



**Quantifying aboveground biomass and carbon stock of
Acacia mangium at Bandar Jeli, Jeli, Kelantan**

by

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DECLARATION

I declare that this thesis entitled Quantifying aboveground biomass and carbon stock of *Acacia mangium* at Bandar Jeli, Jeli, Kelantan .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.

Signature :



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**Quantifying aboveground biomass and carbon stock of *Acacia mangium* at
Bandar Jeli, Jeli, Kelantan**

ABSTRACT

Acacia mangium is a fast-growing tropical tree species that is commonly used in reforestation and agroforestry projects due to its adaptability and rapid growth. In Malaysia, particularly in Jeli, Kelantan, there is limited data on above ground biomass and carbon storage potential of *Acacia mangium*. Measuring this parameter would provide valuable information for forest management and carbon accounting. Moreover, there is uncertainty in using standard allometric models to estimate biomass and carbon stocks in *Acacia mangium*. This study aims to estimate the biomass of *Acacia mangium* above ground in a representative stand in Bandar Jeli, Jeli, Kelantan, and to evaluate the carbon storage of above ground biomass. The diameter at breast height (DBH) is measured using a diameter tape. Aboveground biomass (AGB) was calculated using a specific allometric equation that required only DBH data, and carbon stocks were estimated using guidelines from the Intergovernmental Panel on Climate Change (IPCC). The results showed that the mean value of diameter at breast (DBH) was 14.79 cm while total of 45.44 AGB was 11.36 Mg/ha, and carbon stock was 21.36 MgC/ha between plots. This study succeeded in generating carbon stock data of *Acacia mangium* in Bandar Jeli using AGB. This data can contribute to the estimation of carbon sequestration and improve the understanding of carbon dynamics in the region.

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**Mengukur biojisim atas tanah dan stok karbon *Acacia mangium* di Bandar Jeli,
Jeli, Kelantan**

ABSTRAK

Acacia mangium ialah spesies pokok tropika yang berkembang pesat yang biasa digunakan dalam projek ladang hutan dan agropertanian atau perhutanan tani kerana kebolehsuaian dan pertumbuhan pesatnya. Di Malaysia, khususnya di Bandar Jeli, Jeli, Kelantan, terdapat data terhad tentang biojisim di atas tanah dan potensi simpanan karbon *Acacia mangium*. Mengukur parameter ini akan memberikan maklumat berharga untuk pengurusan hutan dan pengukuran karbon di kawasan tersebut. Selain itu, terdapat ketidakpastian dalam menggunakan model alometrik piawai untuk menganggar stok biojisim dan karbon dalam *Acacia mangium*. Kajian ini bertujuan untuk menganggarkan biojisim atas tanah *Acacia mangium* yang tumbuh di Bandar Jeli, Jeli, Kelantan dan menilai simpanan karbon biojisim di atas tanah. Diameter pada aras dada (DBH) diukur menggunakan pita diameter. Biojisim di atas tanah (AGB) dikira menggunakan persamaan alometrik khusus yang hanya memerlukan data DBH, dan stok karbon dianggarkan menggunakan garis panduan daripada Panel Antara Kerajaan mengenai Perubahan Iklim (IPCC). Keputusan menunjukkan nilai purata bagi DBH ialah 14.79 cm manakala jumlah AGB ialah 45.44 Mg/ha, dan stok karbon ialah 21.36 MgC/ha antara plot. Kajian ini berjaya menjana data stok karbon *Acacia mangium* di Bandar Jeli menggunakan AGB. Data ini boleh menyumbang kepada anggaran penyerapan karbon dan meningkatkan pemahaman tentang dinamik karbon di rantau ini.

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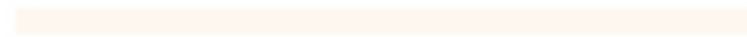
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LIST OF ABBREVIATIONS

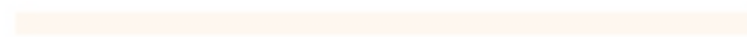
IPCC Intergovernmental Panel on Climate Change



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LIST OF SYMBOLS

CO ₂	Carbon dioxide
DBH	Diameter at breast height
AGB	Aboveground biomass
C/ha/yr	Carbon per hectare per year
Mg	Megagramme
%	percentage
>	More than
<	Less than
°C	Degree celcius
m	Meter
h	height
°	degree
N	Latitude
E	longitude

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Acacia mangium is a species of the Mimosoideae subfamily native to Australia's North Queensland, which became an increasingly popular choice for afforestation because it could adapt to a variety of soil types on degraded land and weedy hillsides. *Acacia mangium* is a fast-growing tropical forest tree and had been introduced to many countries for plantation forestry (Kha, 2000). Due to its high timber productivity and suitability for tropical climates, *Acacia mangium* was an important plantation species in Malaysia (Routray et al., 2018).

The timber industry had established extensive plantations of *Acacia mangium* in several state in malaysia. This was because *Acacia mangium* had grown uncontrollably and had damaged the existing forest ecosystem. However, data on biomass production and carbon storage by *Acacia mangium* at different ages, site conditions, and management regimes were lacking (Routray et al., 2018).

This study was very important to estimate the biomass and carbon storage potential of *Acacia mangium* trees to evaluate ecosystem services such as carbon sequestration (Basuki et al., 2009). However, several studies had been conducted in Malaysia to assess biomass accumulation and carbon stocks

in *Acacia mangium* plantations (Routray et al., 2018), especially in the Sabah and Sarawak.

Reliable quantification of aboveground biomass and carbon storage could have supported long-term management and utilization of *Acacia mangium* for carbon sequestration and climate change mitigation (Ketterings et al., 2001). It could have assisted in calculating the carbon offset potential of these plantations.

The tropical forests of Malaysia played a crucial role in sequestering carbon and mitigating climate change, making it imperative to understand the carbon dynamics of its dominant tree species. *Acacia mangium*, as an introduced tree species in the region, had gained prominence due to its fast growth and adaptability. However, limited comprehensive data existed regarding its aboveground biomass and carbon storage, which was essential for informed forest management and carbon accounting. Biomass content could be measured by direct or indirect methods (Bonham, 2013).

The goal of this study was to quantify the aboveground biomass and carbon stocks of *Acacia mangium* stands in Bandar Jeli using field inventory and allometric modeling approaches. The findings were expected to provide localized models and datasets to improve biomass and carbon accounting in *Acacia mangium* in Malaysia.

1.2 Problem Statement

There was limited data on the aboveground biomass and carbon storage potential of *Acacia mangium* in Malaysia, especially in Jeli, Kelantan. Measuring these parameters would have provided valuable information for

forest management and carbon accounting. In addition, there was also uncertainty in using standard allometric models to estimate biomass and carbon stocks in *Acacia mangium*. Location-specific models needed to be developed and tested to improve accuracy. Therefore, this study was somewhat helpful in measuring the aboveground biomass and carbon stock data of the *Acacia mangium* found in Bandar Jeli, Kelantan, and able to determine the allometric equation model which is suitable for *Acacia mangium* species in Bandar Jeli, Kelantan.

1.3 Expected Outcome

The study aimed to quantify the aboveground biomass and carbon stock of *Acacia mangium* in Bandar Jeli, Kelantan, Malaysia, providing valuable insights into the species' carbon sequestration potential. The study provided precise estimates of the biomass, which was essential for understanding the species' carbon storage capacity. The carbon storage within the aboveground biomass was estimated, aiding in climate change mitigation efforts. This study contributed to scientific knowledge by providing data on Bandar Jeli ecosystems and their role in carbon cycling.

1.4 Objective

- a. To determine the aboveground biomass of *Acacia mangium* in representative stands within the Bandar Jeli, Kelantan.
- b. To estimate the carbon storage of the aboveground biomass.

1.5 Scope of Study

The selection of the study site covered the stand of *Acacia mangium* in the Bandar Jeli area. Field inventory of *Acacia mangium* trees with a diameter at breast height (DBH) of 10 cm and above was conducted. Measurement of DBH and stem height for tree samples was carried out using standard forest inventory procedures. The height of the tree used was the average height of *Acacia mangium* trees. Biomass and carbon stock calculations were only calculated in the trunk part of the tree. An allometric model was used to estimate stem biomass based on DBH, stem height, and other variables using stratified random sampling. The stem carbon stock estimate was calculated using the total biomass and was estimated using the amount of carbon found in the tree, which was 50%. Analysis of stem biomass and carbon storage across different tree size classes was conducted. Biomass calculation in *Acacia mangium* trees was very important to calculate the carbon stock in trees.

1.6 Significant of Study

Understanding *Acacia mangium* potential for carbon storage in Bandar Jeli, Kelantan, requires research on quantifying the plant's aboveground biomass and carbon stock. The findings will also support sustainable forest management practices in Bandar Jeli, Kelantan aiding in decision-making processes regarding conservation strategies, afforestation initiatives, and sustainable land use practices. A crucial species in forestry and agroforestry systems, *Acacia mangium* requires exact measurement of its aboveground biomass and carbon stock in order to determine how much it contributes to

carbon sequestration. The discoveries made from *Acacia mangium* will advance scientific understanding by improving models of the global carbon budget and enhancing the dynamics of tropical forests. When developing climate policies, precise assessments of the carbon stock in *Acacia mangium* stands are crucial because they allow for more informed decision-making at the local, state, and federal levels. Strategies for improving carbon sequestration capacities, reducing the effects of climate change, and achieving global climate goals can be facilitated by this information. The study's applications include directing afforestation and conservation initiatives. The findings may influence environmental policies and conservation efforts in tropical regions, supporting carbon offset initiatives, land-use planning, and forest conservation strategies.

