Assessing of aboveground biomass and carbon stock of *Leucaena leucophala* at Bandar Jeli, Jeli, Kelantan

by

NUR AISHAH IZZATI BINTI ABDULLAH

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DECLARATION

I declare that this thesis Assessing Aboveground Biomass and Carbon Stock of *Leucaena leucocephala* 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

Name: : NUR AISHAH IZZATI BINTI ABDULLAH

Date : 7/8/2024

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In the most merciful and benevolent name of Allah

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TABLE OF CONTENT

CHAPTER 5 CONCLUSION AND RECOMMEDATION

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

LIST OF ABBREVIATIONS

IPCC	Intergovernmental Panel on Climate Change

LIST OF SYMBOLS

%	Percentage
m	Meter
>	More than
cm	Centimetre
AGB	Aboveground biomass
Mg	Megagram
C	Carbon
ha	Hectare
DBH	Diameter at breast height
Kg	Kilogram
In	Lorne
H	Tree height

Menilai biojisim di atas tanah dan

stok karbon *Leucaena leucophala* di Bandar Jeli, Jeli, Kelantan

ABSTRAK

Kajian bagi mengkaji biojisim di atas tanah di bandar Bandar Jeli, Jeli, Kelantan telah dijalankan. Empat plot persampelan rawak berstrata dengan 44 individu pokok *Leucaena leucocephala* telah dipilih untuk kajian ini. Diameter pada paras dada (DBH) ≥ 5 cm dan keatas diukur untuk setiap dirian yang dipilih dalam semua plot. Model alometrik digunakan untuk mengira biojisim dirian di atas tanah pokok *Leucaena leucocephala* untuk mendapatkan karbon yang dipegang oleh pokok dalam batangnya. Julat bagi DBH bagi kajian *Leucaena leucocephala* di empat plot di Bandar Jeli, Jeli, Kelantan ialah 8.23 cm hingga 13 cm. Jumlah biomas atas tanah bagi kajian ini ialah sebanyak 93.08 Mg/ha manakala untuk stok karbon ialah 43.75 Mg C/ha. Analisis ujian Varians (ANOVA) memberikan keputusan yang tidak signifikasi (nilai P ≤ 0.05) biojisim di atas tanah dan stok karbon di antara plot. Maklumat kajian ini berguna untuk biojisim di atas tanah dan stok karbon *Leucaena leucocephala dan* boleh digunakan untuk kajian akan datang.

Assessing of aboveground biomass and

carbon stock of *Leucaena leucophala* at Bandar Jeli, Jeli, Kelantan

ABSTRACT

Aboveground biomass was estimated around the urban rainforest of Bandar Jeli, Jeli, Kelantan. Four stratified random sampling plots with 44 individuals of *Leucaena leucocephala* trees were established for this study. The diameter at breast height (DBH) range ≥ 5 cm and above were measured for each chosen stands in all plots. An allometric model was used to calculate the stand aboveground biomass of *Leucaena leucocephala* trees to get the carbon the trees hold in their stems. The means for DBH for this study of *Leucaena leucucephala* in four plots located at Bandar Jeli, Jeli, Kelantan is 8.23 cm to 13 cm. The total aboveground biomass for this study is 93.08 Mg/ha meanwhile for carbon stock, 43.75 Mg C/ha. Analysis on Variance (ANOVA) test gave their insignificant result (P-value ≤ 0.05) between the aboveground biomass and carbon stock among the plots. Hence, this study, a useful information related to aboveground biomass and carbon stock of *Leucaena leucocephala* can be used for future studies.

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Leucaena leucocephala, also known as 'Petai belalang', is a fast-growing leguminous tree native to Central America, has gained global attention for its numerous applications in agroforestry, soil development, and as a possible bioenergy feedstock (Rubio-Casal et al., 2018). Understanding the carbon dynamics of *Leucaena leucocephala* is becoming increasingly important for both environmental protection and climate change mitigation as demand for sustainable land management practises grows.

Pan et al. (2011) state that trees' ability to trap carbon in their aboveground biomass is an important component of the global carbon cycle. However, there is a significant vacuum in detailed estimates of *Leucaena leucocephala*'s aboveground biomass and carbon store. While earlier study has investigated its potential as a carbon sink in agroforestry systems (Nair et al., 2010), a comprehensive assessment of its carbon stock capacity necessitates precise quantification of aboveground biomass.

Accurate calculations of aboveground biomass and carbon stock are critical for designing effective climate change mitigation measures and satisfying international obligations such as those contained in the Paris Agreement (Masson, 2018). In this context, *Leucaena leucocephala*, with its rapid growth and nitrogen-fixing ability, offers promise as a significant addition to carbon sequestration efforts (Jha and Dhyani, 2015).

This study expands on previous studies by applying modern tools, such as allometric equations, to quantify the aboveground biomass and carbon stock of *Leucaena leucocephala* at a finer spatial scale. Such extensive analyses are required to improve our understanding of the species' carbon stock capability in various habitats and land-use situations.

1.2 Problem Statement

This study purpose of the invasive species *Leucaena leucocephala* as a source of carbon since this tree role as carbon stock holder is not well known yet. In the tropical humid rainforest setting of Bandar Jeli, the study surveys individuals with stem sizes ranging from ≥ 5 cm and above, analysing its growth patterns and capacity for storing carbon. Its aboveground biomass and carbon stock range over invasion gradients, from dense pockets to scattered occurrences, and this study seeks to shed light on these differences. This tree species is not common, yet it is found in small quantities in some locations, which underlines its importance of assessing its contribution to the plant community's overall carbon sequestration.

1.3 Objectives

a. To determine the aboveground biomass of *Leucaena leucocephala's* stem.

b. To evaluate the carbon stock, contain in of *Leucaena leucocephala's* stem.

1.4 Scope of Study

The purpose of this study is to calculate the aboveground standing stem biomass and carbon stock of invasive *Leucaena leucocephala* populations in Bandar Jeli, Kelantan. Bandar Jeli is located in the humid tropical region of peninsular Malaysia and has an area of around 304.36 km^2. This study examined *Leucaena leucocephala* populations along riverbanks and forest borders in Bandar Jeli, where prior study has revealed significant invasion. *Leucaena leucocephala* stems from ≥ 5 cm and above in diameter at breast height (DBH) have been evaluated as the target population to get the amount of aboveground biomass and carbon stock held by this tree species at study area. Aboveground and carbon stock is being estimated since they are monitoring climate change, creating efficient forest management plans, and guaranteeing the sustainable use of natural resources. On the other hand, *Leucaena leucocephala* species is being chosen to estimate its aboveground biomass and carbon stock due to this species is well known as invasive species however people seem unbothered about its role as carbon stock holder. The findings are shown the present extent of biomass carbon deposited in invasive *Leucaena leucocephala* stands in riparian and disturbed scrubland habitats in Bandar Jeli.

1.5 Significant of Study

The study of *Leucaena leucocephala's* aboveground biomass and carbon stock at Bandar Jeli, Malaysia, is greatly aided by this study. *Leucaena leucocephala,* which is valued for its quick growth and capacity to fix nitrogen, is essential to tropical agroforestry systems. Gaining an understanding of its biomass and potential for stocking carbon is essential for promoting sustainable land management techniques and aiding in the fight against climate change. The results of this study provided important new information about *Leucaena leucocephala* ability to sequester carbon in the unique environment of Bandar Jeli. This kind of information is crucial for maximizing agroforestry tactics, strengthening the resilience of ecosystems, and advancing environmental sustainability. Furthermore, by highlighting the importance of agroforestry in accomplishing environmental and socioeconomic goals, the study is in line with larger measures addressing climate change and sustainable development. This study will advance the knowledge of tropical agroecosystems by estimating the carbon stock of *Leucaena leucocephala*.

CHAPTER 2

LITERATURE REVIEW

2.1 *Leucaena leucocephala*

Figure 2.1(a) shows *Leucaena leucocephala's* stem, a rapidly growing and nitrogen-fixing. This tree also a leguminous tree that plays wide range of roles in both biotic (living thing) and abiotic (non-living thing) components of ecological systems. Leucaena is an American-born species that has spread over the world and is used in a variety of agriculture and environment setting.

