantan.

Anggaran Penyerapan Karbon Casuarinaceae pada Umur Tanam yang Berbeza di Pantai Senok, Bachok

ABSTRAK

Perubahan iklim, yang disebabkan oleh peningkatan paras karbon dioksida (CO2) atmosfera, merupakan masalah global yang utama. Hutan memainkan peranan penting dalam mengurangkan perubahan iklim melalui penyerapan karbon, proses menyerap dan menyimpan CO2 atmosfera melalui fotosintesis dan pengumpulan biojisim. Matlamat kajian ini adalah untuk menganggar potensi penyerapan karbon bagi Casuarinaceae berbeza umur di Pantai Senok, Bachok, Kelantan. Kajian ini melibatkan 3 petak pokok casuarina dengan umur tanaman berbeza pada umur 15, 14 dan 2 tahun dengan memasukkan diameter pada ketinggian dada (DBH) dalam cm dan jumlah ketinggian pokok dalam cm. 440 pokok Casuarinaceae diukur dalam kajian ini. Keputusan menunjukkan peningkatan ketara dalam stok karbon dengan peningkatan umur penanaman. Casuarinaceae yang berumur 15 tahun. mempunyai kapasiti penyimpanan karbon tertinggi dengan 12.82 t/ha. Sebaliknya, tanaman berumur 2 tahun mempunyai stok karbon terendah iaitu 2.22 t/ha. Diikuti dengan penyerapan karbon ialah 47.06 t/ha untuk umur 15 tahun dan 8.16 untuk pokok berumur 2 tahun. Kajian ini menunjukan kepentingan Casuarinaceae untuk penyerapan karbon yang boleh membawa kepada mitigasi perubahan iklim di Pantai Senok, Bachok, Kelantan.

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LIST OF ABBREVIATIONS

DBH	Diameter Breast Height
JPNK	Kelantan State Forestry Department
AGB	Above Ground Biomass
D	Diameter
ρ	Wood specific gravity
CO2	Carbon dioxide
cm	Centimeter
ha	Hectare
kg/ha	Kilogram Per Hectare
tC/ha	Total Carbon Per Hectare
tCO_2/ha	Total Carbon Dioxide Per Hectare
t/ha	Ton Per Hectare

LIST OF SYMBOLS

/	Division slash
+	Addition
=	Equal to
*	Multiplication
%	Percentage

CHAPTER 1

INTRODUCTION

1.1 Background of study

The botanical classification of *Casuarina*, often known as Pokok Rhu, places it under the family Casuarinaceae. This genus of flowering plants is indigenous to various regions, including Australia, Southeast Asia, the Indian subcontinent, the western Pacific Ocean islands, and eastern Africa. The tree species known as Casuarinaceae, generally referred to as ironwood or sheoak, has been widely cultivated owing to its notable ability to sequester carbon. However, in the study area located at Pantai Senok, Bachok. The Kelantan State Forestry Department (JPNK) and non-governmental organizations (NGOs) have been engaged in the periodic planting of *Casuarina equisetifolia* trees since 2009 as part of the state's Coastal Area Conservation Program. *Casuarina equisetifolia* trees are cultivated on a global scale for various purposes such as beach establishment, erosion control, wind- breaking, coastal sand dune stabilization, and decorative use (NRC, 1984). Furthermore, according to Danielsen et al. (2005), *Casuarina equisetifolia* wood is suggested as a suitable material for construction purposes and as a means to alleviate the consequences of potential tsunamis and other natural calamities.

The phenomenon of carbon sequestration in *Casuarina equisetifolia* pertains to the mechanism by which carbon dioxide is captured and retained from the atmosphere, with the aim of mitigating climate change. Additionally, this process involves the assessment of the amount of carbon sequestered by these plants. The amount of carbon sequestered in *Casuarina equisetifolia* plantations may vary

according on the age of the planted trees, as observed by Wang et al. (2013).

Furthermore, numerous studies have been undertaken to evaluate the carbon storage and sequestration capacity of *Casuarina equisetifolia* plantations at varying stages of growth. These investigations have revealed that the total carbon storage in *Casuarina equisetifolia*. plantations exhibit an upward trend as the stand ages, with the most substantial accumulation occurring in fully developed and over-mature plantations. Nevertheless, a separate investigation conducted a comparative analysis of *Casuarina equisetifolia* coastal shelterbelt planting of varying ages. The findings revealed that the rate of carbon accumulation in the plant biomass exhibited an upward trend as the stand age grew yet experienced a decline beyond a specific developmental stage.