CHAPTER 2

LITERATURE REVIEW

2.1 *Acacia mangium*

Acacia mangium, also known as mangium, hickory wattle, or brown salwood, is a tropical forest tree species in the Fabaceae (pea) family. It is specifically classified in the Fabaceae subfamily Mimosoideae, which consists primarily of woody legumes native to Australia and tropical Asia (Maslin et al., 2003). Figure 2.1 shown full of *Acacia mangium* taxonomy according to Hnatiuk (1990).

Taxonomy of *Acacia mangium*

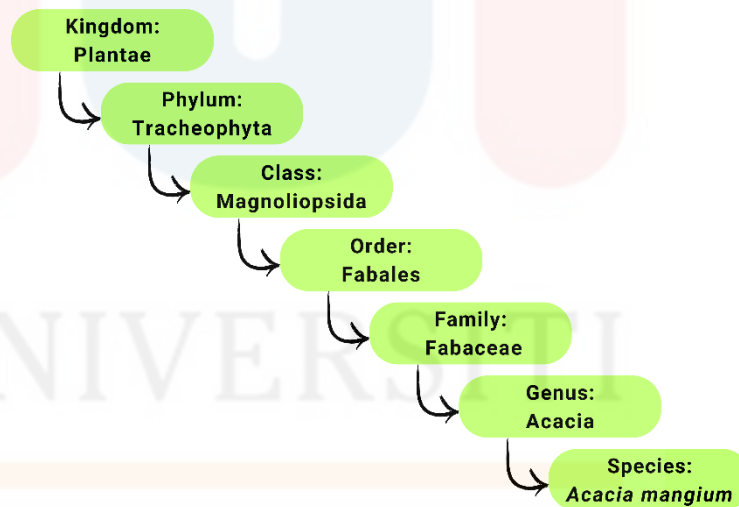


Figure 2.1: Taxonomy of *Acacia mangium* (Hnatiuk, 1990)

The species was named *Acacia mangium* Willd. by the German botanist Carl Ludwig Willdenow in 1797. Some taxonomists have since reclassified it as *Racosperma mangium* (Penman et al., 2003), though *Acacia* is still the more widely accepted designation (Murphy et al., 2023). *Acacia mangium* is one of

the largest and fastest growing tropical acacias within the *Acacia* genus, which contains over 1,000 species worldwide (Murphy et al., 2023). It is native to northeastern Queensland, Australia, as well as New Guinea, the Maluku Islands, and western Indonesia (Jaafar et al., 2022). It thrives in lowland tropical forests and regrowth areas because it is an early successional species (Kha, 2000).

Although no distinct subspecies of *Acacia mangium* have been identified, some taxonomic varieties, such as *Acacia mangium* var. *hosei* and *Acacia mangium* var. *cerina*, have been described (Maslin et al., 2003). Further phylogenetic studies examining genetic variation between wild populations throughout its native range would help shed more light on this species' intraspecific taxonomy (Gamba et al., 2020).

As a vascular tracheophyte, *Acacia mangium* belongs to the Plantae kingdom and is classified under the Magnoliopsida class, Fabales order, and Fabaceae family (Murphy et al., 2023), firmly placing it among the flowering dicotyledonous plants. Its scientific name honors Carl Ludwig Willdenow, a German naturalist and taxonomist who published the species description and type locality data for the first time in 1797 (Von Linne, 1833).

2.1.1 Morphology and Characteristics of *Acacia mangium*

In its natural habitat, *Acacia mangium* can grow to a height of 20–30 meters (65–100 feet) and a diameter of at least 50–100 centimeters (20–40 inches). Figure 2.2 shown the *Acacia mangium* tree in average height. Inner bark is reddish-brown and fibrous; bark is hard, dark, or grey-brown, with deep vertical grooves. The native habitat of *Acacia mangium* is depicted. In the

lowland tropical regions, the species is found in warm to hot, humid, and subhumid zones.



Figure 2.2: *Acacia mangium* tree (Forestry Department of Peninsular Malaysia, 2002)

When conditions are right, seedlings grow quickly, reaching a height of 25–30 cm in 3–4 months. The fastest-growing tropical plant is thought to be *Acacia mangium*. *Acacia mangium* grows in mildly sloping areas with heavily acidic, well-drained soils as well as poorly drained soils that flood during the rainy season (Hegde et al., 2013). This species is ideal for the pulp and paper industries because it can be used to make cardboard, paper, and other materials. In addition to repairing the soil's structure, acacia cultivation helps stop landslides and floods (Oliveira et al., 2021). The sustainability of acacia-based plantations is being investigated in basic terms due to the fragility of peat, its

low nutrient content, and the challenge of managing the water environment that supports the growth of these trees. Surface runoff, missions, and subsidence can cause peat loss, but biomass buildup will lead to carbon enrichments.

2.1.2 Impact of *Acacia mangium* on Ecosystem Service

Acacia mangium is a fast-growing tree species that has been introduced and widely planted for forestry and restoration purposes in many tropical countries. However, large-scale *Acacia mangium* plantation establishment can have a significant impact on a variety of ecosystem services.

Acacia mangium has been shown to alter soil properties via rapid nutrient uptake and litter decomposition. While this increases soil fertility, excessive nutrient extraction and acidification in monoculture plantations can degrade soils over time (Aggangan et al., 1998). *Acacia mangium* has high water utilization can also reduce streamflow in watersheds where extensive plantations have replaced natural vegetation (Sein et al., 2011).

Acacia mangium plantations can have a negative impact on habitat provision and other regulating services by altering stand structure and biodiversity. When compared to native forests, *Acacia mangium* stands have lower natural succession and understory plant diversity (Ouédraogo et al., 2013). This decrease in plant and structural diversity corresponds to a reduction in habitat availability for native fauna (Vasil & Thorpe, 2013).

However, compared to other land uses such as pasture or cropland, *Acacia mangium* plantations may improve certain services such as carbon sequestration and timber production. To maximize these provisioning services while minimizing trade-offs with other ecosystem services, optimal plantation

management and adequate restoration protocols are required (Liu et al., 2018). *Acacia mangium* can have mixed impacts on ecosystem services, enhancing certain services like carbon sequestration and timber production but disrupting others like water filtration, nutrient cycling, and pollination. To balance these aspects, sustainable forest management practices, agroforestry and mixed plantations, invasive species control, and restoration initiatives are recommended.

The plant's extensive root system can help control soil erosion and provide habitat for some species that can adapt to or benefit from its characteristics. However, it also has the potential to become invasive, displacing native flora, leading to changes in ecosystem structure and function. The thick leaf litter and allelopathic compounds produced by *Acacia mangium* wild can alter soil chemistry and negatively affect the germination and growth of native plant species.

2.1.3 Distribution of *Acacia mangium* in Malaysia

Because of its adaptability and economic usefulness, *Acacia mangium*, which is native to tropical parts of Australia, Papua New Guinea, and Indonesia, has been widely adopted in many countries, including Malaysia (Hegde et al., 2013). The geographic range, ecological effects, and economic relevance of *Acacia mangium* in Malaysia were examined in this study.

In the 1970s, plantation forestry and reforestation efforts brought *Acacia mangium* to Malaysia for the first time. The species flourishes in Malaysia's tropical environment, which provides the warm temperatures and copious amounts of rainfall necessary for its development (Ratnasing et al., 2020). *Acacia mangium* plantations were first created in Peninsular Malaysia, specifically in areas like Johor, Selangor, and Pahang. Its cultivation gradually spread to East Malaysia, encompassing the states of Sarawak and Sabah.

Acacia mangium grows well in the interior regions and coastal plains of Peninsular Malaysia. Large tracts of degraded land, logged-over woods, and abandoned agricultural land have all been planted with the tree in Sabah and Sarawak (Lee, 2005). *Acacia mangium* is widely grown across Malaysia due to its resilience to several types of soil, including acidic and infertile soils.

Although the introduction of *Acacia mangium* has not only generated ecological difficulties, but it has also favorably impacted Malaysia's attempts to reforest and restore land. Reduced biodiversity can result in regions where the plant predominates because of its fast growth and thick foliage, which can outcompete natural flora. Slowly deteriorating, its leaf litter modifies the dynamics of soil nutrients and may have an impact on the regrowth of native plant.

In some cases, plantations of *Acacia mangium* have occasionally been attributed to higher fire hazards because of the buildup of dry leaf litter. These plantations may be more vulnerable to pest and disease outbreaks due to their monoculture, which might have an adverse effect on the nearby ecosystems (Lee, 2005). In Malaysia's forestry industry, *Acacia mangium* is essential. Because of its quick growth rate and high wood density, it's a great supply of

wood for building materials, paper, and furniture. The tree's capacity to fix nitrogen via symbiotic partnerships with root bacteria improves soil fertility, which is advantageous for other agricultural endeavors.

In addition, *Acacia mangium* plantings have been used for carbon sequestration initiatives in addition to producing lumber, aiding Malaysia's endeavors to lessen the effects of global warming. Communities in the surrounding area are supported economically by the plantations' earnings, which also help the nation's economy.

The distribution of *Acacia mangium* in Malaysia reflects was because *Acacia mangium's* spread throughout Malaysia is indicative of both its usefulness to the forestry sector and its capacity to adapt to tropical climates. Its implementation has brought about financial gains and assisted in reforestation, but it has also created ecological problems (Koutika & Richardson, 2019). Maintaining Malaysia's native biodiversity while balancing the economic benefits of *Acacia mangium* requires the use of sustainable management techniques. To minimize any possible harm and guarantee the long-term viability of Malaysia's *Acacia mangium* plantings, more investigation and observation are required.

2.2 Biomass and Carbon Stock

The entire mass of living things inside an ecosystem is referred to as biomass. It consists of fungus, microbes, animals, and plants. Carbon content or dry weight units are commonly used to quantify biomass. In terrestrial ecosystems, plant material, especially the stems, branches, leaves, and roots of trees and other plants, contains the bulk of biomass.