Figure 2.1: *Leucaena leucocephala* tree (Bageel et al., 2020)

2.1.1 Morphology of *Leucaena leucocephala*

Based on Figure 2.2, the tree has a shallow, widely dispersed root system. Small spherical nodules in the roots contain nitrogen-fixing bacteria, allowing *Leucaena leucocephala* to thrive effectively in low fertility soils (Zaharah & Bah, 1999).

Leucaena leucocephala's white blooms are fluffy spheres with circular heads that are typically 1 cm in diameter. Hashim et al. (2010) report, the tree produces long, flattened, pale brown seed pods with 10-20 seeds per pod. The seeds are around 5mm long, oblong in shape, and glossy brown in colour.

Invasive populations of *Leucaena leucocephala* in Malaysia commonly propagate through self-seeding once established from the original seed material brought from Mexico and Central America (Krisnan et al., 2013).

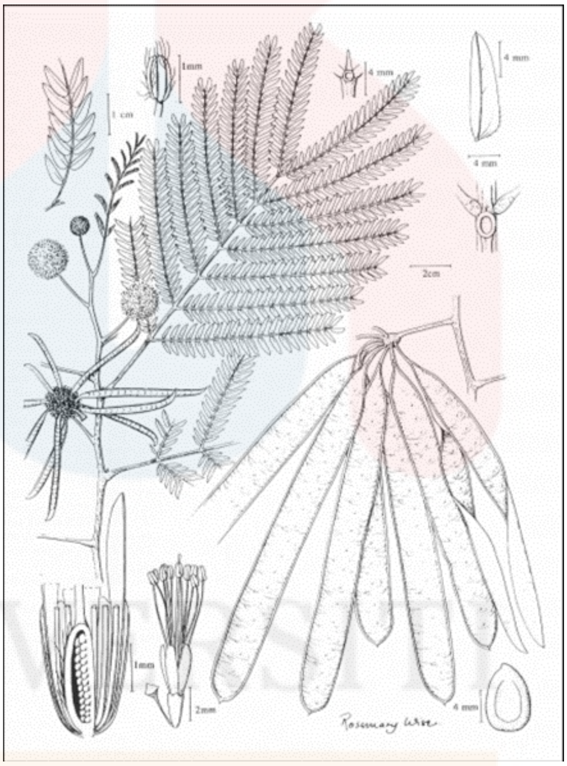

Figure 2.2: Morphology characteristic of *Leucaena leucocephala* (Walton 2003)

2.1.2 Taxonomy of *Leucaena leucocephala*

The taxonomy referred to Figure 2.3 of *Leucanea Leucocephala*, an invasive tree from Central America is from Kingdom Plantae, Class of Magnoliopsida, Order of Fabales, Family of Fabaceae and Genus of Leucaena.

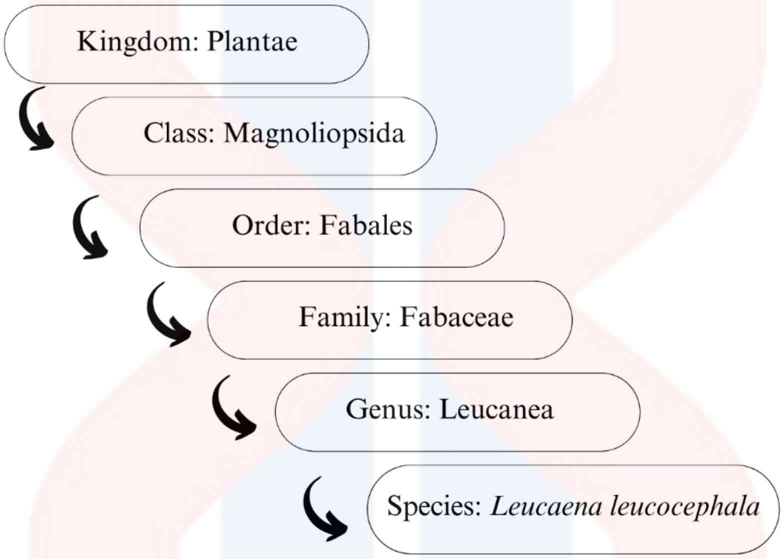

Figure 2.3: The taxonomy of *Leucaena leucocephala* (Lichvar et al., 2016)

2.1.3 Benefits of *Leucaena leucocephala*

Leucaena leucocephala plays role as an alternative protein source. This tree is a good plant for honeybees. It contains high palatability, a digestibility between 50% and 70% while its good nutritional value is 22-28% protein. Its forage can be a valid feed stuff for ruminitis like sheep and goat along with non-ruminitis, like pig and rabbit. Leucaena has high protein and B-carotene content, can also use as an excellent source of calcium, phosphorus, and other minerals based on the mineral availability in soil (Angelis et al., 2021). As food science, *Leucaena leucocephala* foliage used as animal feed, and leaves and seeds as human food on central America, Indonesia, and Thailand (Aquino et al., 2023).

Oyster mushroom cultivation times can be shortened by applying rice straw supplemented with 10% *Leucaena leucocephala* leaf, making it appropriate for tropical climates. The brief period between spawning and complete mycelia colonization, which encourages mycelia growth and primordial creation, is the cause of this. The study moreover discovered that the supplement utilized is a naturally occurring, abundant, and reasonably priced source, guaranteeing sustained manufacturing in tropical areas (Andrew et al., 2023).

Lead and cadmium, two heavy metals that are particularly studied in this study's impacts on plants, are shown to have the ability to inhibit seed germination and growth. This is caused by alterations in cell membrane selection permeability and the disintegration of food ingredients that have been stored in seeds. Although the exact mechanism of cadmium poisoning is unknown, it has an impact on the length and growth of seedlings. *Leucaena leucocephala* seedlings may be able to flourish in contaminated environments based on their decreased dry weight and limited tolerance to toxic pollutants (Shafiq et al., 2008).

For medication purpose, *Leucaena leucocephala* seeds contain a new lectin that exhibits strong hemagglutination and glycoprotein characteristics. Studies on sugar inhibition have shown that the lectin is quite powerful, with glucose being the most potent inhibitor. This implies that *Leucaena leucocephala* leaf may be helpful in determining a disease's diagnosis and possibility for treatment. Under both reducing and non-reducing conditions, the isolated lectin demonstrated high purification and co-precipitation (Madayi et al., 2020).

The use of *Leucaena leucocephala* galactomannan as a carrier for delivering sulfonamide to the colon. It uses a two-step direct esterification strategy, analyzing factors, determining optimal galactomannans concentration, characterizing the prodrug, and evaluating its stability, in vitro drug release, and antiproliferative potential on human colon cancer cell lines (Kaur et al., 2021).

Green synthesis involves synthesizing green nanoparticles using *Leucaena leucocephala* leaf extracts. Metal oxide Nps like Zinc Oxide, Copper Oxide, MnO2- NPs, and Magnesium Oxide are studied for wastewater decontamination, adsorption, and water treatment due to their non-toxic nature. Based on this study, it found out that these nanoparticles to be novel, efficient, and cost-effective, but require an additional step of extract preparation (Munir et al., 2023).

2.2 Distribution of *Leucaena leucocephala* in Rainforest Ecosystem

Corlett and Primack's book differs the Amazon and Malaysian rainforests, highlighting the similarities in climate and forest structure. The Amazon rainforest, the world's primary remaining continuous tropical rainforest, covers Brazil, Peru, Colombia, and other South American countries. Both are humid tropical rainforests, with high temperatures, humidity, and lot of rainfall. The book mentions the Amazon and Malaysian rainforests as the two largest remaining rainforest ecosystems (Corlett & Primack, 2011).

Costa Rica and Malaysia have a humid tropical climate and a multilayered forest structure. Both regions have plenty of rainfall, high temperatures, and humidity, making them suitable for tropical rainforest development. They are also recognised as biodiversity hotspots, supporting a vast range of plant and animal species, as in contrast to the Amazon rainforest, which is frequently listed as the most biodiverse in the world (Ruiz-Díaz et al., 2024).

West African rainforests, mostly those in Cameroon, are similar to Malaysian rainforests in terms of climate and forest structure. Both regions include a humid tropical setting with high temperatures, humidity, and abundant rainfall, which promotes tropical rainforest growth. The rainforests in both regions are multilayered, with an emergent layer of tall trees, a canopy layer, and a dense understory (Mbatchou, 2004).

