CARBON STOCK IN PULAU PINTU GEDONG MANGROVE FOREST, MALAYSIA

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FACULTY OF SCIENCE
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CARBON STOCK IN PULAU PINTU GEDONG MANGROVE FOREST, MALAYSIA

ABSTRACT

Mangrove forests are regarded as the most significant carbon (C) sink in the tropics. They could play an important role in tackling climate change mitigation by reducing deforestation in the environmental, social, and economic sphere. The aims of the present study were to assess the species composition, phytosociological conditions and the ecosystem carbon stock in the tidal gradient of mangrove forest in Pulau Pintu Gedong in the west coast of Peninsular Malaysia. Blue Carbon stock was quantified in soil, downed wood and trees, saplings and seedlings components. The mean ecosystem carbon stock was about 783.58 ± 135.93 Mg /ha at two stations (one is fringe mangrove, and another is interior mangrove). Soil organic carbon stock contributed the largest share with a mean value of 636.55±87.36 Mg/ha. Approximately 632349.06 Mg C were estimated for the study site covering total of 807 ha of mangrove forest area. The prospective carbon pool from two stations of mangrove range from 3228.50 to 2522.98 Mg of CO_2e/ha which is vulnerable to any kind of land conversion factor. Based on Multilateral Development Bank, the estimated price of carbon was made, and it was estimated with a range of 69.62 million – 109.07 million US$ in whole Pulau Pintu Gedong Island. This research shows that Pulau Pintu Gedong mangrove forest stores significant quantity of Carbon and therefore must be preserved and ensured sustainable management to maintain or increase the storage of carbon.

Key words: Mangroves, carbon, ecosystem, soil carbon, forest biomass.

CARBON STOCK IN PULAU PINTU GEDONG MANGROVE FOREST, MALAYSIA

ABSTRAK

Ekosistem bakau boleh memainkan peranan penting dalam mitigasi perubahan iklim dengan mengurangkan penebangan hutan di lingkungan alam sekitar, sosial dan ekonomi. Tujuan kajian ini adalah untuk menganggarkan biomjisim, parameter fitososiologi dan stok karbon ekosistem (biojisim dan tanah) di dua kecerunan air pasang surut di hutan bakau di Pulau Pintu Gedong Semenanjung Malaysia. Penyimpanan karbon ekosistem meningkat dari zon intertidal yang rendah ke kawasan intertidal yang tinggi. Ekosistem stok karbon telah diukur termasuk tanah, kayu dan pokok, anak pokok dan poko mati. Secara purata, kira-kira 783.58 ± 135.93 Mg / ha dianggarkan di Pulau Pintu Gedong. Karbon organik tanah kebanyakannya menguasai jumlah stok di tapak kajian kami dengan purata 636.55 ± 87.36 Mg / ha. Kira-kira 632349.06 Mg C dianggarkan bagi kawasan kajian yang seluas 807 hektar. Nilai pasaran semasa bagi jumlah C yang dianggarkan ialah USD 69.62 juta - 109.07 juta. Unjuran takungan karbon dioksida dari hutan bakau berkisar dari 3228.50 to 2522.98 mg CO_2e / ha yang terdedah kepada sebarang faktor penukaran tanah. Kajian ini menunjukkan bahawa hutan bakau Pulau Pintu Gedong menyimpan banyak kuantiti karbon atmosfera dan oleh itu perlu dipelihara dan memastikan pengurusan yang mampan untuk meningkatkan penyimpanan karbon.

Kata kunci: Bakau, karbon, ekosistem, karbon tanah, biomas hutan.

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C	Carbon
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
CH_4	Methane
DBH	Diameter at breast height
ETS	Emissions Trading Scheme
GHG	Green House Gas
MDB	Multilateral Development Bank
Mg C	Mega Gram Carbon
NPP	Net Primary Production
NTFP	Non-Timber Forest Products
SOC	Soil Organic Carbon
TOC	Total Organic Carbon
IVI	Important Value Index

CHAPTER 1: INTRODUCTION

1.2 Introduction

Mangroves are composed of halophytic trees and shrub species that grow between the lowest and the highest tide level and adapted to life in harsh coastal conditions. They have a complex salt filtration system and complex root system to cope with salt-water immersion and wave action (Wah et al., 2011). They are also adapted to the anoxic (low oxygen) conditions of waterlogged mud. In addition, Mangroves are totally different from upland forests in terms of physical structure, composition, and environment.