The quantity of carbon contained in biomass and other organic materials, such as soil and dead wood, is referred to as the carbon stock. All living things include carbon, which may be stored in a variety of forms such as lipids, proteins, and carbs. Essentially storing carbon in their biomass, plants use photosynthetic processes to transform atmospheric carbon dioxide into organic molecules.

Comprehending the correlation between biomass and carbon stock is vital in comprehending the carbon cycle and the function of ecosystems in ameliorating climate change. For instance, forests serve as carbon sinks, storing vast volumes of carbon in their biomass and soil. Research by Pan et al. (2011) estimates that the biomass and soil of tropical forests alone store 471 billion tons of carbon, which makes up a sizeable amount of the world's carbon stock.

Researchers utilize several methodologies such as remote sensing techniques, ecosystem modeling, and field measurements to approximate the amount of biomass and carbon stock (Goetz et al., 2009). These techniques entail gathering information on variables like wood density, diameter, height, and species of trees. The information is then coupled with conversion factors or allometric equations to determine the biomass and carbon content.

Notably, the precision of estimations of biomass and carbon stock is contingent upon the caliber of the data and the suitability of the techniques employed for a given ecosystem or geographic area. To increase the accuracy of these estimations and provide guidance for sensible environmental management and policy, ongoing research and breakthroughs in measuring methodologies are required.

2.2.1 Aboveground Biomass using Allometric Models for *Acacia mangium*

The term "biomass" describes the entire mass of organic material found in an ecosystem. Aboveground biomass includes dead plant material like leaf litter, woody debris, and fallen branches, as well as all live plants including trees, shrubs, grasses, and herbs (Bardgett, 2005). A precise assessment of aboveground biomass is necessary to comprehend the dynamics and stocks of carbon in forest ecosystems. Based on observable variables like tree diameter, height, and wood density, allometric models offer a trustworthy way to estimate the biomass of trees and forests (Picard et al., 2012). This paper investigates the use of allometric models to calculate aboveground biomass in Malaysian plantations of *Acacia mangium*.

A mathematical formula known as an allometric model uses characteristics that are simpler to assess in the field to estimate the biomass of trees. In these models, tree height, wood density, and crown size are often included as well as tree diameter at breast height (DBH), which serves as the main predictor (Thenkabail et al., 2004). To measure and harvest sample trees destructively in order to determine the biomass of each component using volume and density calculations or direct weighing, these models are created (Basuki et al., 2009).

The correlations between the quantifiable factors and the biomass of various tree components are determined using regression analysis (Thenkabail et al., 2004). The models must be locally calibrated and validated due to the variability of these interactions with respect to species, site conditions, stand age, and environmental variables (Picard et al., 2012). These regionally

tailored models guarantee improved biomass estimation accuracy and accurate depiction of local forest conditions.

The fast growth and high biomass productivity of *Acacia mangium* make it a popular choice for pulpwood production and the creation of forest plantations in Malaysia. The potential for large carbon sequestration of *Acacia mangium* is demonstrated by the fact that within ten years, aboveground biomass in these plantations may reach above 200 Mg/ha (Routray et al., 2018). In Malaysia, soil organic carbon can accumulate quickly under *Acacia mangium* stands (Hamad-Sheip et al., 2021).

Understanding and managing carbon stocks in forest ecosystems depend on the accurate estimation of aboveground biomass using allometric models. For accurate evaluations of biomass and carbon stocks in *Acacia mangium*, species-specific allometric models must be applied in Malaysia. These models support initiatives for mitigating climate change by making it easier to track afforestation and reforestation projects.

For the non-destructive estimate of aboveground biomass in Malaysian *Acacia mangium* plantations, the application of allometric models is essential. These models offer precise biomass estimates that are necessary for comprehending carbon dynamics and efficiently managing forest resources, once they have been locally calibrated and verified. *Acacia mangium*'s quick growth and high biomass output highlight its importance for carbon sequestration and the general sustainability of Malaysian forest plantations. There are several studies about aboveground biomass in Malaysia as shown in Table 2.1 previous studies on measure of aboveground biomass in Malaysia.

Table 2.1: Previous studies on measure of AGB in Malaysia

No	Method	Method	Area	Year	Author
1	DBH Height of tree Aboveground biomass Carbon stock	DBH>10 cm above measure and converted to aboveground biomass. $AGB=0.1173*DBH^{2.454}$ <i>Acacia mangium</i> plantations with 2 plantations variants which is second generation <i>Acacia mangium</i> and <i>Acacia</i> hybrid plantations that were approximately 10 years old	Acacia Plantations in Sarawak	2018	Adam & Jusoh
2	DBH Height of tree Aboveground biomass Carbon stok	Stratified random selection. DBH>10cm is measured and converted to aboveground biomass. $AGB=e^{-2.134}=2.53 \times \ln(DBH)$ Using positioning system (GPS) devices	Sabah	2015	Seo et al.
3	DBH Height of tree Aboveground biomass Carbon stok	DBH >10cm measure and convert to 2 type of AGB high wood density class $AGB=0.05633 \times DBH^{2.75756}$ medium wood density class $AGB=0.00023 \times DBH^{3.75745}$	Perak	2015	Majid et al.
4	DBH Height of tree Aboveground biomass	AGB = $0.3210(DBH)^{1.3925}$, DBH = 0.3 to < 5 cm DBH = diameter at breast height (cm), AGB = aboveground biomass (kg dry mass)	Southeastern Puerto Rico	1992	Weaver et al.
5	Linear allometric equation. ($Y=aX^b$), ($1/Y=1/aX^b + 1/Y_{max}$) All regressions are significant ($P < 0.01$)	>5cm	Pasoh Forest Reserve, Negeri Sembilan	2010	Niiyama et al.

* Y= height; X= DBH; a=1.61; b=1.00; Ymax=69

6	<p>Allometric equation for aboveground biomass. Ln</p> $Y = -2.17 + 1.02 \ln(\text{DBH})^2 + 0.39 \ln(h)$ <p>*dbh= diameter at breast height (cm); h= height of tree</p>	>3cm	Niah River Watershed, Sarawak	2006	Jepsen et al.
7	<p>Allometric equation is used:</p> $y = ax^b$ <p>*y=biomass; x=DBH (cm) or H (m) or DBH² x H (cm² m); a and b= coefficients estimated by regression</p> <p>*DBH= diameter at breast height (cm); H= height of tree</p>	>5cm	Lambir hill National Park, Sarawak.	2009	Kenzo et al.
8	<p>The differences of allometric equations are used to estimating total above- ground biomass (kg) for mixed species.</p> <p>Total biomass = c + αD</p> <p>Total biomass = c + $\alpha D + \beta L$ (Total biomass)</p> $0.9 = c + \alpha D$ <p>Total biomass = c + αD^2</p> $\text{Log}_{10}(\text{total biomass}) = c + \alpha(\text{log}_{10} D)$ $\text{Log}_{10}(\text{total biomass}) = c + \alpha(\text{log}_{10} D) + \beta(\text{log}_{10} L)$ <p>*equation number; D: liana diameter; L:liana length.</p>	<5cm & >30cm	National Park, Penang.	2013	Addo-Fordjour et al.

2.2.2 Carbon Stock and Sequestration Potential of *Acacia mangium* in Malaysia

Plants use photosynthesis to transform atmospheric CO₂ into carbohydrates, which results in the storage and sequestration of carbon in biomass. According to the IPCC (2006), carbon makes up around 50% of the dry weight of plant biomass. To determine the capacity for forests to sequester carbon, it is essential to estimate their biomass and carbon stocks. The important role Malaysian *Acacia mangium* plantations play in sequestering carbon is shown by this essay's analysis of the methodologies used to estimate the amount of carbon stored in these plantations.

Forests play a crucial role in the global carbon cycles by storing carbon. The ability of forest ecosystems to sequester carbon can be better understood by estimating biomass and carbon stocks accurately. Photosynthesis results in the storage of carbon in plant tissues, which accounts for approximately 50% of the dry weight of biomass (IPCC, 2006). Trees are essential for slowing down climate change because they take up CO₂ from the atmosphere, transform it into carbohydrates, and store it as carbon.

Fast-growing *Acacia mangium* trees are commonly planted in Malaysia and have a large amount of potential for storing carbon. Due to its quick growth, it may produce large amounts of biomass, which, when managed responsibly, can sequester a significant amount of carbon (Routray et al., 2018). Within ten to fifteen years in well-maintained plantation stands, *Acacia mangium* can attain great productivity and significant carbon buildup (Ketterings et al., 2001).

Previous research on the quantification of carbon stock of *Acacia mangium* that research has shown that Malaysian *Acacia mangium* plantings have a substantial capacity to sequester carbon. For instance, carbon stocks in *Acacia mangium* plantings may increase to 200 Mg/ha in as little as 10 years, providing a significant amount of carbon storage. In a similar vein, Routray et al. (2018) emphasized *Acacia mangium*'s quick biomass growth and high productivity, which make it a useful plant for carbon sequestration initiatives.

Acacia mangium plantations develop quickly, according to different research by Ketterings et al. (2001). Significant carbon buildup happens in the first ten years following planting. In order to estimate carbon stocks and comprehend the carbon dynamics of *Acacia mangium* plantations, our findings highlight the significance of species-specific research and precise field measurements.

Importance of accurate carbon stock estimation it was because comprehending and effectively addressing carbon sequestration in forest ecosystems requires precise assessment of carbon stocks. Exact evaluations of Malaysia's carbon supply depend on the use of species-specific studies on *Acacia mangium*. Climate change mitigation methods benefit from these evaluations because they make it easier to monitor afforestation and reforestation activities. For Malaysian *Acacia mangium* stands, more investigation is required to improve carbon fraction estimations (Adam & Jusoh, 2018).