1.2 Problem Statement

Casuarinaceae contain high potential to sequestrate carbon. However, there is very scarce research exploring the carbon sequestration potential of Casuarinaceae specifically in Pantai Senok, Bachok. To fully realize the ecological and social advantages of the trees, research on carbon content is required to determine the effects of different planting ages on the plantation's ecosystem health. The findings of this study will contribute to a better understanding of the carbon sequestration of Casuarinaceae planted in different ages at Pantai Senok, Bachok.

1.3 Objective

The objective of this study is to estimate carbon sequestration of Casuarinaceae in different planting aged at Pantai Senok, Bachok.

1.4 Scope of Study

The primary focus of this study is to estimate carbon sequestration of Casuarinaceae The carbon sequestration had been estimating the above ground biomass (AGB) by measuring all the diameter-at-breast height (DBH) of Casuarinaceae trees planted at Pantai Senok, Bachok.

1.5 Significant of Study

This study is important in providing information on the amount of carbon stored by these trees at different stages of growth. The study can also provide insights into the role of Casuarinaceae plantations in carbon cycle and their contribution to overall carbon storage in ecosystems. Besides, the findings of this study can be used to inform land management and reforestation strategies, particularly in coastal areas where Casuarinaceae plantations are commonly established for coastal protection and land restoration purposes.

CHAPTER 2

LITERITURE REVIEW

2.1 Family Casuarinaceae

Casuarinaceae is described as woody, angiosperm evergreen trees with green, pendulous, photosynthetic branchlets, and reduced scale-like leaves arranged in whorls around the branchlets. The male and female flowers are arranged in separate spikes, and the fruit is a cone containing grey or yellowish-brown winged seeds.

Casuarinaceae is a genus of trees that has various uses and characteristics. It is a nitrogen-fixing tree that is widely planted for reclamation of unstable coastal ecosystems, erosion control, and windbreaks along coastlines and estuaries (Rojas-Sandoval et al., 2021). According to research conducted by Riley et al., (2019) in Turkey, there has been some confusion regarding the identification of Casuarina species, with recent field observations suggesting that *Casuarina cunninghamiana* is the correct determination instead of *Casuarina equisetifolia* L. With that when the identification of species, we must be thorough. Casuarinas are considered ideal for agroforestry due to their nitrogen-fixing ability, fast growth, and desirable stem form.

In addition, certain species of Casuarina, such as *Allocasuarina* and *Casuarina pauper*, have been identified as having potential for agroecosystem improvement in water-limited and semi-arid areas, such as Central Anatolia, Turkey (Marappa et al., 2020).

Furthermore, studies have shown that certain Frankia isolated from *Casuarina equisetifolia* have plant growth-promoting potential and can inhibit

phytopathogens (Riley et al., 2019).

2.2 Carbon sequestration

In the Earth's atmosphere, carbon is present in the form of carbon dioxide, constituting a small percentage of approximately 0.04%. However, the presence of carbon is of utmost importance in sustaining life on our planet. For instance, carbon is a crucial component in the growth and development of plants. Through the process of photosynthesis, plants absorb carbon dioxide from the atmosphere, converting it into carbohydrates and releasing oxygen back into the atmosphere. When these plants perish or undergo combustion, the carbon that was stored within them is released back into the surrounding atmosphere.

Carbon is a versatile element with various allotropes and hybridized states that allow for a wide range of applications. It is used in energy generation and storage, optics, electronics, electrocatalysis, corrosion control, bio-sensing, agriculture, water treatment, and the production of composite materials (Shabalin, 2014). Carbon-based materials, such as carbon nanotubes, fibers, and graphene, have been explored as alternatives to amorphous carbon for electrocatalyst support in fuel cells (Okwundu et al., 2018).