Leucaena leucocephala can be found in the rainforests of all three regions which are Brazil (Amazon), Central America (Costa Rica), West Africa (Cameroon), and Malaysia itself. *Leucaena leucocephala* has been introduced and grown in several sections of the Brazilian Amazon for its nitrogen-fixing qualities and forage value (Dias et al., 2008), meanwhile this species is a widely planted tree species in Costa Rica, particularly in agroforestry systems and as a shade tree in coffee plantations (Segura et al., 2006). *Leucaena leucocephala also* has been introduced and promoted in Cameroon for a variety of applications, including soil improvement, fuelwood, and fodder (Franzel et al., 2014), meanwhile at Malaysia, it is commonly grown in agroforestry systems and reforestation projects (Lau et al., 2015).

2.3 Aboveground Biomass and Carbon Stock

All living plant materials above the soil surface, including stems, stumps, branches, bark, seeds, and foliage, is referred to as aboveground biomass (Brown, 1997). Aboveground biomass is the total dry weight of all plant parts generated above ground level in trees such as *Leucaena leucocephala*, including stems, branches, twigs, leaves or leaflets, flowers, fruits, and seeds. Quantitative estimations of aboveground biomass in *Leucaena leucocephala* across growth phases provide an assessment of its productivity and accumulation of plant material above ground, which can guide applications ranging from bioenergy to agroforestry.

The entire quantity of carbon stored in various carbon pools in forest ecosystems such as biomass (above and below ground), dead wood, litter, and soil is referred to as carbon stock (Eggleston et al., 2006). The aboveground carbon stock of invasive *Leucaena leucocephala* populations is the total carbon stored in the dry weight of all plant parts above ground, primarily stems and branches. We can estimate the total aboveground carbon accumulated by measuring *Leucaena leucocephala* aboveground biomass per unit area and using carbon content fractions. Quantifying variations in aboveground carbon stocks of *Leucaena leucocephala* across invasion fronts and over time provides insights into its carbon sequestration or emission implications.

2.3.1 Importance of Aboveground Biomass and Carbon Stock of *Leucaena leucocephala*

The aboveground carbon uptake and storage of *Leucaena leucocephala* helps evaluate its promise as a fast-growing tree species for carbon capture and sequestration technologies to mitigate greenhouse gas emissions (Santos et al., 2022).

Leucaena leucocephala's high biomass productivity, coppicing ability, and nitrogen fixation capacity make it an ideal bioenergy feedstock for renewable fuel production systems (Pandey et al., 2016).

Leucaena leucocephala, as a pioneer leguminous tree, improves soil fertility through nitrogen fixation and can be integrated in agroforestry systems to supply fodder, fuelwood, and lumber while increasing crop yields (Bagnall et al., 2019).

Quantifying distribution patterns and standing biomass aids in determining the environmental implications of invasive *Leucaena leucocephala* on native biodiversity and carbon cycling (Parrotta et al., 2015).

2.4 Allometric Model and Allometric Equation

Allometric models are models that analyze biological scaling and relationships between an organism's size and other factors such as metabolism, growth rate, lifespan, and so on. Allometric equations, in particular, define the mathematical link between biological variables using power laws and exponents known as allometric scaling factors or allometric coefficients (Gayon, 2000).

2.4.1 Allometric Models Used in Estimating Aboveground Biomass in Malaysia

There are some previous studies on models used to predicting aboveground biomass in Malaysia as shown at Table 2.1.

Table 2.1: The previous studies on allometric models

No.	Method	Year/DBH	Area	Author
1.	$W = 0.0128DBH^{2.60}$ W= weight of aboveground biomass; DBH= diameter at breast height	>5 cm	Sabah	Fromad et al. (1998)
2.	$Y = 0.1173D^{2.454}$ Y= aboveground biomass D = diameter at breast height	11.6 to 41.5 cm	Sarawak	Adam and Jusoh, 2018
3.	High wood density $0.05633xDBH^{2.75736}$ Medium wood density $0.00023xDBH^{3.75745}$ DBH= diameter at breast height	>10 cm	Perak	Majid and Nurudin, 2015
4.	Stem = $0.313x(DBH^2xH)^{0.9773}$ Branch= $0.136x(stem)^{1.070}$ Leaves=$1.25x[((0.124)x(stem^{0.794}))]/(0.124x(stem^{0.794})] + 125$ DBH= diameter at breast height; H= height	≥ 5 cm	Negeri Sembilan	Kato et al., 1978
5.	$y = 0.2544xD^{2.368}$ Y= aboveground biomass	≥ 5 cm	Perak	Kueh and Lim, 1999
6.	$w = 0.0477d^{2.6998}$ W = aboveground biomass d = diameter at breast height	5 years	Sarawak	Heriansyah (2005)

2.5 Sampling Plot Size Based on Previous Studies

There are some plotting sizes per the whole area size from the previous studies of all over the world, including Malaysia as shown at Table 2.3.

Table 2.2: The previous studies on sampling sizes.

No.	Area	Sampling size (%)	Whole area size (Hectare)	Authors
1.	Malaysia	0.0004	130500	Avitabile et al., 2016
2.	Malaysia	0.06	2	Meiling et al., 2005
3.	Malaysia	0.04	80	Saner et al., 2012
4.	Malaysia	0.6	500	Kauffman et al., 2016
5.	America	1.2	84	Brown et al., 1989
6.	Africa	0.16	100	Glenday, 2006
7.	Canada	0.013	29000	Barrett et al., 2010
8.	Amazon	0.0054	54000	Stropp et al., 2009

2.6 Sampling Plot Size Based on Inventory Plot

These are the plot size according to Jemali and Majid (2023) based on the tree DBH as shown in Table 2.3.

Table 2.3: The plot size based on tree DBH (Jemali and Majid, 2023)

Inventory Plot	Measurement (m)	Size (m^2)	Size (ha)	Inventory Intension (%)	Diameter Class	Explanation
Main	50 x 20	1000	0.1	10.0	DBH > 45 cm	Big tree
					DBH > 15cm – 45 cm	Small tree
Second	25 x 20	500	0.05	5.0	DBH > 15cm – 30 cm	Kayu jaras besar
Third	10 x 10	100	0.01	1.0	DBH > 5cm – 15 cm	Small wood size
Fourth	5 x 5	25	0.0025	0.25	Height > 1.5m DBH < 5cm	Offspring
Fifth	2 x 2	4	0.0004	0.04	Height > 15cm – 1.5 m	Offspring

2.7 Estimating Carbon Stock

Based on previous studies by Jepsen (2006) the formula to estimate aboveground carbon is by 50% from the dry biomass. Adam and Jusoh (2018) stated on their previous study that from IPCC 2006, carbon can be estimated by multiplying to 0.47 from dry biomass. According to previous study of Wassihun et al. (2019), they also agreed that carbon is 50% from the aboveground biomass weight.

2.8 Invasive Species as Carbon Stock Holder at Malaysia

Aside of *Leucaena leucocephala*, there is another famous invasive species commonly found all over the Malaysia but the dominancy is located at Sarawak. This tree species, *Acacia mangium*, is a species under Fabaceae family, same with *Leucaena leucocephala*. Aside of timber purpose and paper making, *Acacia mangium* has been studied by few researchers from Malaysia for its potential on holding carbon stock in their standings. Apposite from *Leucaena leucocephala*, there is no specifically study yet about estimating aboveground and carbon stock for this species, but *Acacia mangium* is as shown in Table 2.4 below.