Understanding the role that Malaysian *Acacia mangium* plantings play in sequestering carbon and mitigating the effects of climate change requires an estimation of their carbon storage. To determine how well these plants can

sequester carbon, accurate assessment of carbon stocks is necessary. *Acacia mangium* has the ability to make a substantial contribution to Malaysia's carbon storage capacity under sustainable management.



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CHAPTER 3

MATERIAL AND METHOD

3.1 Study Area

Within the study site, Bandar Jeli sits in an area of 304.36 hectares. Bandar Jeli's geographic coordinates are 5°42'02.5"N and 101°50'35.6"E. Figure 3.1 below shown the map of Bandar Jeli, Jeli, Kelantan.

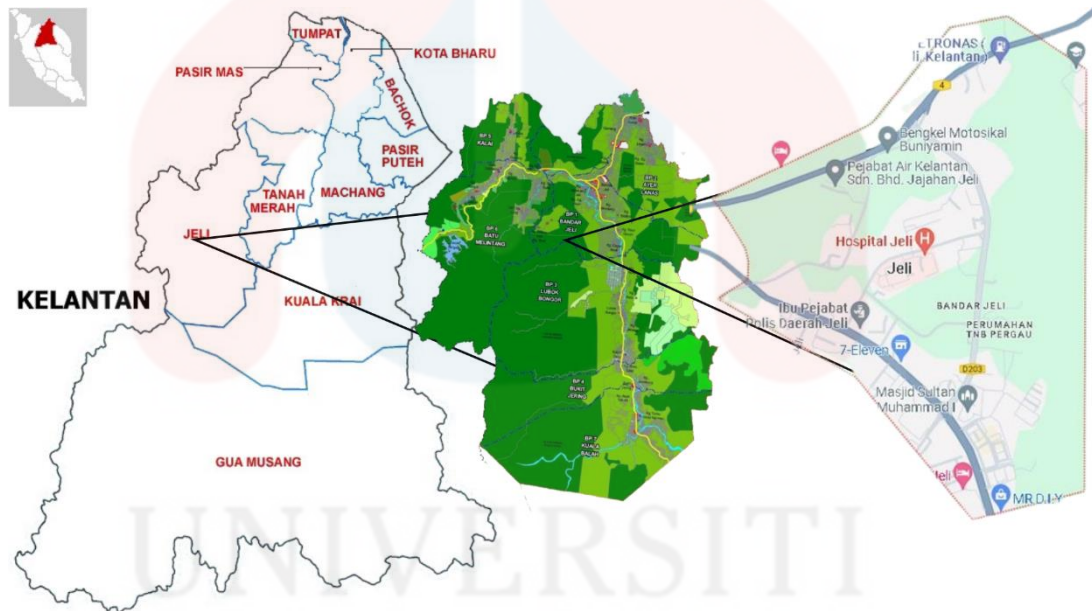


Figure 3.1 Map of Bandar Jeli, Jeli, Kelantan (Google, 2023)

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3.2 Material

The material was used to conduct this study, diameter at breast (DBH) tape was used to measure DBH *Acacia mangium*, meanwhile raffia string was used to build the sampling plot in Bandar Jeli.

3.2.1 Sample of *Acacia mangium*

Acacia mangium are species used in studying aboveground biomass and carbon stock. This species was chosen because it has a high quantity of biomass and is a tree that can be found around Kelantan, especially in Bandar Jeli. *Acacia mangium* trees was selected randomly and measured DBH with a diameter of 10 cm above only.

3.3 Method

This study was using four method which is stratified random sampling, aboveground biomass, and carbon stock for this study to be carried out successfully. To better understand this study, Figure 3.3 shown the research flow chart for this study in simple way.

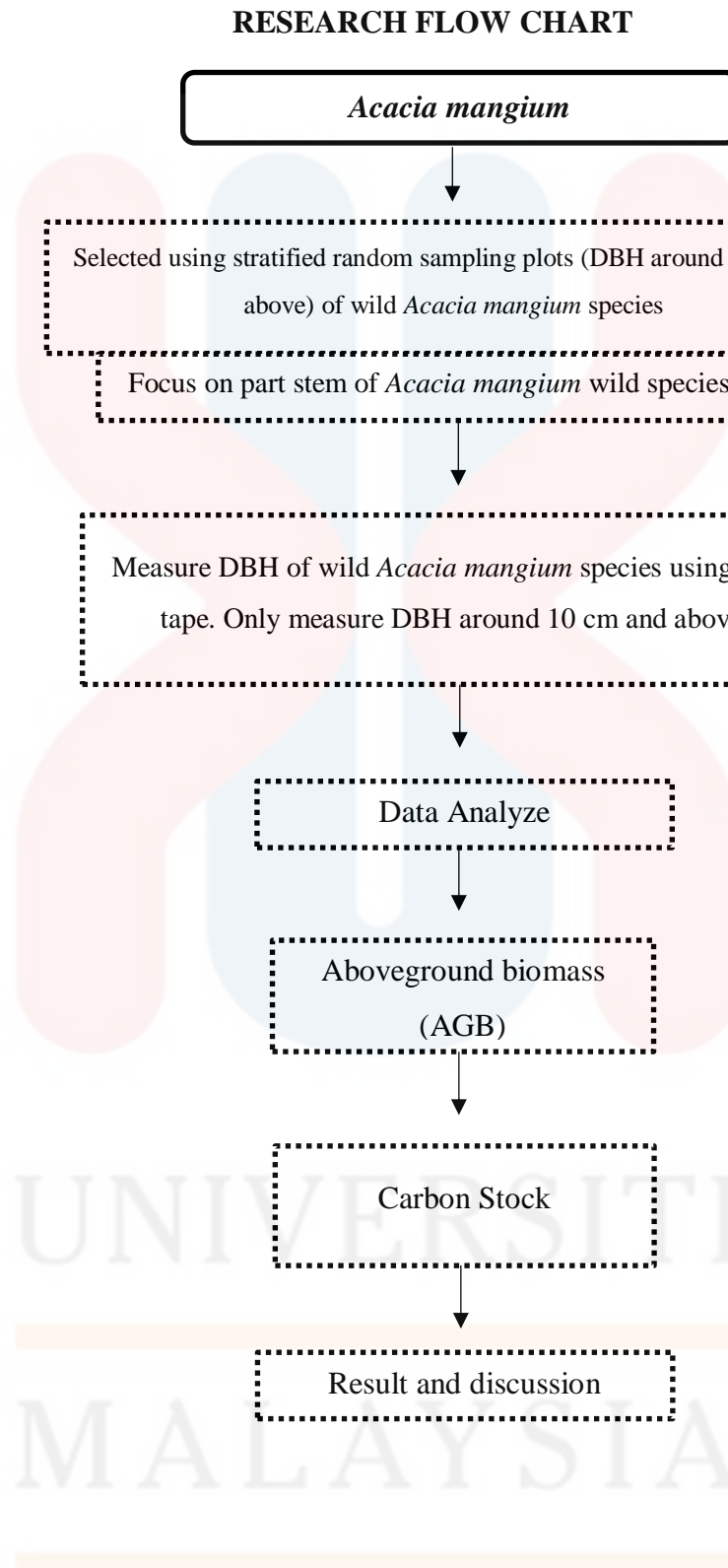
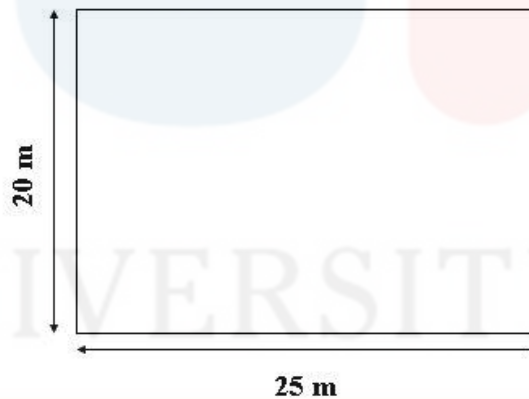


Figure 3.3: Research flowchart for quantifying aboveground biomass and carbon stock of *Acacia mangium* in Bandar Jeli, Jeli, Kelantan

3.3.1 Stratified Random Sampling Plots

In ecological studies, especially forestry and vegetation assessments, stratified random sampling is a technique that is used to guarantee representative sampling across various strata or subgroups within a larger area. With this approach, the study area is divided into discrete strata according to specific features which is topography area of Bandar Jeli, and sampling plots are then randomly chosen within each stratum (Barnet et al.,1994).

In Bandar Jeli, or any other specific location, a stratified random sampling approach can yield representative data across various stands or conditions when quantifying aboveground biomass and carbon stock of *Acacia mangium*. Field data collection will involve the random establishment of a sampling plot measuring 20m x 25m (0.05 ha).



A stratified random sample design has been employed to estimate aboveground biomass across a range stand conditions. Field data was collected involve the random establishment of a sampling plot measuring 20m x 25m (0.5 ha). This size plot was selected based on the reference of the forest inventory method found in the Field Work Technique book. Based on Table

3.1 showing the parameters that need to be measured for each inventory compartment.

Table 3.1: Parameters that need to be measured for each inventory compartment
(Jemali & Majid, 2023)

Inventory Compartment	Size (m)	Width		Inventory Intensity (%)	Tree Size Class	Explanation
		(m ²)	(ha)			
First	50 x 20	1000	0.1000	10.00	DBH>45cm DBH>30cm-45cm	Big tree Small tree
Second	25 x 20	500	0.0500	5.00	DBH>15cm-30cm	Large jaras wood
Third	10 x 10	100	0.0100	1.00	DBH>5cm-1.5cm	Small jaras wood
Fourth	5 x 5	25	0.0025	0.25	Height>1.5m DBH<5cm	Sapling
Fifth	2 x 2	4	0.0004	0.04	Height>15cm-1.5m	Seedlings

There are 4 plots that had been set up at Bandar Jeli. The plot was built randomly according to where the *Acacia mangium* grows. Table 3.2 shows the coordinates of the four plots that was built. The plots built in different place in Bandar Jeli.