Nevertheless, it is imperative to evaluate the carbon stores existing inside the forest to gauge the magnitude of carbon exchange occurring between the forest ecosystem and the atmosphere. Assessing the carbon sequestration capacity of a forest enables the estimation of carbon emissions into the atmosphere resulting from degradation or deforestation within a particular forested region. In addition, the estimated carbon stocks in the forest facilitates students' comprehension of the methodologies employed for quantifying these stocks, enabling them to gain insights

into the present status of carbon stocks and anticipate potential changes in their quantities. In addition, nitrogen/metal-functionalized carbons and composites show promise as non-precious metal electrocatalysts for polymer electrolyte fuel cells (Kamai, 2019) and according to Trogadas et al., (2014) carbon is also a key material in lithium-ion batteries and super capacitors. Overall, carbon's unique properties and structures make it an essential material in various fields, with ongoing research and development to enhance its applications.

2.3 Carbon calculation

Since a century ago, the patterns of C stock throughout forest growth have drawn a lot of interest. Carbon could be evaluated and measured. Various techniques can be employed to ascertain the biomass and carbon stocks present above the ground. The development of an allometric equation for a tree involves the calculation of the link between many field measurements of tree parameters, including trunk diameter, diameter at breast height, tree species, tree height, crown density, age, and bioclimatic variables (Brown et al., 1997).

In this study, the aboveground biomass of Casuarina was estimated by using Chave et al. (2005). Another carbon calculation formula from different sources has been evaluated as in Table 2.3 following Kumar and Sharma (2015), the Chave calculation is the best fit for Casuarinaceae.

Table 2.3 Comparison of the carbon calculation algorithm

No.	Regression for Carbon equation	Reference
1.	$AGB= 0.0829 \times D^{2.43}$	Kenzo et al. (2009)
2.	$In (AGB) = 2.196 \times In(D) – 1.201$	Basuki et al. (2009)
3.	$AGB = 21.297 − 6.95(D) + 0.7403(D)^2$	Segura et al. (2005)
4.	$In (AGB) = 2.62 \times In (D)–2.30$	Yamakura et al. (1986)
5.	$AGB = \rho *exp ((1.239+1.980In (D) + 0.207(In (D))^2 – 0.0281(In(D))^{3)}$	Chave et al. (2005)

Source: Kumar and Sharma (2015)

CHAPTER 3

MATERIALS AND METHOD

3.1 Study Area

The study was carried out at Pantai Senok, Bachok, Kelantan. Pantai Senok is a popular beach area located in Bachok, Kelantan, Malaysia with latitude and longitude of 6.1638° N, 102.3473° E (Figure 3.1). The Pantai Senok is popular for the beauty of rows of pine trees planted along the beach until many people called it ‘Malaysia's Nami Island'. The scenic views with pine trees lined along the beaches and clear waters had potentially caused the area to be developed as one of the best tourist attractions in Kelantan.

Casuarinaceae or pine tree has been planted continuously since 2009 as an initiative for greening the area. It was done majorly by the Kelantan Forestry Department (JPNK). Casuarinaceae tree planting is among the state government's initiatives in preserving the environment in addition to intensifying efforts to overcome the issue of forest encroachment and the success of publicizing forest reserves.