Table 2.4: Carbon stock of invasive species at Malaysia

Researchers	Tree type	Mean DBH (cm)	Aboveground Biomass (Mg/ha)/(tonne/ha)	Carbon Stock (Mg C/ha)
Adam and Jusoh, 2015	Hybrid	12.8 – 40.9	113.3 Mg/ha	53.3 Mg C/ha
	2^{nd} Gen	11.6 – 41.5	178.9 Mg/ha	84.1 Mg C/ha
Lee, et al., 2015	1 year	8.84	19.76 Mg/ha	9.37 Mg C/ha
	3 years	15.10	66.68 Mg/ha	39.26 Mg C/ha
	5 years	18.39	139.99 Mg/ha	66.36 Mg C/ha

From the paper by Adam and Jusoh (2015), there was a study area located in the Bintulu district of Sarawak, Malaysia, on an *Acacia mangium* plantation. Field sampling was done in two 10-year-old stands of *Acacia hybrid* and *Acacia mangium* (2nd generation) between June 2011 and September 2012. Random sampling plots of 30 x 30 metres were set up in each stand. For the purpose of calculating biomass, 35 2nd generation *Acacia mangium* trees were taken from the sampling plots. Tree diameter at breast height (DBH), which was used as the independent variable in the development of allometric equations, was one factor influencing the aboveground biomass. Tree growth and biomass accumulation were also influenced by site characteristics such as well-drained soils, a climate with approximately 3,600 mm of annual rainfall, and comparatively level topography. For this study, site conditions like well-drained soils, climate with annual rainfall around 3,600 mm, and relatively flat terrain also influenced tree growth and biomass accumulation for this tree species.

The Table 2.4 shown that mean DBH for Adam and Junoh (2015) are from 12.8 cm to 40.9 cm for *Acacia mangium* hybrid type and 11.6 cm to 41.5 cm for *Acacia mangium* 2nd generation respectively. Meanwhile for aboveground biomass, *Acacia mangium* hybrid and *Acacia mangium* 2nd generation hold 113.3 Mg/ha and 178.9 Mg/ha with 53.3 Mg C/ha and 84.1 Mg C/ha for carbon stock.

On the other hand, the studied by Lee et al. (2015), The goal of the study on *Acacia mangium* in Sarawak, Malaysia, was to evaluate the productivity, carbon content, and soil nutrients of stems at various ages. Plantations in the central lowland region of Sarawak, with ages ranging from

1 year, 3 years, and 5 years, were included in the sampling areas. This region primarily consists of Red-Yellow Podzolic soils, which are known for their low fertility and water-holding capacity. The pH of the soil, the total nitrogen content, and the amount of accessible phosphorus are factors that affect the aboveground biomass and carbon stock of *Acacia mangium*. It has been discovered that these factors decrease significantly as the stand ages. Furthermore, the processes used for soil preparation, such as mechanical clearing, stacking, and burning of forest residues, have a significant impact on the features of the soil and, by extension, the biomass and carbon stock. The study shows how important it is to keep updated on changes in soil qualities in order to control and raise forest plantation productivity.

The mean DBH for 1 year. 3 years and 5 years for *Acacia mangium* from Lee et al., 2015 are 8.84 cm, 15.10 cm, and 18.39 cm with 19.76 Mg/ha, 66.68 Mg/ha, and 139.99 tonne/ha for aboveground biomass and 9.37 Mg C/ha, 39.26 Mg C/ha, and 66.36 Mg C/ha for the carbon stock of trees stands hold.

2.9 Factors Influencing Aboveground Biomass and Carbon Stock

Based on past researchers made by Basuki et al. (2009), Chave et al. (2014), and Kenzo et al. (2009), and Slik et al. (2010), there are few factors influencing the aboveground biomass and carbon stock for tree species. The factors include diameter at breast height data, applying specific species allometric model, and forest structure.

In fact, one of the biggest factors influencing aboveground biomass and carbon stock estimation in tropical humid rainforests, like those in

Malaysia, is diameter at breast height (DBH). This parameter has been thoroughly investigated and included in a number of different allometric formulas for estimating biomass. For example, study by Basuki et al. (2009) was carried out in East Kalimantan, Indonesia, which shares many characteristics with the tropical rainforests of Malaysia. According to their findings, the most significant predictor for calculating aboveground biomass was DBH.

On the other hand, DBH was used as the key variable in the pantropical biomass equations developed by Chave et al. (2014). Today, tropical forests, including those in Malaysia, is widely employ these formulas. Due to its great connections with tree biomass and relative ease of measurement, DBH is a highly effective predictor. It's crucial to remember that, despite its importance, DBH is not the sole factor affecting estimates of biomass and carbon stocks.

Using species-specific allometric equations has also been helpful in enhancing the accuracy of biomass estimates. Kenzo et al. (2009), for example developed formulas especially for dipterocarp species found in Sarawak, Malaysia. The varied growth trends and biomass distribution of various tree species can be captured by these species-specific equations, providing accurate projections across many kinds of tropical forests.

Lastly, biomass and carbon stock can be influenced by the forest's main composition and structure. Slik et al. (2010) assessed how biomass estimations in Southeast Asian forests, including regions like Malaysian rainforests, which were impacted by forest structure. They found that the biomass of forests is influenced by a number of factors including wood specific gravity gradients, basal area, and stem density.

CHAPTER 3

MATERIALS AND METHOD

3.1 Study Area

Based on the Figure 3.1, study area is located in Bandar Jeli, Kelantan, Malaysia (5.6990° N, 101.8464° E). It covered an area of 304.36 km^2. Within this location, stands of *Leucaena leucocephala* were examined to determine their aboveground biomass and carbon stock. The terrain is a typical of the region, with schools, valleys, tiny towns, and agricultural areas. Stratified random sampling method has been used for plotting in estimating aboveground biomass and carbon stock of *Leucaena leucocephala*. The plots used were scattered across the larger 304.36 km^2 region in regions that represent the range of conditions in which *Leucaena Leucocephala* is discovered. Within each plot, data for diameter at breast height has been collected to determine the aboveground biomass and carbon stock contain on the stems.

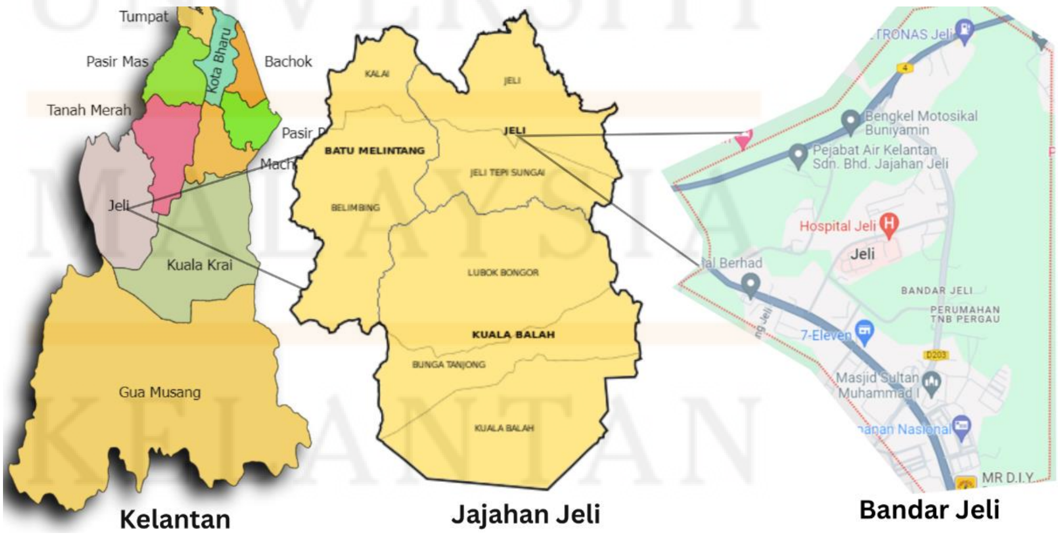

Figure 3.1: Location of Bandar Jeli. (Google Earth 2024)

From Figure 3.1, there were four plots have been set up to collect DBH data of *Leucaena leucocephala* as it shown in Figure 3.2, using stratified random sampling.