Table 3.2: Coordinate of the plots

Plot	Coordinates
1	5°41'24"N 101°50'55"E
2	5°41'26"N 101°50'52"E
3	5°41'29.0"N 101°50'47.0"E
4	5°41'52"N 101°50'49"E

Figure 3.2 are the areas that have been selected to be used as sampling sites. The area was chosen based on where *Acacia mangium* grows. In most of these areas, *Acacia mangium* grows wild and is found in large numbers.

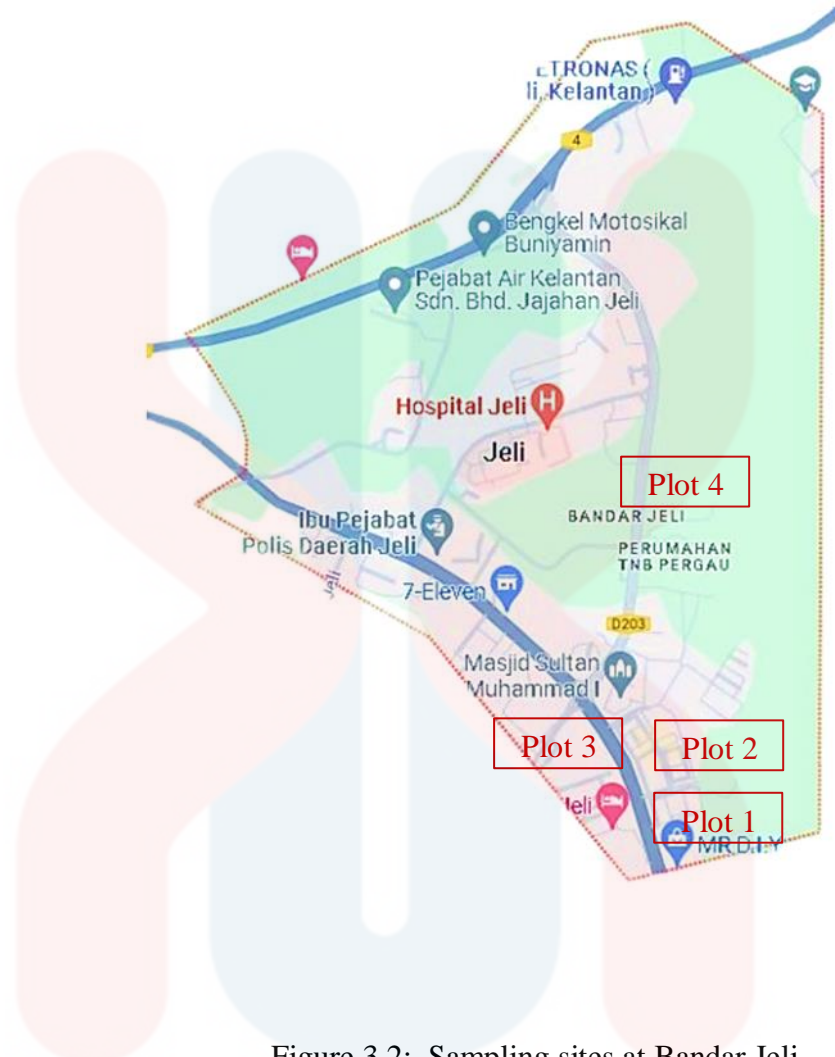


Figure 3.2: Sampling sites at Bandar Jeli

3.3.2 Aboveground Biomass

In particular, the biomass allometric model for stem biomass estimation focuses on determining the biomass of the stem portion of trees. The amount of living matter contained in the stem can be estimated using this model, which helps with the evaluation of carbon stocks, forest productivity, and ecosystem dynamics.

Based on Chapter 2, Section 2.2.1, three equations were chosen to estimate aboveground biomass of *Acacia mangium* at Bandar Jeli, Malaysia. Equation 3.1 shows a species-specific model by Adam & Jusoh (2018), which is a scale coefficient of 0.1173 and a power of 2.454 was estimated by them using data from 77 examples of *Acacia mangium* trees in the second generation of 10 years standing in Sarawak plantation. Species specificity, accuracy of prediction, ease of use, and relevance to this study aim to make this a reasonable choice for estimating stem biomass of *Acacia mangium*.

$$\text{Aboveground biomass (kg)} = 0.1173 \times \text{DBH}^{2.454} \quad (3.1)$$

Where:

- 0.1173 is the scaling coefficient derived from regression analysis
- DBH is the tree diameter (cm) measured at 1.3 m above ground level
- 2.454 is the power term estimated for the relationship between DBH and biomass.

This equation that has been developed using mathematical calculation which is assumed we have a dataset with n pairs of measurements ($\text{DBH}_i, \text{AGB}_i$).

$$X_i = \log(\text{DBH}_i) \text{ and } Y_i = \log(\text{AGB}_i)$$

Calculate the means:

$$X = \frac{1}{n} \sum_{i=1}^n X_i$$

$$Y = \frac{1}{n} \sum_{i=1}^n Y_i$$

Compute slope b:

$$b = \frac{\sum_{i=1}^n (X_i - X)(Y_i - Y)}{\sum_{i=1}^n (X_i - X)^2}$$

Compute the Intercept a:

$$a = Y - bX$$

Back-transform the Coefficients: exponentiate the intercept:

$$\text{Scaling Coefficient} = \exp(a)$$

The mathematical calculation:

Data provided following values of 77 samples:

- $\sum X_i = 154.2$
- $\sum Y_i = 124.8$
- $\sum X_i Y_i = 2264.7$
- $\sum X_i^2 = 307.8$

Plug these into the formula for b and a:

$$b = \frac{\sum_{i=1}^n (X_i - X)(Y_i - Y)}{\sum_{i=1}^n (X_i - X)^2}$$

$$X = \frac{\sum X_i}{n} = \frac{154.2}{77} = 2.0026$$

$$Y = \frac{\sum Y_i}{n} = \frac{124.8}{77} = 1.621$$

$$\sum (X_i - X)(Y_i - Y) = \sum X_i Y_i - nXY = 2264.7 - 77 \times 2.0026$$

$$2264.7 - 77 \times 2.0026 \times 1.621 = 116.7$$

$$\sum (X_i - X)^2 = \sum X_i^2 - nX^2 = 307.8 - 77 \times (2.0026)^2 = 29.4$$

$$b = \frac{116.7}{29.4} = 3.97$$

Next, calculate A:

$$a = Y - bX = 1.621 - 3.97 \times 2.0026 = 1.621 - 7.94 = -6.319$$

$$a = 10^A = 10^{-6.319} = 1.1173$$

There the detailed explanation of how such an equation can be developed and how the scaling coefficient (0.1173) and power term (2.454) can be determined through mathematical calculations.

3.3.3 Carbon stock

Based in Chapter 2, Section 2.2.2, paragraph 1 mention according IPCC 50% was carbon storage. There carbon fraction use to estimated aboveground biomass to Carbon stock is estimated by multiplying the aboveground biomass by a carbon fraction, typically 0.47 (IPCC, 2006) as shown by Equation (3.2). that carbon fraction was used by researcher that research carbon stock of *Acacia mangium* plantations in Sarawak Using locally derived allometric models improves the accuracy of biomass and carbon stock quantification.

$$\text{Carbon stock} = \text{AGB} \times 0.47 \quad (3.2)$$

Where:

- AGB is aboveground biomass
- 0.47 is carbon fraction

3.3.4 Data Analyze

Data will be collected through several methods and analyzed in several ways, among which are:

a) Descriptive Statistics

Calculate basic descriptive statistics (mean, median, minimum, maximum, standard deviation) for DBH, AGB and carbon stock estimates across all sample plots (Zar, 1999).

b) Graphs

Graphs serve as effective tools for analyzing and presenting data related to aboveground biomass and carbon stocks of *Acacia mangium* by showcasing relationships between variables in a straightforward manner. The utilization of linear graphs helps visualize trends, correlations, and patterns between biomass or carbon stocks and relevant factors, such as time, treatments, or environmental conditions.

Study by Clark et al. (2001) discusses approaches for calculating aboveground biomass in tropical forests and offers details on fieldwork techniques and error analyses. Although it is not unique to *Acacia mangium*, it provides insightful knowledge on the larger framework of biomass estimation that is applicable to particular species such as *Acacia mangium*.

c) Analysis of Variance (ANOVA): Single Factor

ANOVA single factor, or one-way ANOVA, is a statistical method used to determine whether there are significant differences between the means of three or more independent groups. This tests the null hypothesis that all

group means are equal against the alternative that at least one is different. This method involves calculating the between-group and within-group variances and using them to calculate the F-statistic, which is then compared to a critical value to assess significance. The primary advantages of one-way ANOVA in research include its ability to handle multiple groups simultaneously, control the Type I error rate, and provide a foundation for further post-hoc analysis if significant differences are found. This makes it a powerful tool for experiments across various fields, such as education, where it can help determine the most efficient teaching methods based on student performance (Agresti & Franklin, 2007; Gravetter & Wallnau, 2017).

CHAPTER 4

RESULT AND DISCUSSION

4.1 Descriptive Statistics

Data has been analysis and shown in illustration such as graph. Data below was mean of DBH, AGB and carbon stock.