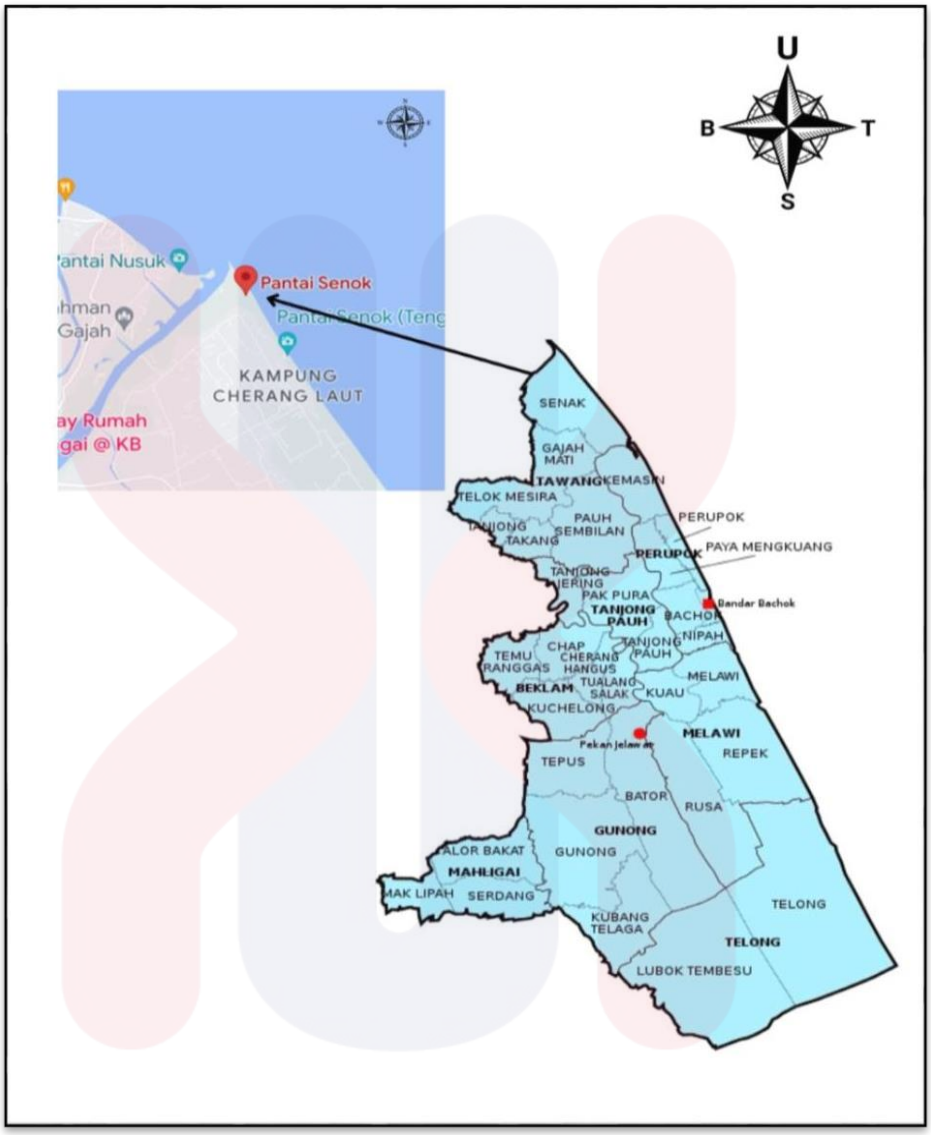

Figure 3.1: The location of the study area.

3.2 Materials

In order to estimate the above-ground biomass (ABG) and carbon of *Casuarina* trees, the diameter-at-breast-height (DBH) of trees at different planting aged were measured. Among the equipment that were used in this study is DBH tape for measuring the circumference of the tree, a pen, and field notebook to record the DBH reading and other equipment as presented in Table 3.2.

Table 3.2 Field equipment used for data collection

No	Item	Image	Description
1.	DBH tape		Used to measure the diameter at breast height (DBH) of the tree in centimeters
2.	Laser distance meter		Used to measure tree height in meter.
3.	Hand-held GPS		Used to locate and tag the coordinate of the plots.
4.	Pencil /Pen		Used to record the measurements data of diameter at breast height (DBH), tree height of each trees measured

5.	Field note book 	Used to keep records of the measurements diameter at breast height (DBH) of the plant.

(Photo source: Google Image)

3.3 Method

3.3.1 Field Data Collection

The data of field collection started after the planting area with different age of *Casuarina* trees have been verified using secondary data by JPNK. Information recorded were numbers of Casuarinaceae, year planted, DBH, estimated tree height and condition of land. The total area per hectare of planted Casuarinaceae trees was calculated. The DBH dan tree height data of each tree measured were recorded before data been transferred to the MS Excel for further analysis of carbon stock and carbon sequestration.

3.3.2 Data analysis

In order to estimate the ABG and carbon stock of the Casuarinaceae at different planting ages, an allometric equation by Chave et al. (2005) was utilized in this study. The allometric equation for estimating the AGB is shown in Equation 1.

$$AGB = \rho * \exp((1.239+1.980 \ln(D) + 0.207(\ln(D))2 - 0.0281(\ln(D))3)$$

…Equation 1

Where;

ABG is above ground biomass

ρ is wood specific gravity

D is the diameter of the tree.

Meanwhile, the total of the carbon stock was calculated using a conversion factor of 2 applied to the above-ground biomass as shown in Equation 2.