At present, the world faces significant difficulties due to increase in atmospheric CO_2 that is causing global warming. Global warming is mainly owing to greenhouse gas (primarily, CO_2) emissions from man-made sources (IPCC, 2013). There is a wide range of possibly promising CO_2 sources that can be divided into CO_2 point sources and atmospheric CO_2 (von der Assen et al., 2013). Point sources are stationary manufacturing processes that produce CO_2 through fermentation, calcination and, most notably, carbon fuel combustion. Approximately 78 percent of CO_2 are emitted from fossil fuel energy plants (von der Assen et al., 2016). It has been assumed that CO_2 will range from 467 to 555 ppm and the average global temperature will rise from 2 to 42ºC by 2050 (Anderson & Bows, 2011; IPCC, 2013). This could contribute extreme changes in climate and weather, worldwide. Sea level rise is also a major issue because of increased temperature which results in melting of glacier and polar land ice (Barua et al., 2010).

In this case, forests can play a significant role in alleviating worldwide climate change through atmospheric carbon sequestration (Adame et al., 2013). Mangroves have the ability to absorb up to four times more carbon dioxide by unit area than upland terrestrial forests (Donato et al., 2011). They also store largest amount of soil carbon which is two to three times more than aboveground carbon (Alongi, 2012; Donato et al., 2011; Khan et al., 2007). Moreover, mangrove forest has incredible biological diversity that leads a vital role in transferring organic matter and energy from land to its adjacent marine ecosystems (Khan et al., 2007). The source of energy and organic matter originates from detritus of litter fall, branches etc. The content of organic carbon depends on the density of the mangroves because higher content of organic carbon is directly related with higher litter production (Kaseng et al., 2018). As Mangroves lies in the coastal intertidal zone, it acts as a nutrient filter between land and sea (Bouillon et al., 2008).

Mangroves, the swamp forests are being widely utilized for ecological and socio-economic purposes. After occurring Indian Ocean tsunami in December 2004 and Hurricane Katrina in 2005, the world got a new understanding and appreciation of the importance of mangroves. This ecosystem stabilizes coastlines, protect communities from storms, stabilize bottom sediments, provide critical habitats for many animals, and most importantly store vast amounts of carbon. In many coastal areas, communities are still critically dependent on the ecosystem services that mangroves provide.

At present Malaysia has total 630,000 ha of mangrove forests (Omar et al., 2018). Between 1990 and 2017, the level of deforestation of mangroves was about 0.1 percent per year. Among the total area, 61% found in Sabah, 22% in Sarawak and 17% in Peninsular Malaysia (Omar et al., 2018). Of this total land of peninsular Malaysia, only 83.2% is Permanent Forest Reserve (PFE) whereas 16.85% is declared as State land Mangroves (Abd Shukor et al., 2004). However, most of the modifications took place primarily outside the Permanent Forest Reserve and in accordance with the structural planning of the States. The most prominent causes of mangrove deforestation were the expansion of agricultural land for plantations and aquaculture sectors. Other conversions engaged development of settlement and industrial fields, while minor causes are discovered to be factors such as local mangrove consumption for fuelwoods and coastal erosion (Omar et al., 2018).

The Klang Islands mangroves covered around 15,064 ha in 2018 (Varga et al., 2019). The Klang Islands contain eight large mangrove islands (locally known as pulau) (Hattam et al., 2020). There are three inhabited islands (Pulau Carey, Pulau Indah and Pulau Ketam) and five uninhabited Islands (Pulau Klang, Pulau Pintu Gedong, Pulau Che Mat Zin, Pulau Selat Kering and Pulau Tengah which have been identified as the Klang Islands Mangrove Forest Reserve, (Norhayati et al., 2009).

Though mangroves have well known value of ecosystem services yet very few studies have been conducted on mangroves in Klang Island. Some studies have been done on flora and fauna of mangrove of Klang Island (Chong et al, 1990; Norhayati et al., 2009; Sasekumar & Chong, 1998). Study on biodiversity and macro parasitic distribution has been also done. Another study was done on Stand structure and biomass estimation in the Klang Islands (Rozainah et al., 2018). We decided to study on this site because Pulau Pintu Gedong is one of the uninhabited islands in Klang and it is declared as Mangrove Forest Reserve as well. Another reason for the selection of this site is that no study has been conducted on blue carbon stock potential.

1.2.1 General Objectives

This study aims to know the carbon storage capacity of Pulau Pintu Gedong mangrove forest which is an important consideration in global warming maintenance because of their oxidation into gasses and emission into the atmosphere.

1.2.2 Specific Objectives

- To identify phytosociological parameters in Pulau Pintu Gedong mangrove forest.
- To estimate aboveground and belowground carbon stock in Pulau Pintu Gedong mangrove forest.
- To estimate soil carbon content, CO_{2e} and market value of carbon.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Mangroves are classified as assemblages of salt tolerant trees and shrubs that grow on the tropical and subtropical coastlines in the intertidal regions. In areas where freshwater combines with seawater and where sediment consists of accumulated mud deposits, they grow luxuriously.