4.1.1 Class and mean of DBH

Figure 4.1 shown the bar chart provided depicts the distribution of class and mean of diameter at breast height (DBH) for *Acacia mangium* in Bandar Jeli, Jeli, Kelantan. The data shows that the majority of trees are in the DBH class of 16-20 cm, followed by the DBH class of 11-15 cm. There are very few trees in the DBH 6-10 cm class, and no trees in the 0-5 cm DBH class. Meanwhile for mean of DBH was Plot 4 exhibits the highest DBH at approximately 16.75 cm, followed by Plot 3 at approximately 15.25 cm. Plots 1 and 2 show lower DBH values, both close to 14.00cm and 13.75cm, respectively.

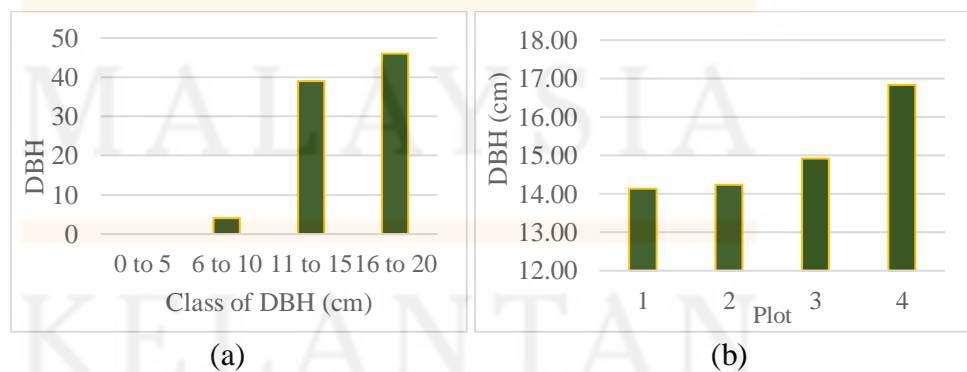


Figure 4.1: (a) and (b) Class and mean of DBH for *Acacia mangium*

The distribution of DBH in the *Acacia mangium* population in Bandar Jeli, Kelantan, indicates a comparatively mature stage of growth. The dominance of larger DBH classes (above 10 cm) suggests favorable conditions such as ample sunshine, water availability, and soil nutrients. The absence of trees in the smallest DBH class (0-5cm) and low numbers in the 6-10cm class point to limited natural regeneration and recruitment challenges. These findings are aligned with Koutika et al (2011), who noted rapid growth and biomass accumulation under optimum conditions

Meanwhile, for mean DBH the lower DBH values in Plots 1 and 2 suggest less optimal conditions or higher competition among trees, limiting their growth. Plot 3, with intermediate DBH, probably benefits from moderate site conditions and management practices, leading to better growth than Plots 1 and 2 but not as high as Plot 4. Understanding these factors is crucial for forest management, as improving site conditions and management practices can enhance tree growth, biomass, and carbon sequestration.

4.1.2 Aboveground Biomass

The figure 4.2 illustrates the above ground biomass (AGB) of *Acacia mangium* across four different plots in Bandar Jeli, Kelantan. The AGB values, measured in megagrams per hectare (Mg/ha), show the biomass accumulation in each plot. Plot 2 shows the highest AGB at approximately 14 Mg/ha, followed by Plot 1 at approximately 12 Mg/ha. Plots 3 and 4 had lower AGB values, both slightly above 10 Mg/ha.

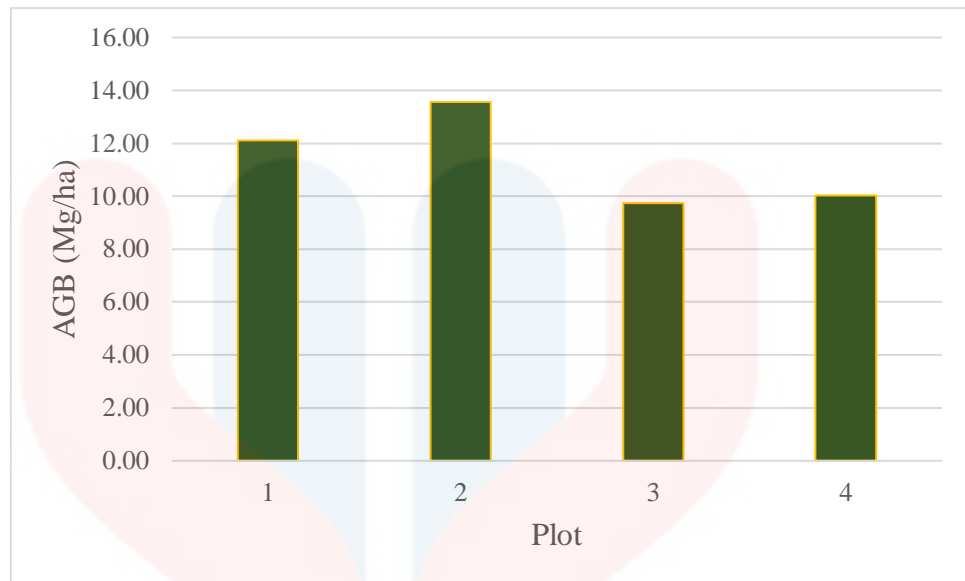


Figure 4.2: Total of AGB for four sampling plots of *Acacia mangium*

Differences in AGB across the plots can be attributed to various factors such as soil fertility, moisture availability, and sunlight, as highlighted by studies such as Brown & Lugo (1982) and Siregar et al. (2008). Management practices, standing age, density, and genetic variability also play crucial roles in biomass accumulation. For instance, managed plots frequently show higher biomass due to better growing conditions.

The higher AGB in Plot 2 may be due to better site conditions or superior management practices, possibly indicating older trees or higher stand density. Similar AGB values in Plots 3 and 4 suggest that they share comparable site conditions and management practices. Overall, the differences in AGB among plots can be explained by a combination of site-specific factors, management practices, stand characteristics, and genetic variability. Further research is necessary to provide a clearer understanding of these differences.

4.1.3 Carbon Stock

The bar graph Figure 4.3 represents the carbon stocks of *Acacia mangium* across four different plots in Bandar Jeli, Kelantan. Carbon stock, measured in megagrams of carbon per hectare (MgC/ha), is an important indicator of the forest's ability to sequester carbon. Plot 2 has the highest carbon stock at around 6.5 MgC/ha, closely followed by Plot 1 with approximately 6.0 MgC/ha. Plots 3 and 4 had lower values, each around 5.0 MgC/ha.

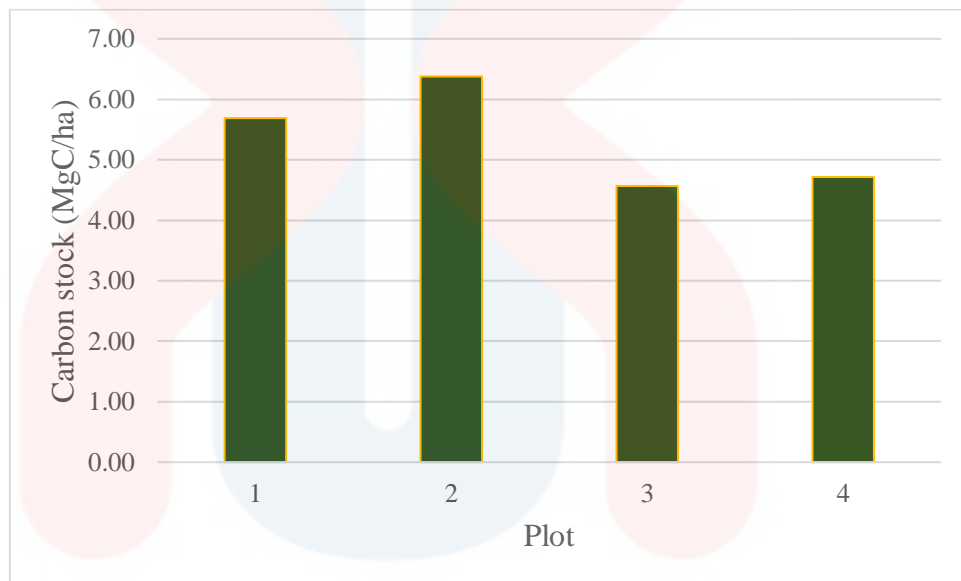


Figure 4.3: Total of carbon stock for four sampling plots of *Acacia mangium*

The carbon stock of *Acacia mangium* in Bandar Jeli, Kelantan, correlates with above-ground biomass (AGB), as higher biomass leads to larger carbon storage. This is obvious from the data, where Plot 2, with the highest AGB, also has the highest carbon stock. Studies by Brown and Lugo (1982) support the link between biomass and carbon sequestration. Variations in soil fertility, moisture, and sunshine significantly affect tree growth and carbon accumulation, with favorable conditions in Plot 2 resulting in higher values. Effective management practices also improve growth and carbon storage, as noted by Siregar et al. (2008).

Stand age and density are crucial for carbon stock, as younger, denser stands may have lower individual tree biomass but higher overall biomass, affecting carbon storage, as discussed by Kirby & Potvin (2007). Genetic variability also affects growth rates and carbon stocks, with Krisnawati et al. (2011) highlighting the advantages of genetic improvements. Thus, differences in carbon stock between plots can be attributed to AGB, site conditions, management practices, stand age, density, and genetic variability. Further research with detailed site-specific data and management practices could clarify these differences.

4.2 Comparisons on DBH, AGB and Carbon Stock of *Acacia mangium* using Statistic Analysis

Statistical analysis used ANOVA and Tukey test to compare groups of different plots. It assesses the significance of these differences between groups. The results show whether this difference is significant or not.

4.2.1 Analysis of Variance (ANOVA)

The table 4.1 show ANOVA analysis for Diameter at Breast Height (DBH), Aboveground Biomass (AGB), and Carbon Stock of *Acacia mangium* in Bandar Jeli, Kelantan, yields significant insights into the differences between the plots. For DBH, the sum of squares is 83.224 with 3 degrees of freedom, resulting in a mean square of 27.741 and a F-value of 5.914 The corresponding P-value is 0.00102884, which is less than the significance level of 0.05, indicating that there are significant differences in DBH between the plots.