Carbon Stock = Total AGB / 2 …. Equation 2

According to Fransen (2022) one carbon molecule and two oxygen molecules make up CO_2. Oxygen has an atomic weight of 16 (u) whereas carbon has an atomic weight of 12 (u). The ratio of CO_2 to C is 44/12 = 3.67. This figure is used to determine the weight of C in trees. As a result, carbon sequestration was calculated by multiplying the total weight of carbon in the tree by 3.67. Carbon sequestration for Casuarinaceae Was estimated using formula as in Equation 3.

Carbon sequestration = Carbon Stock x 3.6 ….Equation 3

Data was analyzed using MS Excel, and interpretation was done after the findings were thoroughly reviewed and contextualized

CHAPTER 4

RESULTS AND DISCUSSION

4.1 DBH and tree density of Casuarinaceae by planting age

A total of 440 Casuarina trees were measured from three planting plot at different age. The descriptive statistic was calculated and the utmost mean average DBH was recorded at 35.57cm from tree aged 14 years old. It was followed by trees from 15 and 2 years old plots with 18.67cm and 14.83cm, respectively. The minimum tree size is 2.1 cm and the biggest was 35.6 cm. Tree density in 14 years old *Casuariana* show the highest density with 600 trees/ha. Meanwhile 2 and 15 years old consist of 279 tree/ha and 103 trees/ha respectively. Table 4.1 show the DBH and tree density of all plots surveyed.

Table 4.1 DBH Distribution and tree density by Age planting

Planting year	Tree age	Average DBH (cm)	Min -Max DBH (cm)	Tree height (m)	Tree density /ha
2022	2	14.83	2.1-27.1	9.61	279
2010	14	35.57	3.7-65.0	13.89	600
2009	15	18.67	7.7-35.6	15.80	103

The youngest plot planted in 2022 shows the lowest average DBH with 14.83 cm. However, the difference between 2 years old and 15 years old is only 3.83 cm. This was expected due to the 15-year-old planted Casuarinaceae being located in an area where recreation is the main purpose. The soils were compacted, and the planting gap is only 3 meters, causing very high competition between trees.

Despite high competition and compacted soils, the 15-year-old Casuarinaceae demonstrated remarkable growth resilience. This suggests that, while initial growth

rates may be hampered by adverse conditions, Casuarina trees can still achieve significant DBH over time.

Additionally, the relatively small difference in DBH between the 2-year-old and 15-year-old plots highlights the potential impact of site-specific factors on tree growth. For instance, at the recreational area, human trampling on soil that cause compaction, limited root expansion spaces and nutrient uptake were among potential factors that cause the tree growth (Kozlowski, 1999). Furthermore, the close planting distance had increased the competition for light, water, and nutrients, which can stifle growth despite the trees' age.

4.2 Above Ground Biomass (AGB) of Casuarinaceae

The total above ground biomass (AGB) of Casuarinaceae from different planting age show that the highest of AGB was recorded at age 15 years old trees with total ABG of 25.65 t/ha followed by 14- and 2-years old Casuarina trees with 21.54 t/ha and 4.45 t/ha respectively (Figure 4.2).

Casuarinaceae are widely planted for various purposes including timber, erosion control, and as windbreaks. One significant aspect of these trees is their ability to sequester carbon, which is crucial for mitigating climate change. The carbon stock in Casuarinaceae can vary significantly depending on factors such as tree age, planting density, soil quality, and environmental conditions.