Based on geophysical, geomorphological and biological considerations, mangrove wetlands are usually divided into six groups. They are (a) dominated by rivers, (b) dominated by currents, (c) dominated by waves, (d) dominated by composite rivers and waves, (e) mangroves in drowned limestone valleys and (f) mangroves in carbonate environments (Thom, 1984). On coasts dominated by terrigenous sediments (shallow aquatic soil composed of material originating from the ground surface), the first five types of mangrove wetlands can be found, while the last can be seen on oceanic islands, coral reefs and carbonate banks.

2.2 Mangrove distribution in Malaysia

It was estimated earlier that about 580,000 ha mangrove forest lied in Malaysia (Chan, 1987). But only 105,537 ha is situated in Peninsular Malaysia (Latiff & Faridah-Hanum, 2014). The total extent of mangrove distribution in Malaysia was presented in the following Table 2.1. It has been noticed that Sabah has the largest area in terms of forest coverage i.e, about 60% of total forest of Malaysia lies in Sabah.

Table 2.1: Mangrove forest reserves (ha) in Malaysia

State	Total area (In ha)	Total area (In Percentage)
Johor	21,180	3.75
Kedah	8,355	1.48
Perlis	Not available	-
Negeri Sembilan	204	0.04
Pahang	3,916	0.69
Perak	40,683	7.21
Pulau Pinang	870	0.15
Selangor	19,503	3.45
Kelantan	Not available	-
Terengganu	1,822	0.32
Melaka	80	0.01
Sub-total	97,517	-
Sabah	340,689	60.34
Sarawak	126,400	22.39
Grand total	564,606	100

*Source:(Latiff & Faridah-Hanum, 2014)

2.2.1 Abundance and composition of mangrove plants

Mangrove is a type of forest which has low floristic composition compared to other type of forest. But mangrove forest is rich in flora and fauna as an ecosystem. However, there are some studies that reported that mangroves in east coast of Peninsular Malaysia differ significantly from the west coast and Sabah and Sarawak in terms of floristic composition, biomass and net productivity. In the east coast of peninsular Malaysia, the distribution of flora is very poor than west coast. This is because in east coast, the mangrove faces large waves due to the exposure of South China Sea (Latiff & Faridah-Hanum, 2014). There are mostly five vegetation types that was suggested by Watson (1928) depending on the dominance of species and its composition which are as follows.

- *Avicennia-Sonneratia* type
- *Bruguiera cylindrica* type
- *Bruguiera parviflora* type
- *Rhizophora* type
- *Bruguiera gymnorhiza* type

The classification given by Watson (1928) is an important aspect to know the changes of mangroves that took place over time that indirectly changed the dominance type. (Wan et al., 2010) demonstrated and represented the whole floral composition of Langkawi Archipelago. Another comprehensive study was done by (Shah et al., 2016) who illustrated the diversity and composition of plants in Sarawak. Nine mangrove plants were found by this study. In this study they also recorded some major species such as *Rhizophora apiculata, Xylocarpus granatum*, and *Nypa fruticans.* (Soepadmo & Zain, 1991) found 32 species of mangrove plants in Selangor where *Avicennia alba, Sonneratia alba, Rhizophora mucronata, Rhizophora apiculata*, *Bruguiera cylindrica* and *Bruguiera parvifolia* were recorded as dominated species.

Hydrological regimes (both freshwater inflows and tides), substratum topography and texture, salinity and their interactions result in very high habitat heterogeneity in mangrove ecosystems, ensuring an equally diverse biodiversity (Gopal & Chauhan, 2006).

2.3 Importance of mangrove

There is no doubt that mangrove has beneficial effects in terms of both ecological and ecosystem aspects. Mangrove forests serve as the basis for the most dynamic marine food chain. Today, one of the most important issues is global warming, and mangroves are the largest C-sequester among other forests (American Geophysical Union). Increasing attempts are being made to more correctly map worldwide carbon stocks and fluxes (Baccini et al., 2012; Saatchi et al., 2011), but these syntheses have mainly ignored mangroves owing to their tiny spatial range and the mapping difficulties they pose.

2.3.1 Ecosystem services

Mangrove has a wide range of ecosystem value and they are divided into direct and indirect value, alternative use value and existence use value. Again, Mangroves offer several ecosystem services that was categorized into four groups by Millennium Ecosystem Assessment 2005. This includes the following-

- Provisioning (e.g., timber, fuel wood, and charcoal)
- Regulating (e.g., carbon sequestration, flood, storm and erosion control; prevention of saltwater intrusion)
- Supporting (e.g., breeding, spawning and nursery habitat for commercial fish species; biodiversity),
- Cultural services (e.g., recreation, aesthetic, ecotourism)

2.3.1.1 Pollution control

Mangrove has the capacity to trap the pollutants by using their unique root system and soil. It can also immobilize nutrients and heavy metals from waste water generated from urban-industrial areas and oil-spill. For instance, waste water from industrial and domestic sources pollute the upstream and it mixed with sea by flowing downstream through mangrove to sea. So, mangroves are considered as a purifier of pollutants (Ambus & Lowrance, 1991; Conley et al., 1991).