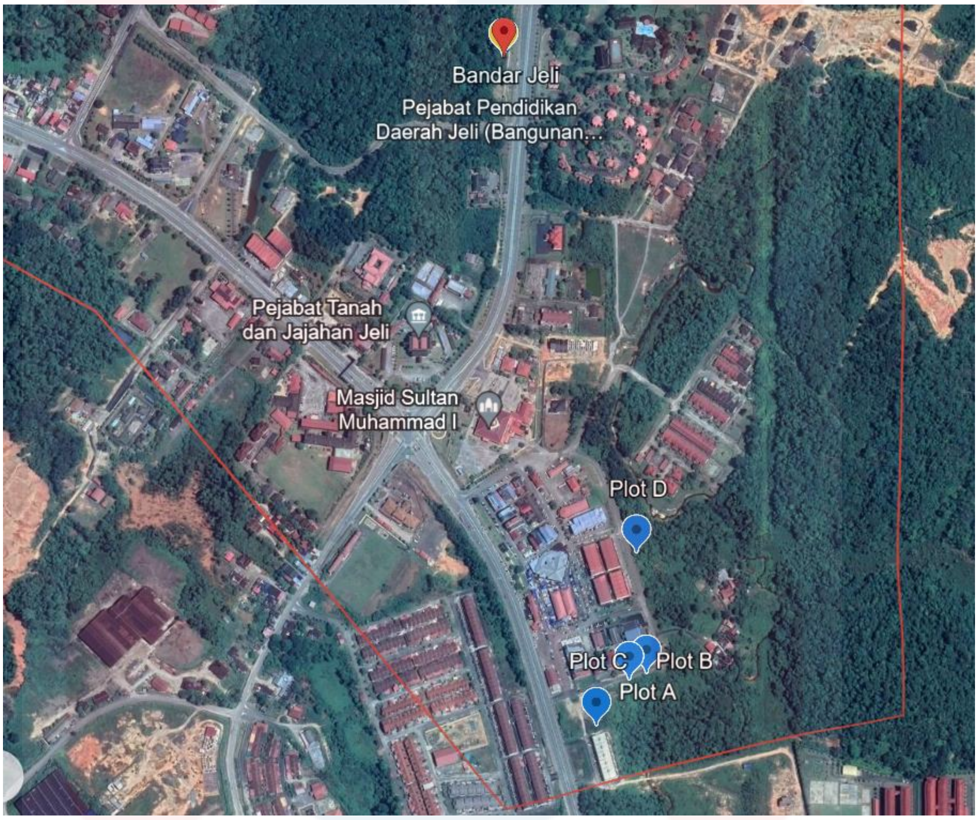

Figure 3.2: Location for four sampling plots at Bandar Jeli. (Google Earth, 2024)

3.2 Material

The aboveground stems biomass and carbon stock of *Leucaena leucocephala* determined using field diameter at breast height (DBH) measurements and allometric models. The DBH of all standing *Leucaena leucocephala* stems exceeding the ≥ 5 cm and above threshold were using a diameter tape at 304.36 km^2 study zone. The findings gave baseline data and will help on determining the carbon stock potential of this species' aboveground stems in Bandar Jeli, Kelantan.

3.3 Method

The aboveground biomass and carbon stock of *Leucaena leucocephala* assessed in Bandar Jeli, Kelantan, using sample plots of 1.31% of the total area. Stems larger than 5cm in diameter were identified, and their biomass and carbon stock were being estimated using diameter at breast height (DBH) and the most suitable allometric equations like the flow chart as shown in Figure 3.3.

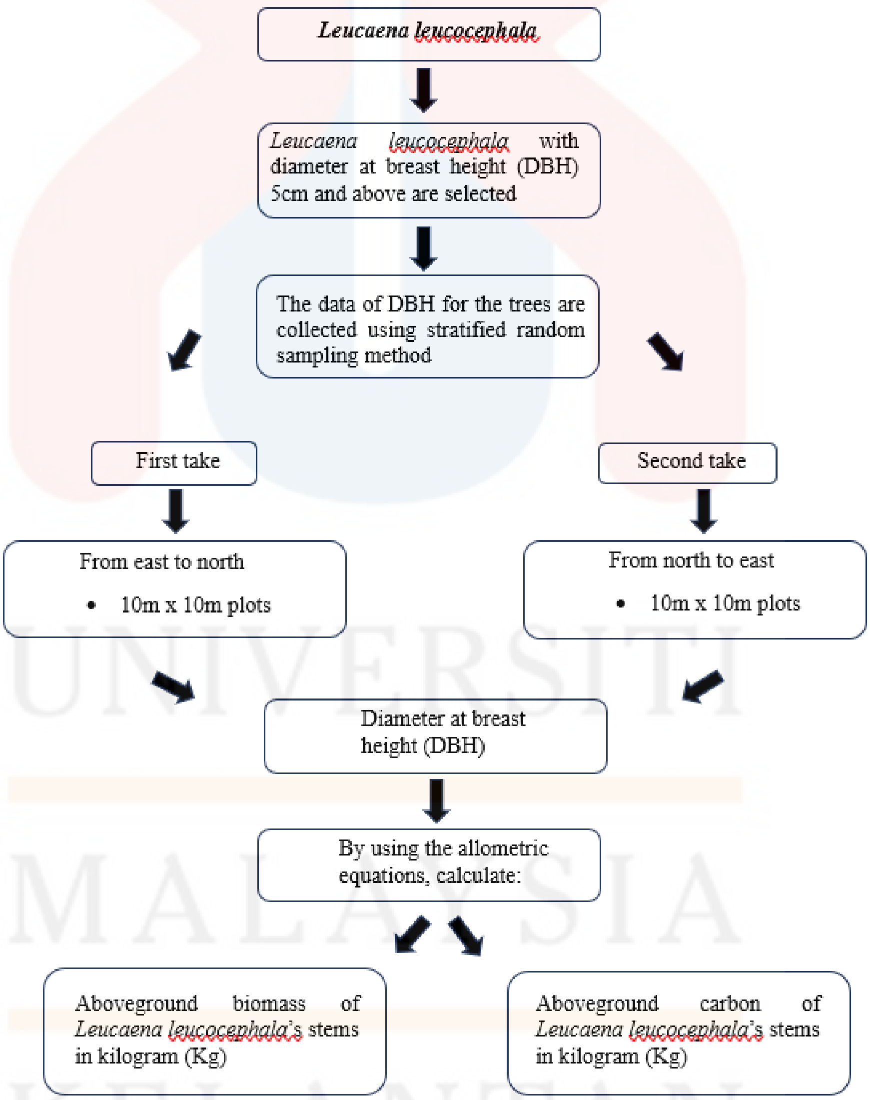

Figure 3.3: *Leucaena leucocephala*'s flowchart to estimate aboveground biomass and carbon stock at Bandar Jeli

3.3.1 Sampling Data Size

According to Table 2.3 in Chapter 2, there is no specific or guideline for study size proportion per overall study size. Based on the availability of *Leucaena leucocephala* trees at the sampling site, Bandar Jeli, the sampling data size collected for the study area was 1.31% (0.4 $km^{2)}$ with four plots of 10m x 10m were plotted at Bandar Jeli. The plot size was chosen from plot size given from Jemali and Majid (2023) in *Teknik Kerja Lapangan dalam Sains Sumber Asli* based on the tree DBH (Chapter 2, Section 2.6, Table 2.4) as shown in Figure 3.4.

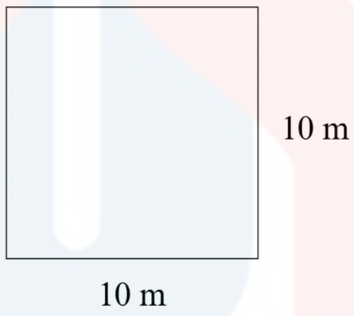

Figure 3.4: Plot size for data collection

3.3.2 Aboveground Biomass

From Table 2.1 in Chapter 2, the most suitable allometric model to use in order to estimate the aboveground biomass of *Leucaena leucocephala* from Fabaceae family is the one from Kato et al. (1978), modified by Kueh and Lim. (1999). The reason of why this allometric question is the most suitable one is because Kueh and Lim estimate the aboveground biomass of trees at lowland tropical forest with diameter at breast height (DBH) were ≥ 5 cm. The dominant DBH data range for their paper were trees with DBH below than 15 cm. On the other hand, there was a Fabaceae family tree was estimated its aboveground biomass using this equation. So, this equation was chosen to estimate aboveground biomass in kilogram (Kg) of *Leucaena leucocephala* at this study area too as shown by Equation 3.1.

$$y = 0.2544xD^{2.368} \quad \textbf{(3.1)}$$

Where,

Y is aboveground biomass in Kg

D is diameter at breast height cm

The equation's values of 2.368 and 0.2544 were selected because they best suit the data gathered from measuring the biomass and diameters of the trees. These values were determined mathematically by the researchers (Kueh and Lim, 1999), which improved the accuracy of the equation used to forecast tree biomass based on diameter. These parameters ensure that the forecasts are as near to reality as feasible for the particular trees that were analysed.