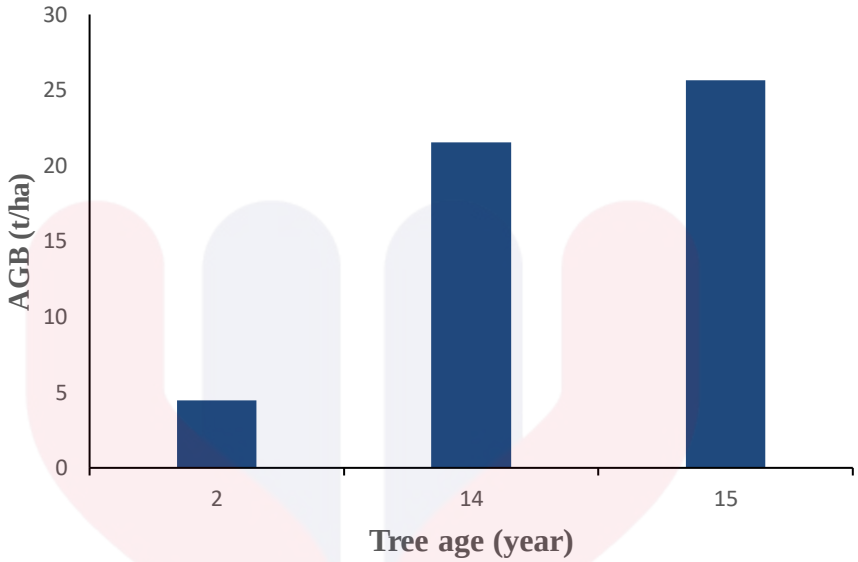

Figure 4.2 AGB of Casuarina tree species at different planting age.

This result is parallel with several finding by Wang et al. (2013), Köhl et al. (2017), Keim et al. (2005) where when tree grow older and bigger the AGB increase over time.

4.3 Carbon Stock and Carbon Sequestration

Using allometric equation by Chave et al. (2005), which incorporated the wood density and DBH, carbon stock and carbon sequestration were calculated and the results is shown in Table 4.3. The highest carbon stock was 12.82 tC/ha at 15 years old plots area and followed by trees planted 14 and 2 years ago with 10.77 tC/ha and 2.22 tC/ha, respectively. Carbon sequestration per hectare followed the same trend with 47.06, 39.52 and 8.16 tCO_2/ha. This study found a positive relationship between the tree age and carbon stock which translated by linear equation, y = 8.8904x. The linear model is a good fit for the data, which explaining 86.2% of the variation in this study.

Table 4.3 Estimated carbon stock and carbon sequestration in different planting age.

Year planted	Tree Age	Carbon Stock (tC/ha)	Carbon Sequestration (tCO_2/ha)
2022	2	2.22	8.16
2010	14	10.77	39.52
2009	15	12.82	47.06

A comprehensive study by Panwar and Bhardwaj (2015) on carbon sequestration potential of *Casuarina equisetifolia*, a species closely related to this study, highlights that older plantations (over 10 years old) had significantly higher carbon stocks compared to younger ones due to greater biomass accumulation. The study also noted the impact of planting density and soil conditions on carbon storage capacity.

A study by Wang et al. (2013) examining different aged of *Casuarina equisetifolia* plantations in South China showed that carbon sequestration in both plant and soil biomass increased with increasing of stand age. In his study, the 18-year-old plantations had the highest total biomass and carbon stock, indicating the importance of age and maturity in maximizing carbon sequestration potential.

In addition, trees planted in 2010 have minimal human interference compared to 2009. The plating location is far from the recreational area with less trampling impact. When an area facing human interference, it can bring the compaction, pollution, and destruction of habitats as well as could cause trees to become stressed and slow down their development rates. Therefore, minimizing such disruptions can aid to promote healthy and natural tree growth.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Understanding above ground biomass, carbon stock, and carbon sequestration is crucial for assessing ecosystem health, guiding conservation efforts, and developing strategies to mitigate climate change by accurately measuring the amount of carbon stored in vegetation and the potential of forests and other ecosystems to absorb and sequester carbon from the atmosphere. Casuarinaceae sequester carbon, making them a valuable asset in our fight against climate change.

Results from this study clearly showed that the 15 years old Casuarinaceae stand emerged as a true champion, boasting the highest potential for carbon sequestration among the studied plots. The oldest Casuarinaceae had the highest carbon storage capacity with 12.82 tC/ha. In contrast, the youngest (2 years old) planting trees had the lowest carbon stock of 2.22 tC/ha. Carbon sequestration followed the same trends with 47.06 tCO_2/ha for 15 years old and 8.16 tCO_2/ha for 2 years old trees. This study highlights the importance of matured Casuarinaceae for carbon sequestration which can leads to mitigation of climate change at Pantai Senok, Bachok, Kelantan.

5.2 Recommendations

For future research, it is recommended that:

- Overall map of planting area should be transparently revealed by the authorities to avoid bias in area selection.
- More comprehensive data should be collected by considering several age gaps that can representatively show the trends of carbon stock and carbon sequestration of Pantai Senok area
- To obtain more accurate and comprehensive results, more trees and plot shall take into account, but have to consider the cost, time and workforce factors.
- Investigating the soil and temperature might help in explaining the reason of growth rate and nutrition takes from the trees.

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