2.3.1.2 Coastal erosion

The most important role of mangroves is that the unique root structure of plants protects vulnerable coastlines from wave action because they hold the soil together and prevent coastal erosion. By filtering out sediments, the forests also protect coral reefs and seagrass meadows from being smothered in sediment. In areas where mangroves have been cleared, coastal damage from hurricanes and typhoons is much more severe. It had proven in 2004 when a tsunami struck the coasts of the Langkawi Islands, Kedah and Perak. Othman (1994) also brought out the importance of mangrove in coastal protection as it has the capacity to land-building through accretion.

2.3.1.3 Fisheries

Mangrove forests are home to a large variety of fish, crab, shrimp, and mollusk species. These fisheries form an essential source of food for thousands of coastal communities around the world. The forests also serve as nurseries for many fish species, including coral reef fish. A study on the Mesoamerican reef showed that there are as many as 25 times more fish of some species on reefs close to mangrove areas than in areas where mangroves have been cut down. This makes mangrove forests vitally important to coral reef and commercial fisheries as well (Rath).

2.3.1.4 Livelihood provision

In tropical region, mangrove products are principal resources of earnings for coastal groups. Even though fishing and associated activities are typically the top livelihood alternatives, harvest of mangrove timber and other NTFPs are supplementary resources of profits contributing significantly to the subsistence desires of these groups who lives in coastal areas (FAO, 2003).

2.4 Degradation and loss of mangrove

2.4.1 Commercial purposes

Mangrove timber (particularly *Rhizophora spp.*) is good for charcoal manufacturing because of its high calorific price, heavy weight, dense and hard structure (Aksornkoae,1993). As mangrove plants survive in salt water, they have high decay resistant to salt. For this reason, it has become a preferred material for pilings and fishing structures in coastal regions. However, poor management strategy has frequently led to unsustainability. Surprisingly the Matang Mangrove Forest Reserve in Peninsular Malaysia has been managed to show the good management strategy over 100 years on a 30-year cycle of rotation (Gan, 1995).

2.4.2 Over-exploitation by traditional users

Conventional use has traditionally had little impact upon mangroves because it includes at a low level. However, as populations grow demand for merchandise boom, and this can lead to over-harvesting and a decline in the natural resource and within the absence of sustainable control practices this could lead to the decline in livelihoods of the mangrove-based groups.

2.4.3 Conversion to other land use pattern

There is a huge pressure on food production, due to population growth. For this reason, Mangroves are often transformed for agriculture, aquaculture and salt production. In Philippines, there had been a loss of 73% mangroves between 1918 and 1994 (Primavera, 2000). Out of this, about 70% mangrove was transformed for aquaculture ponds (Primavera, 2000).

Though mangroves are highly beneficial, but it is threatened by human activities. Warren-Rhodes et al. (2011) mentioned the primary cause (i.e., dependency on firewood) of mangrove loss in Solomon Islands. Table 2.3 shows how badly mangrove forest is being degraded by human activities (Alongi, 2002). Warren-Rhodes et al. (2011) suggested the way (i.e., payment for ecosystem services) in which Mangrove forest can be preserved.

Degradation of mangrove forest was an alarming rate in past years and approximately 3.6 million ha of mangrove forest has been lost already (FAO,2008). The soil become bared when the forest is cleared or cut down. The roots of the plant anchor the soil that's why causes widespread erosion when trees are cut down. The disturbance of soil horizon altered the pathway of soil microbial process.

Table 2.2: Human impact on mangrove forest in the world (Alongi, 2002)

Potentially sustainable	**Unsustainable**
➢ Food	➢ Eutrophication
➢ Tannins and resins	➢ Uncontrolled resource exploitation
➢ Medicines and other bioproducts	➢ Disruption of hydrological cycles(damming)
➢ Furniture, fencing, poles (timber)	➢ Release of toxins and pathogens
➢ Artisanal and commercial fishing	➢ Introduction of exotic species
➢ Charcoal	➢ Fouling by litter

- Cage aquaculture	- Build-up of chlorinated and petroleum hydrocarbons
- Ecotourism	- Shoreline erosion/siltation accelerated by deforestation, desertification and other poor land-use practices
- Recreation	- Habitat modification/ destruction/ alteration for coastal development (including pond aquaculture)
- Education	- Global climate change
	- Noise pollution
	- Mine tailings
	- Herbicides and defoliants

2.5 Climate Change and Mangroves

Climate change had already expanded awareness of its potential effects on the coastal region, usually linked with rising sea levels, increase in air and water temperatures, rising atmospheric CO_2, changes in the amount and quality of continental runoff, and changes in the frequency and intensity of extreme weather events (Alongi, 2008). Mangroves are more likely to react to these risks arising from global climate change due to their location at the continent-ocean interface. All of these will change the overall productivity and respiration of mangroves as well as affects the transportation of products to neighboring terrestrial and marine ecosystems (Godoy & Lacerda, 2015).