From the aboveground biomass result got from using Kueh and Lim (1999) allometric equation (Equation 3.1), the aboveground biomass in Kg is converted to megagram (Mg) per hectare.

3.3.3 Carbon stock

According to Section 2.7 in Chapter 2, the formula for determining the carbon stock on the stem was to multiply the aboveground biomass by 0.47, as indicated by IPCC (2006). Because most previous studies agreed that determining the carbon stock contain of the tree was by assuming that they hold at 47 to 50% of the total aboveground biomass.

3.3.4 Data Analysis

The primary findings from the assessment of aboveground biomass and carbon stocks of *Leucaena leucocephala* across the 304.36 km^2 study area were presented using bar graphs for the mean for diameter at breast height (DBH), aboveground biomass, and carbon stock. Following field sampling and analysis, one way Analysis on Variance (ANOVA) to show the data for aboveground biomass and carbon stock of the chosen species, *Leucaena leucocephala* were significant or insignificant.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Descriptive Analysis on Diameter at Breast Height (DBH) of *Leucaena leucocephala*

The class and mean for diameter at breast height data is presented in bar graphs to illustrate it in a better way as they shown in Figure 4.1.

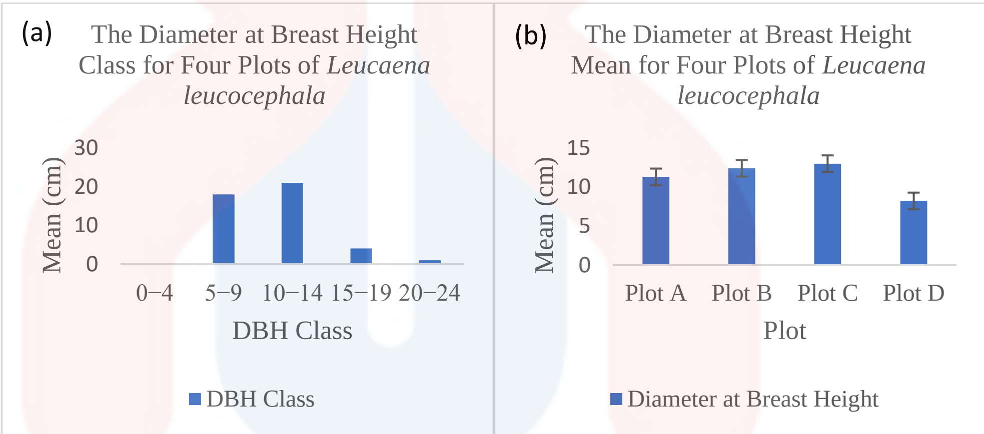

Figure 4.1: (a) The mean of diameter at breast height of *Leucaena leucocephala* and (b) The class for diameter at breast height of *Leucaena leucocephala*

In a tropical humid rainforest at Bandar Jeli, Kelantan, Malaysia, four plots (A, B, C, and D) of *Leucaena leucocephala* are shown in a bar chart (Figure 4.1) that represents the species' class and mean for diameter at breast height (DBH). Figure 4.1(a) Shown there is no DBH class for lower than 4 cm and the highest DBH class are from 10 cm to 14 cm. On the other hand, DBH class 5 cm to 9 cm are many too (18 trees) to be compared with DBH at 20 cm to 24 cm DBH class (1 tree).

For Figure 4.1(b), the mean DBH of plot A is 11.31 cm with the highest DBH is 21.4 cm and the lowest one is 5.4 cm. The highest mean for DBH among the plots is plot C (13 cm) with the highest DBH, 18.1 cm and the lowest one is 10.4. Then, followed by plot B, 13 cm as mean for its DBH with 16.2 cm for the maximum DBH of *Leucaena leucocephala* and 8.2 is the minimum one. Plot D has the least DBH mean (8.23 cm) with the least minimum (6.1 cm) and maximum (11.7 cm) DBH range. This makes the minimum mean DBH for this study is 8.23 cm and the maximum mean DBH for this study is 13 cm. The DBH mean for these four plots is 10.94 cm.

4.2 Aboveground Biomass and Carbon Stock of *Leucaena leucocephala*

From diameter at breast height (DBH) in Figure 4.1, an allometric equation has been used (Equation 3.1) from Kueh and Lim (1999) to determine *Leucaena leucocephala* aboveground biomass at Bandar Jeli, Jeli, Kelantan and the result is shown in Figure 4.2. Then, by using formula made by IPCC 2016, they stated that carbon stock is 47% from aboveground biomass. The carbon stock amount for the four plots in study area is shown in Figure 4.3 below.

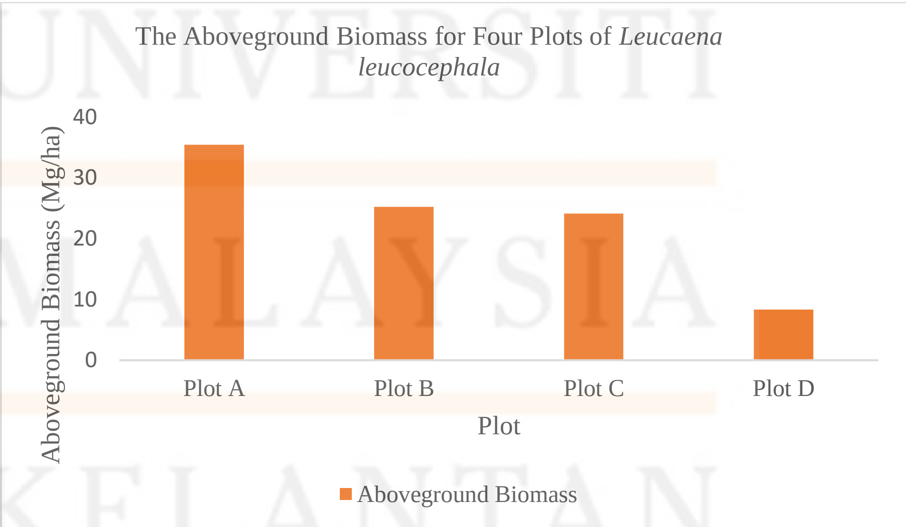

Figure 4.2: The aboveground biomass of *Leucaena leucocephala*

Figure 4.2 shown the aboveground biomass determination for *Leucaena leucocephala* from four different plots located at Bandar Jeli, Jeli, Kelantan. The total aboveground biomass for these four plots is 93.08 Mg/ha. Plot A collected the highest aboveground biomass of *Leucaena leucocephala* species (35.43 Mg/ha), followed by plot B (25.19 Mg/ha). Plot C has slightly less amount of aboveground biomass (24.13 Mg/ha) to be compared with plot B and overall, plot D has the least amount of aboveground biomass, 8.33 Mg/ha.

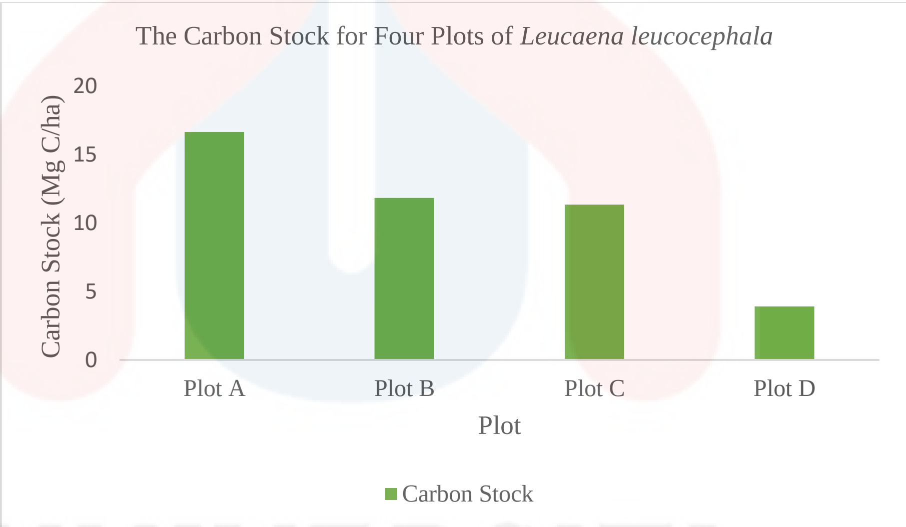

Figure 4.3: The carbon stock of *Leucaena leucocephala*

On the other hand, 47% from aboveground biomass in the carbon stock amount (IPCC 2016) so the Figure 4.3 shown the carbon stock estimation from the four plots. The highest amount carbon stock is held by plot A, 16.65 Mg c/ha and the lowest one is held by plot D, 3.91 Mg C/ha. Plot B and plot C has a very light difference for their carbon stock which is only 0.50 Mg C. Carbon stock of *Leucaena leucocephala* species for plot B is 11.84 Mg/ha and plot C, 11.34 Mg C/ha. The total for carbon stock of *Leucaena leucocephala* at study area is 43.75 Mg C/ha.