Table 4.1: ANOVA on DBH, AGB and carbon stock of *Acacia mangium*

	ss	df	MS	F	P-value
Diameter At Breast (DBH)	83.224	3	27.741	5.914	0.001*
Aboveground Biomass (AGB)	7.238	3	2.413	5.271	0.002*
Carbon Stock	1.704	3	0.568	5.412	0.002*

• significant at P-value <0.05

Likewise, for AGB, the sum of squares is 7.238 with 3 degrees of freedom, leading to a mean square of 2.413 and an F-value of 5.27077. The P-value for AGB is 0.002, also below 0.05, suggesting significant differences in aboveground biomass between the plots.

For Carbon Stock, the sum of squares is 1.704 with 3 degrees of freedom, resulting in a mean square of 0.568 and an F value of 5.412. The P-value here is 0.002, which is below the 0.05 threshold, indicating significant differences in carbon stock between the plots.

These results are consistent with findings from previous studies which highlight the variability in forest measurements due to factors such as site conditions, management practices, and genetic diversity. For example, research by Brown & Lugo (1982) and Siregar et al. (2008) indicate that variations in soil fertility, moisture availability, and silvicultural practices can lead to significant differences in tree growth and biomass. In addition, studies like those by Kirby & Potvin (2007) and Krisnawati et al. (2011) show that standing age, density, and genetic factors can influence biomass accumulation and carbon sequestration. Overall, the ANOVA results underscore the importance

of these factors in understanding the variation in DBH, AGB, and carbon stock between different plots of *Acacia mangium* in Bandar Jeli.

4.2.2 Tukey Test

The Tukey test results for Diameter at Breast Height (DBH), Aboveground Biomass (AGB), and Carbon Stock (CS) has been shown in table 4.2 across the four plots of *Acacia mangium* in Bandar Jeli, Kelantan, reveal several notable patterns

Table 4.2: Tukey test on DBH, AGB and carbon stock of *Acacia mangium* in 4 plots.

	Pair of Plot	Q-statistic	P-value	Inference
DBH	1 vs 2	0.268	0.900	not significant
	1 vs 3	1.718	0.605	not significant
	1 vs 4	5.450	0.001	* p<0.05
	2 vs 3	1.511	0.687	not significant
	2 vs 4	5.329	0.002	* p<0.05
	3 vs 4	3.734	0.048	not significant
	AGB	1 vs 2	0.068	0.900
1 vs 3		1.257	0.787	not significant
1 vs 4		5.148	0.003	* p<0.05
2 vs 3		1.224	0.800	not significant
2 vs 4		5.191	0.002	* p<0.05
	3 vs 4	3.734	0.048	not significant
	1 vs 2	0.066	0.900	not significant

Carbon stock	1 vs 3	1.257	0.787	not significant
	1 vs 4	5.146	0.003	* p<0.05
	2 vs 3	1.225	0.799	not significant
	2 vs 4	5.191	0.002	* p<0.05
	3 vs 4	3.733	0.048	not significant

The comparison shows significant differences in DBH between Plot 1 and Plot 4 (Q-statistic = 5.450, P-value = 0.001), Plot 2 and Plot 4 (Q-statistic = 5.329, P-value = 0.002), and Plot 3 Plot 4 (Q-statistic = 3.615, P-value = 0.048). Plot 4's DBH is significantly greater, indicating site-specific differences consistent with Niiyama et al. (2020). For AGB, significant differences were found between Plot 1 and Plot 4 (Q-statistic = 5.148, P-value = 0.003) and Plot 2 and Plot 4 (Q-statistic = 5.191, P-value = 0.002) is notably higher due to variations in site conditions, as supported by Adam and Jusoh (2018).

In terms of carbon stock, significant differences were observed between Plot 1 and Plot 4 (Q-statistic = 5.146, P-value = 0.003) and Plot 2 and Plot 4 (Q-statistic = 5.191, P-value = 0.002), as follows a pattern similar to AGB due to the direct relationship between biomass and carbon storage. These differences, influenced by such factors as soil fertility and water availability, are consistent with studies by Seo et al. (2015) and Majid et al. (2015). The Tukey test results highlight the importance of site-specific management strategies to optimize biomass production and carbon sequestration in *Acacia mangium* plantations, in alignment with previous research on environmental impacts on forest structure and biomass.

4.2 Comparisons of AGB and Carbon Stock of *Acacia Mangium* in Bandar Jeli, Jeli, Kelantan with Previous Studies in Malaysia

The table 4.3 show compares the findings of the current study on quantifying above ground biomass (AGB) and carbon stock of *Acacia mangium* in Bandar Jeli, Kelantan, with those from previous studies conducted by Adam & Jusoh (2018), Seo et al. (2015), and Majid et al. (2015). The table presents a comparison between the current study on quantifying above ground biomass (AGB) and carbon stock of *Acacia mangium* in Bandar Jeli, Kelantan, and several previous studies. The current study conducted in 2024 in Bandar Jeli, Kelantan, focuses on *Acacia mangium* with a diameter at breast height (DBH) of greater than 10 cm, resulting in an AGB of 45.44 Mg/ha and a carbon stock of 21.36 MgC/ha.

Table 4.3: Comparison on AGB and Carbon stock of *Acacia mangium* with previous Studies in Malaysia

	This study	Niiyama et al.	Adam & Jusoh	Seo et al.	Majid et al.
Year	2024	2020	2018	2015	2015
Area	Bandar Jeli, Jeli, Kelantan	Pasoh Forest Reserve, Negeri sembilan	Acacia Plantations in Sarawak	Sabah	Perak
Species	<i>Acacia mangium</i>	lowland forest	Acacia hybrid and 2nd generation <i>Acacia mangium</i>	Logged-over tropical fores	Logged-over Lowland tropical forest
DBH (cm)	>10cm	>5cm	>10cm	>10cm	>10cm

AGB (Mg/ha)	45.44	536	200	248.8	501.74
Carbon stock (MgC/ha)	21.36		100	90-110	225.55

In comparison, the study by Niiyama et al. (2020) in Pasoh Forest Reserve, Negeri Sembilan, examined a lowland forest with trees having a DBH of greater than 5 cm. This study reported a significantly higher AGB of 536 Mg/ha. The variation can be attributed to the differences in forest types and tree sizes included in the measurement, as a lower DBH threshold often results in higher biomass estimates due to the inclusion of more trees.

Adam & Jusoh's (2018) research in Sarawak focused on Acacia plantations, specifically hybrid and second-generation *Acacia mangium* trees with a DBH larger than 10 cm. Their findings indicated an AGB of 200 Mg/ha, which was higher than the current study. This discrepancy could be due to differences in genetic variation and plantation management practices that may have enhanced growth and biomass accumulation in the Sarawak plantations.

Seo et al. (2015) investigated log-over tropical forests in Sabah, reporting an AGB range of 90-110 Mg/ha. This range falls between the AGB values of the current study and the higher estimates from other studies, suggesting that logged-over forests might have intermediate biomass levels due to ongoing recovery and regrowth processes.

Finally, Majid et al. (2015) studied lowland tropical forests in Perak with a DBH larger than 10 cm, reporting an AGB of 501.74 Mg/ha and a carbon stock of 225.55 MgC/ha. These values are substantially higher than those in the current study. The high biomass and carbon stock in Perak's lowland

tropical forests can be attributed to the mature and dense forest structure, which supports a greater biomass reservoir.

In summary, the variations in AGB and carbon stock across various studies can be attributed to differences in forest types, DBH thresholds, tree species, genetic variations, and forest management practices. The current study's values are at the lower end compared to other regions, which may reflect specific local environmental conditions and management practices in Bandar Jeli, Kelantan. Further investigations could provide more insights into these differences and help refine the biomass and carbon stock estimation models for *Acacia mangium* in different forest settings.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Overall, the objective stated in this study, which is to estimate the aboveground biomass that representative stand of *Acacia mangium* at Bandar Jeli, Jeli, Kelantan and to evaluate the carbon storage of the aboveground biomass has been achieved. The total amount of biomass above ground for plots 1, 2,3 and 4 is 181.77 Mg/ha. While the total carbon stock for plot 1,2,3 and 4 is 85.43 MgC/ha. Meanwhile average of DBH was 14.79 cm while AGB was 2.04 Mg/ha, and carbon stock was 0.96 MgC /ha for 1 individual tree.

The abundance of *Acacia mangium* may have resulted from past and ongoing human disturbances of the forest, which have enhanced the invasion of exotic species. Large carbon storage capacities in the biomass of *Acacia mangium* attest to the species' significance in forest ecosystems and its potential support of sustainable forest management techniques meant to lower atmospheric carbon dioxide concentrations and thwart global warming (Krisnawati et al., 2011). The importance of understanding the biomass and carbon stores of *Acacia mangium* in the context of anthropogenic disturbances and global climate change is emphasized by this study.

There are some limitations of the data obtained because the data taken does not cover half of the Bandar Jeli. To future researchers who do this kind of study, you can increase the sampling plot of the place so that the

aboveground biomass and carbon stock data are obtained more accurately and reflect the whole Bandar Jeli. It also helps you to improve more than my own studies.

5.2 Recommendation

There are some limitations of the data obtained because the data taken does not cover half of the Bandar Jeli. For future researchers who do this kind of study, increase the sampling plot of the place so that the aboveground biomass and carbon stock data are obtained more accurately and reflect the whole Bandar Jeli. It also helps to improving more than current study. Future studies should involve larger sample sizes and more diverse site conditions to confirm these findings, and periodic monitoring of different growth stages will provide a more dynamic understanding of changes in biomass and carbon stocks over time. Last but not least, further research with detailed site-specific data and management practices could provide a clearer understanding of these differences.