It is indicated that sea level is very probable to increase in 95% of the world's coastal regions, with modifications ranging from 0.26 m in the more optimistic designs to 0.98m in the most pessimistic predictions (IPCC, 2013). Though sea level risings are the most evident danger to mangroves, the relative mean sea level (the difference between the mean worldwide sea level and the local isostatic shift owing to glacial rebound at that stage in moment and space) will be the main variable causing the particular mangrove reaction for an individual stand (Godoy & Lacerda, 2015; Nicholls & Cazenave, 2010).

All mangroves don’t react negatively to a situation of climate change. Recent studies have shown that mangrove vegetation is expanding its poleward boundaries in many places. Cavanaugh et al. (2014) pointed that mangroves are expanding northward from their initial latitudinal boundary along the east shore of the United States and further suggested that this expansion is associated with the decline in the frequency of discrete cold occurrences(-4ºC) due to latest global warming. The spatial expansion of mangrove forests has increased along this portion of the North American shore, relative to the area recorded in the 1980s. These incidents would freeze and destroy mangrove vegetation that, during the hotter phases of the year, crossed the poleward boundaries. These occurrences, however, are becoming less frequent and can therefore spread beyond their common land.

2.6 Forest and carbon

Forest ecosystems consist of carbon-based life forms in plants and animals in the form of biomass, along with sometimes big quantities of leaf litter and living or dead organic material in the soil. Trees and shrubs make up the bulk of the aboveground and belowground (roots) biomass in a forest, and their biomass varies considerably according to climate and soil, and the frequency and duration of tidal floods with respect to mangrove vegetation. The age of the forests and their component trees is also a consideration. In comparatively young forests, the amount of carbon storage capacity builds over time as trees and forest also develop. Soil carbon stocks also increase with time (Chakravarty, Rai, Pala, & Shukla, 2020).

All biomass carbon is eventually derived from atmospheric carbon dioxide (CO_2) through plant growth. If forest cover is being reduced or cleared by burning or cutting, it will return to the atmosphere in the form of CO_2, or sometimes methane (CH_4) (Wilson, 2010). Therefore, despite a few daily turnovers (productivity), forests are a permanent store of sequestered carbon in the atmosphere. Some products decrease to go back to the air, but other fractions come into or are stored in food chains in the soil. For longer periods of time, soil carbon can be stable. Mangrove ecosystems can promote biomass burial and, owing to limited break down of biomass in moist soils, they can sometimes form peat. When cleaned and dried, soil carbon can oxidize to the atmosphere (Wilson, 2010).

2.6.1 Carbon in mangrove

Alongi (2014) showed a huge difference in global carbon stock in different forest types. Among all the forest ecosystem, mangrove has the largest soil C pool (Figure 1). He also found the reason behind storing and transporting new fixed C. This ability of mangroves to store large amounts of carbon than other tropical forests make them able to show the capacity in carbon mitigation strategies (Kauffman & Donato, 2012).

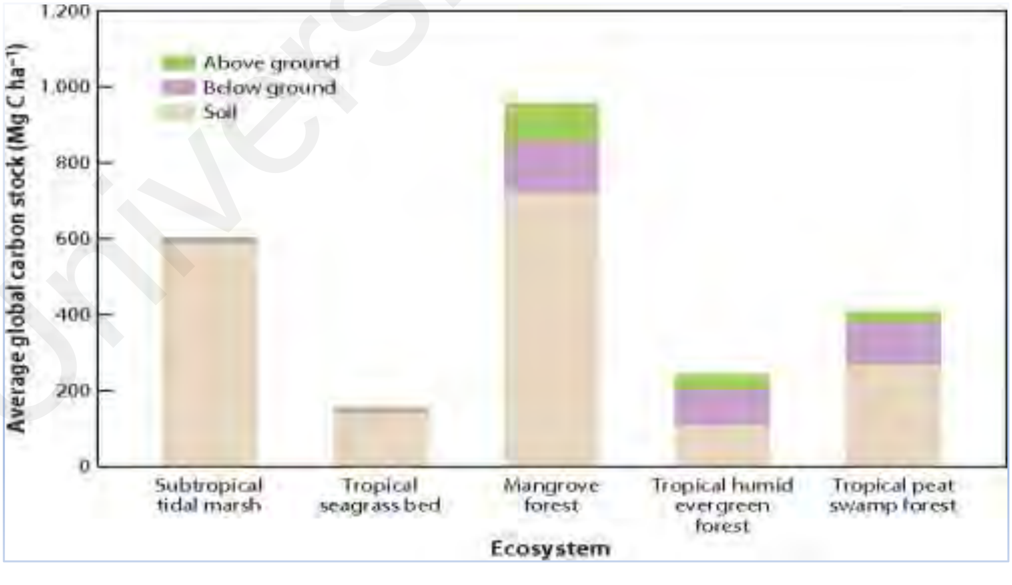


Figure 2.1: Global carbon stock of different forest (Alongi, 2014)

Alongi (2014) pointed out the average ecosystem carbon stock (956 t C ha−1) and Net primary production (11.1 Mg C ha−1 y−1) of mangrove forest. He again found the average carbon sequestration rate and mean burial rate for mangrove soil carbon.