4.3 Comparison of Aboveground Biomass, and Carbon Stock of *Leucaena leucocephala*

The comparison between the plots for aboveground biomass and carbon stock were displayed using Analysis on Variance (ANOVA) and Tukey-test.

4.3.1 Analysis on Varian (ANOVA)

One way ANOVA has been used to get the data for Sum of Square, Degree of Freedom, Freedom, Mean Sum of Square, and P-value as shown at Table 4.1.

Table 4.1: Analysis on Varian (ANOVA) for diameter at breast height (DBH), aboveground biomass, and carbon stock of *Leucaena leucocephala*

Source	Sum of Square	Degree of Freedom	F-value	Mean Sum of Square (MS)	P-value
Aboveground Biomass	17.56028	3	2.336	5.853427	0.090^{ns}
Carbon Stock	3.879066	3	2.336	1.293022	0.090^{ns}

^{ns} Not significant at P-value ≤ 0.05

The four plots in the tropical humid rainforest in Bandar Jeli, Kelantan, Malaysia, exhibit not significant in aboveground biomass and carbon stock according to the ANOVA results for the *Leucaena leucocephala* tree species. The biomass above ground displayed not significant in biomass among the plots, with a sum of squares of 17.56028, a mean sum of squares of 5.853427, and a P-value of 0.090. for Carbon stock, with a total of squares of 3.879066, a mean sum of squares of 1.293022, and a P-value of 0.090, the carbon stock likewise showed not significant result as well.

4.3 Comparison of Aboveground Biomass and Carbon Stock of *Leucaena leucocephala* with other Invasive Species Growth at Malaysia

Based on the previous studies from the past researchers, Table 4.3 shown the comparison the aboveground biomass and carbon stock of *Leucaena leucocephala* with other species growth at Malaysia, especially the one under Fabaceae family too, as *Leucaena leucocephala* species since there is no study on estimating aboveground biomass and carbon stock of *Leucaena leucocephala* at Malaysia yet.

Table 4.2: The comparison between *Leucaena leucocephala* with other invasive species found at Malaysia based on their aboveground biomass and carbon stock

Researchers	Tree type	Mean DBH (cm)	Aboveground Biomass (Mg/ha)	Carbon Stock (Mg C/ha)
This study	*Leucaena leucocephala*	10.94	93.08 Mg/ha	43.75 Mg C/ha
Adam and Jusoh, 2015	*Acacia mangium* (hybrid)	12.8 – 40.9	113.3 Mg/ha	53.3 Mg C/ha
	Acacia mangium (2nd gen)	11.6 – 41.5	178.9 Mg/ha	84.1 Mg C/ha
Lee, et al., 2015	*Acacia mangium* (1 year old)	8.84	19.76 Mg/ha	9.37 Mg C/ha
	Acacia mangium (3 years old)	15.10	66.68 Mg/ha	39.26 Mg C/ha
	Acacia mangium (5 years old)	18.39	139.99 Mg/ha	66.36 Mg C/ha

From Table 4.3, the total of aboveground biomass and carbon stock from those two past studies were greatly higher than *Leucaena leucocephala* founding at Bandar Jeli, Kelantan. Based on Section 2.8 in Chapter 2, the differences of the results for *Leucaena leucocephala*'s aboveground biomass and carbon stock shown a highly insignificant is due to the sampling plot size.

Leucaena leucocephala at Bandar Jeli plots size were of 10 m x 10 m only meanwhile the one from Adam and Jusoh plot sizes were 30 m x 30 m and for Lee et al. (2015), 20 m x 20 m. The amount of aboveground biomass they got, 178.9 Mg/ha and 139.99 Mg/ha shows that the amount of aboveground biomass this tree species hold is higher than *Leucaena leucocephala* (93.08 Mg/ha).

The same happened to carbon stock, 30.8 Mg C/ha and 66.36 Mg C/ha, meanwhile *Leucaena leucocephala* from this study only stock 43.75 Mg C/ha. Mean for diameter at breast height (DBH) for these two studies also bigger than *Leucaena leucocephala* data from Bandar Jeli (10.94 cm) urban rainforest (Adam and Jusoh, 2018 – 22 cm to 23.4 cm meanwhile Lee et al., 2015 – 8.84 cm to 18.39 cm).

To sum up, the plot size, number of plots, DBH mean, are some of influences which can influence the amount of aboveground biomass and carbon stock for tree species but the main influence is tree DBH.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Based on the objectives, the aboveground biomass of *Leucaena leucocephala* hold by four plots at Bandar Jeli are around 93.08 Mg/ha meanwhile for carbon stock are around 43.75 Mg C/ha for all plots. This makes an individual *Leucaena leucocephala* stem holds around 2.11 Mg/ha aboveground biomass and 0.99 Mg C/ha for carbon stock. The main factor influencing the aboveground biomass and carbon stock for this tree species is their diameter at breast height (DBH), this species limitation at study site, and plot size.

5.2 Recommendation

From this study, the recommendations for the next studies in order to improve the technique for estimating aboveground biomass and carbon stock of other species, including *Leucaena leucocephala* itself, the next researchers should increase the number of plots in the study area to gain more accuracy in data collection which can lead to a better result. On the other hand, there might be another allometric model which is more suitable to use in estimating aboveground biomass of *Leucaena leucocephala* species should be discovered by the next studies. Then, the next researcher can also create an allometric equation specifically for *Leucaena leucocephala* species besides choosing the other study site with higher numbers of this tree species.