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APPENDIX A

Raw Data

Table A.1: Raw data for 4 plots *Acacia mangium* at Bandar Jeli

Plot (20 x 25 m ² = 0.05 ha)	No.	DBH (cm)	AGB (Kg)	AGB (Mg)*	AGB (Mg/ha)	Carbon stock (MgC/ha)
1	1	10.2	41.044	0.041	0.205	0.096
	2	10.6	44.927	0.045	0.225	0.106
	3	10.9	47.972	0.048	0.240	0.113
	4	11	49.013	0.049	0.245	0.115
	5	11.5	54.410	0.054	0.272	0.128
	6	11.5	54.410	0.054	0.272	0.128
	7	12.4	64.950	0.065	0.325	0.153
	8	12.6	67.439	0.067	0.337	0.158
	9	12.6	67.439	0.067	0.337	0.158
	10	12.9	71.273	0.071	0.356	0.167
	11	12.9	71.273	0.071	0.356	0.167
	12	13	72.578	0.073	0.363	0.171
	13	13.5	79.309	0.079	0.397	0.186
	14	13.5	79.309	0.079	0.397	0.186
	15	13.8	83.513	0.084	0.418	0.196
	16	14.2	89.313	0.089	0.447	0.210
	17	14.6	95.338	0.095	0.477	0.224
	18	15.6	111.399	0.111	0.557	0.262
	19	16.1	119.972	0.120	0.600	0.282
	20	16.3	123.503	0.124	0.618	0.290
	21	16.4	125.291	0.125	0.626	0.294
	22	16.8	132.591	0.133	0.663	0.312
	23	17.7	149.891	0.150	0.749	0.352
	24	18.2	160.032	0.160	0.800	0.376
	25	18.7	170.556	0.171	0.853	0.401
	26	19.8	195.075	0.195	0.975	0.458
Sub total	26	367.3	2421.819	2.422	12.109	5.691
2	1	10.1	40.105	0.040	0.201	0.094
	2	11.2	51.133	0.051	0.256	0.120
	3	11.2	51.133	0.051	0.256	0.120
	4	11.2	51.133	0.051	0.256	0.120
	5	11.7	56.660	0.057	0.283	0.133
	6	12	60.133	0.060	0.301	0.141
	7	12.2	62.515	0.063	0.313	0.147
	8	12.8	69.981	0.070	0.350	0.164
	9	13	72.578	0.073	0.363	0.171
	10	13.2	75.229	0.075	0.376	0.177
	11	13.4	77.935	0.078	0.390	0.183

	12	13.6	80.696	0.081	0.403	0.190
	13	13.7	82.098	0.082	0.410	0.193
	14	13.7	82.098	0.082	0.410	0.193
	15	14	86.385	0.086	0.432	0.203
	16	14.2	89.313	0.089	0.447	0.210
	17	14.8	98.436	0.098	0.492	0.231
	18	14.8	98.436	0.098	0.492	0.231
	19	15.1	103.189	0.103	0.516	0.242
	20	15.2	104.802	0.105	0.524	0.246
	21	15.3	106.430	0.106	0.532	0.250
	22	15.5	109.728	0.110	0.549	0.258
	23	15.8	114.784	0.115	0.574	0.270
	24	16	118.228	0.118	0.591	0.278
	25	16.2	121.730	0.122	0.609	0.286
	26	17	136.330	0.136	0.682	0.320
	27	17.2	140.130	0.140	0.701	0.329
	28	18.8	172.707	0.173	0.864	0.406
	29	20	199.737	0.200	0.999	0.469
Sub total	29	412.9	2713.792	2.714	13.569	6.377
3	1	12.2	62.515	0.063	0.313	0.147
	2	12.7	68.703	0.069	0.344	0.161
	3	12.8	69.981	0.070	0.350	0.164
	4	13.4	77.935	0.078	0.390	0.183
	5	13.4	77.935	0.078	0.390	0.183
	6	13.6	80.696	0.081	0.403	0.190
	7	13.7	82.098	0.082	0.410	0.193
	8	14.4	92.297	0.092	0.461	0.217
	9	14.7	96.880	0.097	0.484	0.228
	10	14.9	100.006	0.100	0.500	0.235
	11	15.3	106.430	0.106	0.532	0.250
	12	15.3	106.430	0.106	0.532	0.250
	13	15.3	106.430	0.106	0.532	0.250
	14	15.7	113.084	0.113	0.565	0.266
	15	16.5	127.094	0.127	0.635	0.299
	16	16.9	134.453	0.134	0.672	0.316
	17	17.1	138.223	0.138	0.691	0.325
	18	17.3	142.052	0.142	0.710	0.334
19	18.3	162.106	0.162	0.811	0.381	
Sub total	19	283.5	1945.348	1.945	9.727	4.572
4	1	15.3	106.430	0.106	0.532	0.250
	2	15.4	108.072	0.108	0.540	0.254
	3	15.9	116.499	0.116	0.582	0.274
	4	15.9	116.499	0.116	0.582	0.274
	5	16.3	123.503	0.124	0.618	0.290
	6	16.6	128.912	0.129	0.645	0.303
	7	16.8	132.591	0.133	0.663	0.312

	8	16.8	132.591	0.133	0.663	0.312
	9	17.1	138.223	0.138	0.691	0.325
	10	17.3	142.052	0.142	0.710	0.334
	11	17.4	143.989	0.144	0.720	0.338
	12	17.5	145.941	0.146	0.730	0.343
	13	17.7	149.891	0.150	0.749	0.352
	14	18.2	160.032	0.160	0.800	0.376
	15	18.3	162.106	0.162	0.811	0.381
Sub total	15	252.5	2007.329	2.007	10.037	4.717
TOTAL	89	1316.2	9088.287	9.084	45.442	21.358

*Mg = megagram = 1000 kg

APPENDIX B

ANOVA

Table B.1: ANOVA of DBH in 4 plots

SUMMARY					
<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>	
1	26	367.3	14.12692	7.218046	
2	29	412.9	14.23793	5.416724	
3	19	283.5	14.92105	3.016199	
4	15	252.5	16.83333	0.879524	

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	83.22442	3	27.74147	5.913924	0.001029	2.711921
Within Groups	398.7243	85	4.690875			
Total	481.9488	88				

Table B.2: ANOVA of AGB in 4 plots

SUMMARY					
<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>	
0.820878	25	47.61549	1.90462	0.697277	
0.80209	28	53.47375	1.909777	0.516961	
1.250298	18	37.65667	2.092037	0.295014	
2.128594	14	38.01798	2.71557	0.105407	

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	7.238163	3	2.412721	5.27077	0.002264	2.717343
Within Groups	37.07814	81	0.457755			
Total	44.31631	84				

Table B.3: ANOVA of carbon stock in 4 plots

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
1	26	22.765095	0.875581	0.15784615
2	29	25.509644	0.879643	0.11946444
3	19	18.286274	0.962435	0.06978556
4	15	18.868889	1.257926	0.02669525

ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	1.704063	3	0.568021	5.41212994	0.001865	2.711921
Within Groups	8.921032	85	0.104953			
Total	10.62509	88				

APPENDIX C

Sampling

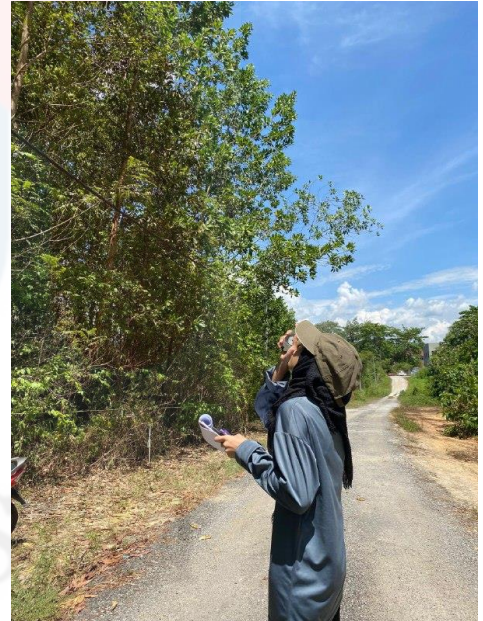
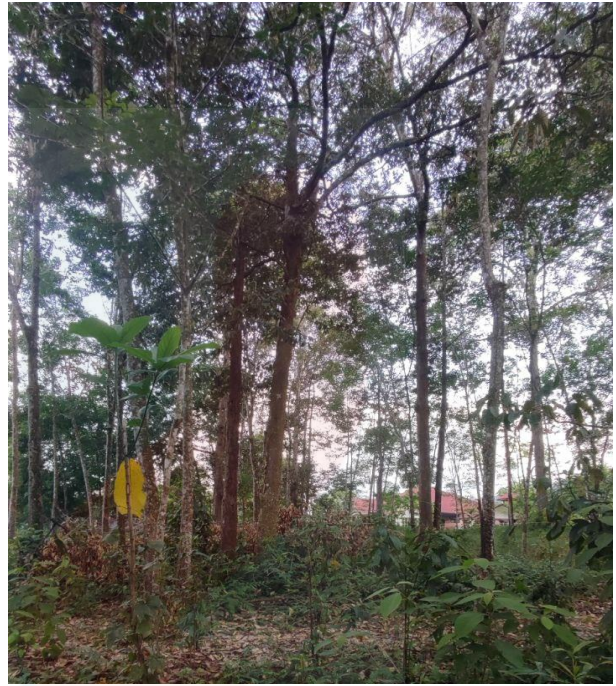
Table C.1: Material of studies

Material	Image
Diameter at Breast (DBH) tape	
Raffia string	



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Figure C.1: Sampling plot at Bandar Jeli, Jeli, Kelantan