The overall forest carbon stock in the undisturbed Kuala Selangor Nature Park was measured at 246.21 t ha-1 C, which is relatively higher than that in the degrading forest in Sungai Haji Dorani at 151.40 t ha-1 C (Hong et al., 2017).

Adame et al. (2018) mentioned about the recovery rate of C in mangrove forest which may need one decade to sequester. But it takes only one year to lose this stored C into atmosphere after cutting the trees. So, the importance of mangrove forest to conserve also lies here.

The amount of C stored in mangrove forest depends on the age of mangrove forests (Adame et al., 2018; Kaseng, 2018). Adame et al. (2018) showed that the matured forest store more C compared to juvenile forest.

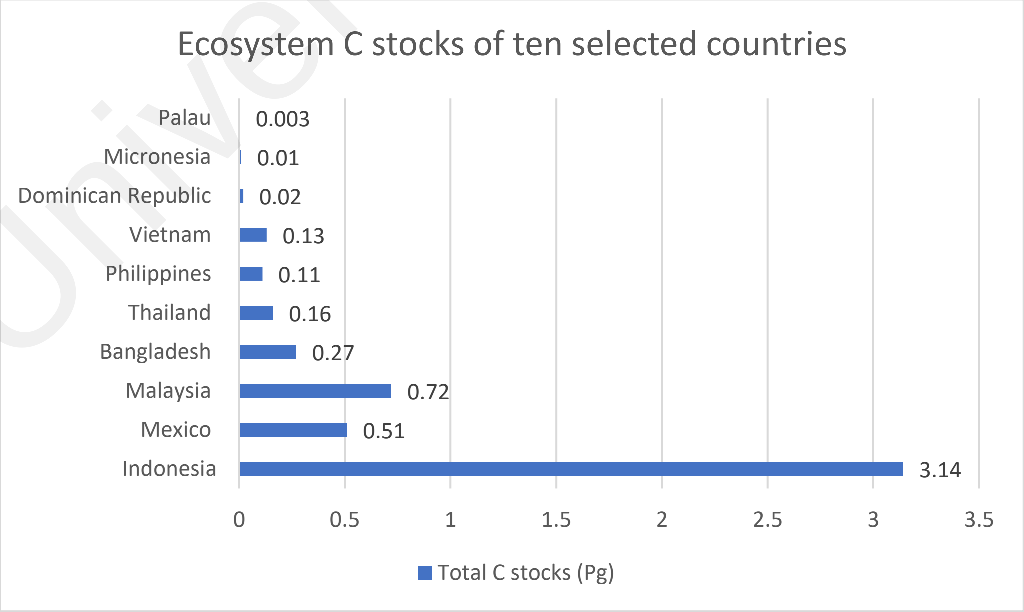


Figure 2.2: Ecosystem C stock of ten selected countries (Murdiyarso et al., 2015)

Donato et al. (2011) found that the most C dense forest in tropics is mangrove and has highest value of mean C storage if compared to other forest reserves of the world. They experimented estuarine and oceanic sites both. Research showed 71-98% belowground soil C storage in oceanic sites and 49-90% in estuarine sites. In this study, they showed that there is a relationship between soil C pool and distance from seaward edge. As the depth of soil increase with the distance from the seaward edge, the C pools of soil also increase for oceanic site.

Research suggested that the depth of soil has influence organic carbon. Guo et al. (2018) experimented that soil mineralization can be recovered with the depth of soil (e.g., more than 60 cm) and the weakest mineralization occurs at 20-60cm depth. But it is different for organic C as it started decreasing in an exponential manner with the depth of soil (Guo et al., 2018).

2.6.2 Carbon-dioxide equivalent (CO_2e)

CO_2e indicates the amount of carbon dioxide (CO_2) that would have the equivalent impact on global warming for any quantity and type of greenhouse gas. Forest deforestation and degradation leads to CO_2 dominated greenhouse gas emissions with the release of additional trace gases like CH_4.Global mangrove mean soil CO_2-C flux accounts for about 20 percent of mangrove net primary production (NPP), according to the carbon budget presented by Bouillon et al. (2008), which indicates that soil CO_2 emissions offset 20 percent of global plant CO_2sequestration .