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APPENDIX A

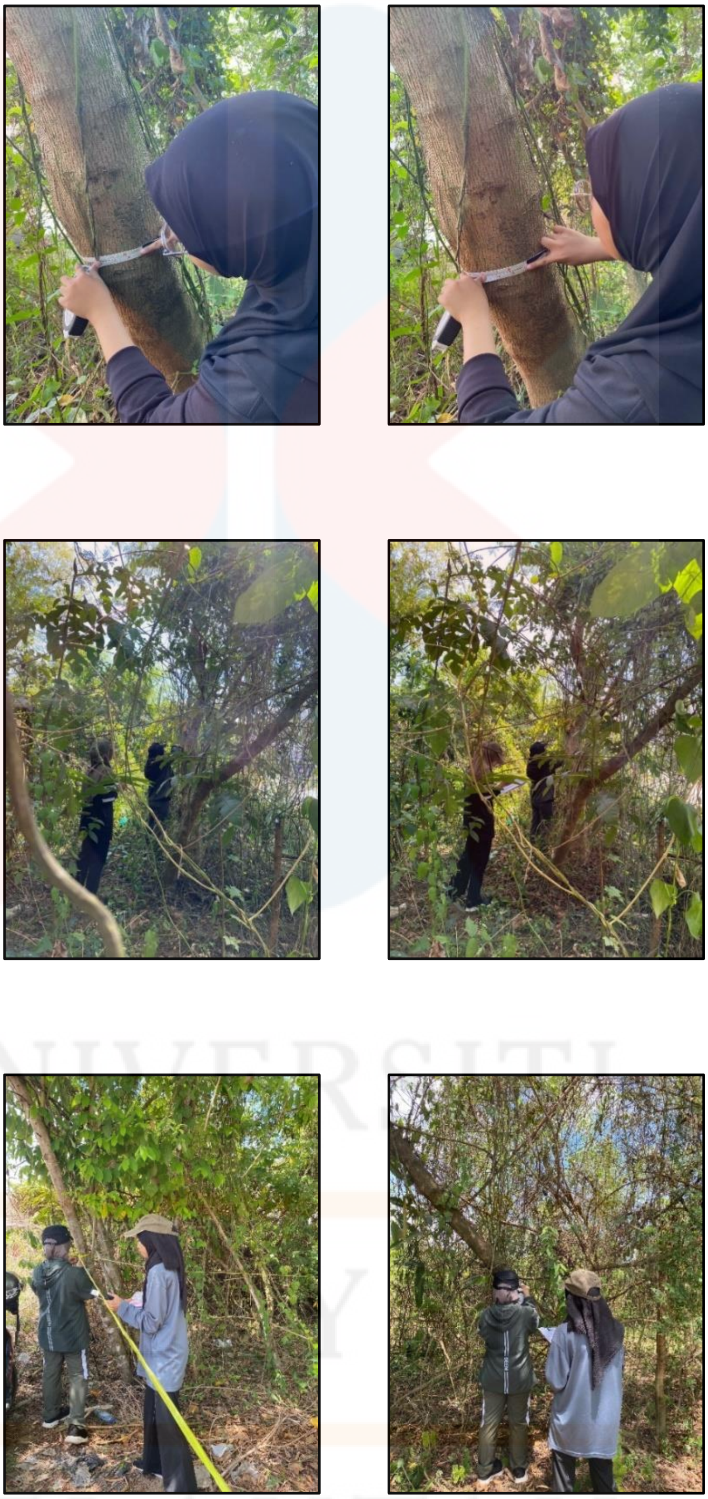

Figure A.1: The view of study site for data collection

APPENDIX B

Table B.1: The coordinate for four plots of *Leucaena lucocephala*

Plot	Coordinate
A	5°41'27"N 101°50'52"E
B	5°41'28"N 101°50'53"E
C	5°41'25"N 101°50'51"E
D	5°41'32"N 101°50'53"E

APPENDIX C

Table C.1: The raw data collection of four plots for *Leucaena leucocephala*

Plot	DBH (cm)	AGB (Kg)	AGB (Mg)	AGB (Mg/ha)	CS (Mg C/ha)
A	5.4	13.808	0.014	0.345	0.162
	7	25.530	0.026	0.638	0.300
	7.5	30.062	0.030	0.752	0.353
	8.2	37.136	0.037	0.928	0.436
	8.3	38.217	0.038	0.955	0.449
	9	46.296	0.046	1.157	0.544
	9.5	52.621	0.053	1.316	0.618
	9.6	53.942	0.054	1.349	0.634
	10.3	63.727	0.064	1.593	0.749
	10.4	65.202	0.065	1.630	0.766
	12.1	93.322	0.093	2.333	1.097
	13.2	114.679	0.115	2.867	1.347
	13.6	123.081	0.123	3.077	1.446
	14.1	134.069	0.134	3.352	1.575
	15.4	165.212	0.165	4.130	1.941
	21.4	360.138	0.360	9.003	4.232
Subtotal		**1417.040**	**3.72**	**93.076**	**43.746**
B	10.4	65.202	0.065	1.630	0.766
	10.4	65.201	0.065	1.630	0.766
	10.5	66.696	0.067	1.667	0.784
	10.6	68.211	0.068	1.705	0.801
	11.3	79.365	0.079	1.984	0.933
	11.6	84.446	0.084	2.111	0.992
	12.6	102.715	0.103	2.568	1.207
	13	110.606	0.111	2.765	1.300
	13.6	123.081	0.123	3.077	1.446
	18.1	242.216	0.242	6.055	2.846
Subtotal		**1007.74**	**1.008**	**25.193**	**11.841**
C	8.2	37.136	0.037	0.928	0.436
	9.1	47.524	0.048	1.188	0.558
	10.2	62.271	0.062	1.557	0.732
	12.4	98.896	0.099	2.472	1.162
	12.8	106.619	0.107	2.665	1.253
	13.5	120.948	0.121	3.024	1.421
	14.8	150.371	0.150	3.759	1.767
	15	155.229	0.155	3.881	1.824
	16.2	186.266	0.186	4.657	2.189
Subtotal		**965.259**	**0.966**	**24.131**	**11.342**
D	6.1	18.429	0.018	0.461	0.217
	6.4	20.648	0.021	0.516	0.243
	7.4	29.121	0.029	0.728	0.342
	7.5	30.062	0.030	0.752	0.353
	8.1	36.072	0.036	0.902	0.424
	8.1	36.072	0.036	0.902	0.424
	8.3	38.217	0.038	0.955	0.449
	8.3	38.217	0.038	0.955	0.449
	11.7	86.180	0.086	2.155	1.013
Subtotal		**333.019**	**0.333**	**8.325**	**3.913**
Total		**3723.060**	**3.723**	**93.076**	**43.746**

APPENDIX D

Table D.1: The raw data for ANOVA aboveground biomass and carbon stock

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
0.34519	15	35.08083	2.338722	4.519496
1.630042	9	23.56345	2.618161	1.92776
0.928397	8	23.20307	2.900383	1.396283
0.460715	8	7.864753	0.983094	0.246233

ANOVA

Source of Varia	SS	df	MS	F	P-value	F crit
Between G	17.56028	3	5.853427	2.33637	0.090028	2.866266
Within Grc	90.19264	36	2.505351			
Total	107.7529	39				

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
0.162239	15	16.48799	1.099199	0.998357
0.76612	9	11.07482	1.230536	0.425842
0.436347	8	10.90544	1.36318	0.308439
0.216536	8	3.696434	0.462054	0.054393

ANOVA

Source of Varia	SS	df	MS	F	P-value	F crit
Between G	3.879066	3	1.293022	2.33637	0.090028	2.866266
Within Grc	19.92355	36	0.553432			
Total	23.80262	39				

APPENDIX E

General allometric equation

$$Y = a\ xD^{b}$$

Kueh and Lim (1999)

$$y = 0.2544xD^{2.368}$$

H.1: Hypothetical Dataset

y is biomass in Kg, a is interception, D is diameter at breast height, b power

H.2: Logarithmic Transformation

In order to get the allometric equation created by Kueh and Lim (1999), allometric equation is being converted to its linear form using logarithms,

$$\log(y) = \log(a) + \log(x) + b \cdot \log(D)$$

Where,

slope b is exponent

$\log(a)$ is intercept for log b

$\log(y)$, $\log(x)$, and $\log(D)$ are the sums

The logarithm is applied,

y	x	D	$\log(y)$	$\log(x)$	$\log(D)$
10	1	2	1.0000	0.0000	0.3010
22	2	4	1.3424	0.3010	0.6021
60	3	6	1.7782	0.4771	0.7782

Sum is calculated,

$\sum \log(y)$	4.1206
$\sum \log(x)$	0.7781
$\sum \log(D)$	1.6813
$\sum (\log(y) \cdot \log(D))$	2.1450
$\sum (\log(y) \cdot \log(x))$	1.1196
$\sum (\log(D))^2$	0.5916
$\sum (\log(x))^2$	0.3090
N	3

H.3: Perform Linear Regression

Slop b:

$$b = \frac{N \sum(\log(D) \cdot \log(y)) - \sum\log(D)\sum\log(y)}{N\sum(\log(D))^2 - (\sum(log(D))^2}$$

In formula

$$b = \frac{3 \ x \ 2.1450 - 1.6813 \ x \ 4.1206}{3 \ x \ 0.5916 - (1.6813)^2}$$

$$b = \frac{-0.4931}{-1.0515} \approx 0.469$$

H.4 Calculate the Intercept

C_0:

$$C_0 = \frac{\sum\log(y) \ - b\sum\log(D)}{N}$$

$$C_0 = \frac{4.1206 - 0.469 \ x \ 1.6813}{3}$$

$$C_0 = \frac{3.3323}{3} \approx 1.111$$

H.5: Insert to Original Question

Coefficient a:

$$a = 10^{C_0} = 10^{1.111} \approx 13$$

Final equation:

$$a = 0.2544 \text{ and } b = 2.368$$

So,

$$y = 0.2544xD^{2.368}$$