Chen et al. (2016) studied the warming effect of soil greenhouse gas emissions with the sequestration rate of plant CO_2 from the plant's net primary production in a productive mangrove wetland in South China to assess the role of mangrove wetlands in reducing the effect of atmospheric warming.

Abino et al. (2014) estimated the total amount of carbon sequestered and stored in the biomass of the natural mangrove stand. He estimated that the amount was 188.50-ton C ha^{-1} equivalent to 691.81 $\mathrm{ton\ CO_{2e}\ ha^{-1}}$. This study suggests that natural mangrove forests are capable of sequestration and storage of enormous amounts of atmospheric carbon regardless of the very low species diversity.

2.6.3 Market value of carbon

The phrase ' carbon price ' has now become well recognized as an emerging drive for a pricing of carbon pollution among countries and businesses to reduce emissions and lead to more clean-up investment. A dangerously warm planet is not just a disaster for the environment but also an economic and social challenge. Putting a carbon value or price at its source can tackle climate change.

Carbon pricing has the potential to radically decarbonize global economic activity by changing consumer behavior, business, and investor behavior, while unleashing technological innovation and generating revenue that can be used productively. In short, well-designed carbon prices offer triple benefits: protecting the environment, driving clean technology investments, and raising revenue. Carbon pricing allows companies to manage risks, plan low-carbon investments, and drive innovation.

According to the European Union (EU) Emissions Trading Scheme (ETS), carbon price will increase from US\$ 7/$\mathrm{tCO_2e}$ to US\$ 16/$\mathrm{tCO_2e}$ in the post 2020 era as more $\mathrm{CO_2}$ will surely evolve in the future (Bank, 2018). A significant characteristic of carbon pricing, which distinguishes it from other measures, is that the policy can be intended to ensure that emission objectives are met, such as a trajectory consistent with the goal of the Paris Agreement to maintain consistency of mean global temperature which was predicted to be US\$40/$\mathrm{tCO_2e}$ to US\$80/$\mathrm{tCO_2e}$ in 2020 reported by the World Bank (2018).

Carbon pricing projects around the world would cover about 11 gigatons of carbon dioxide emissions which is equal to around 20% of worldwide fossil fuel emissions (Bank, 2018). Approximately US$ 33 billion was generated in revenue from carbon pricing in 2017, a $11 billion bump from the $22 billion raised in 2016, according to the State and Trends of Carbon Pricing 2018 of the World Bank. The report also finds that carbon prices are rising compared to one-quarter of emissions covered in 2017, with about half of emissions now covered by carbon pricing initiatives priced at over US$ 10/t$\mathrm{CO_{2e}}$.

Despite promising progress, however, carbon pricing still does not cover 80% of emissions. And half of the current $\mathrm{CO_2}$ emissions are priced at less than $10 per ton of $\mathrm{CO_{2e}}$. This is far below the level required to drive transformation change: estimated at $40-80 per ton by 2020 and $50-100 per ton by 2030 according to the High-Level Carbon Price Commission, co-chaired by Joseph Stiglitz and Lord Nicholas Stern and supported by the World Bank (2017).

CHAPTER 3: METHODOLOGY

3.1 Study site

Pulau Pintu Gedong is one of the outlying islands in the Klang River delta in Selangor. As with the neighbouring islands, it is covered with uninhabited and mangrove swamp. The Pulau Pindu Gedong Forest Reserve covers the whole island. The total area of mangrove forest reserves in Pulau Pintu Gedong is about 807 ha (Forest & Malaysia, 2009). Pulau Pintu Gedong and the neighboring Pulau Selat Kering make one big island separated by a channel. The channel is known as Pulau Selat Kering. The study was conducted at the Pulau Pintu Gedong mangrove forest. Field sampling was done at two (2) different location that is shown in Fig.3.1. The first study site was at seashore (N 02.92125, E 101.25869) and second study site was near creek (N 2.929780, E101.250963).

Meteorological data such as temperature, humidity, rainfall data were collected from The Malaysian Meteorological Department (2018). The warmest and wettest month was April while the coolest month was September. But the dried month was June. The Annual average range of precipitation was recorded 2500 mm. Again, the highest humidity (75-85%) was recorded.

Field study was conducted in the month of December 2018 and ten plots were being established. The geographic coordinates and hydro-geomorphic settings of the mangrove forest had been measured. In situ soil properties were also recorded (Table 3.1).

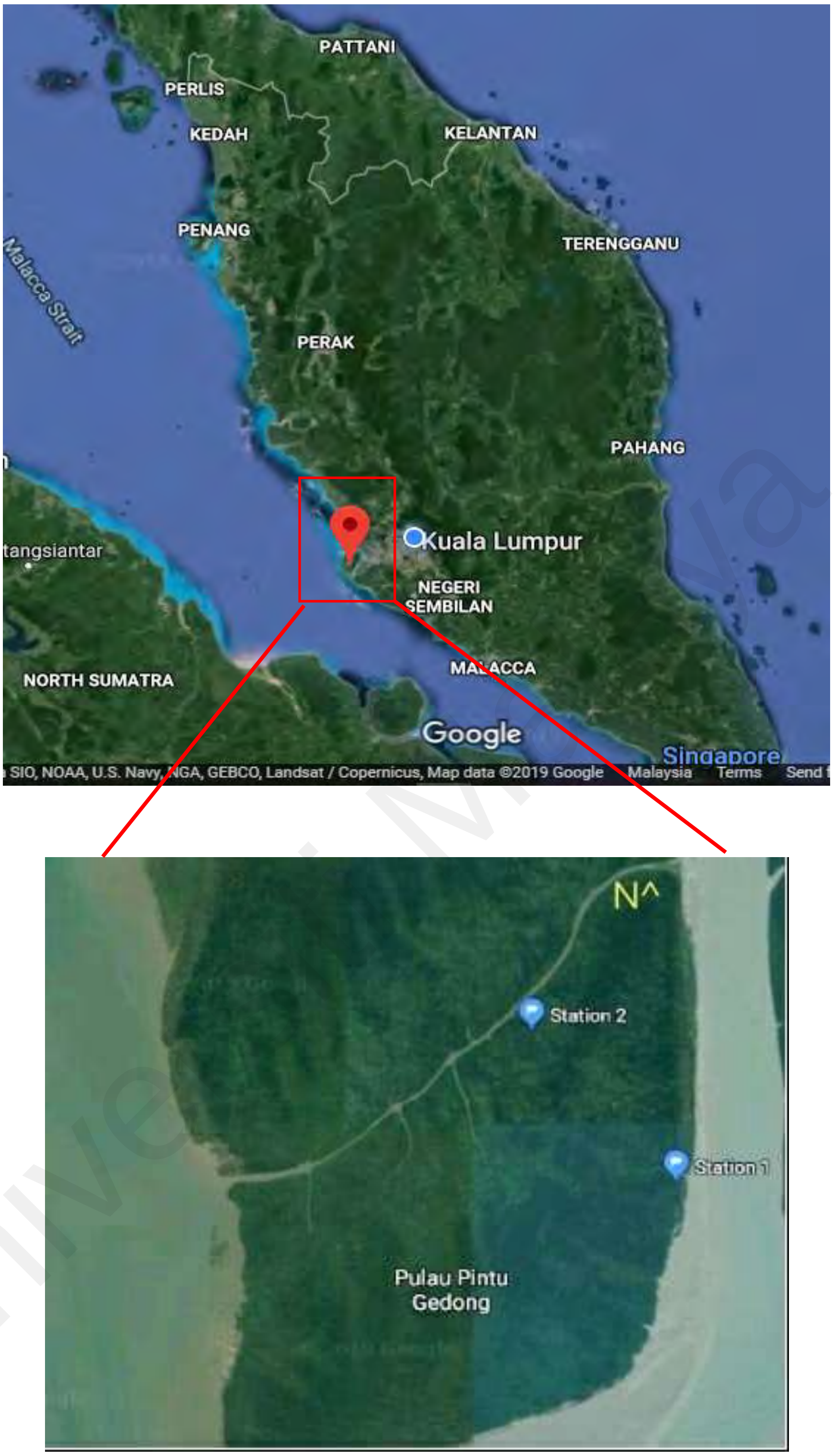


Figure 3.1 Locations of the two selected stations at Pulau Pintu Gedong

Table 3.1: Plot distribution and hydrogeomorphic setting

Site	**Plot ID**	**Hydro-geomorphic setting**
Station 1 N 02.92125 E 101.25869	PP 1	Fringe mangrove
	PP 2	Fringe mangrove
	PP 3	Fringe mangrove
	PP 4	Fringe mangrove
	PP 5	Fringe mangrove
Station 2 N 2.929780 E 101.250963	PG 6	Interior mangrove
	PG 7	Interior mangrove
	PG 8	Interior mangrove
	PG 9	Interior mangrove
	PG 10	Interior mangrove

3.2 Plot establishment

Sampling techniques for our study was based on the protocol that was developed by Kauffman and Donato (2012). To measure aboveground and belowground carbon stock, two (2) transect lines were selected which were arranged perpendicular to the coastline and tidal creek. The location of each transect was determined using GPS (Global Positioning System) navigation device.

Here, total 10 circular plots of 7m radius (0.0154 ha) were taken in 2 transect line where 5 subplots on each transect. Five plots were selected in fringe mangroves and five plots in interior mangrove. Each plot was established at a distance of 25m. The plots were taken in transect line so that it can cover all the variation of mangrove species as much as possible.

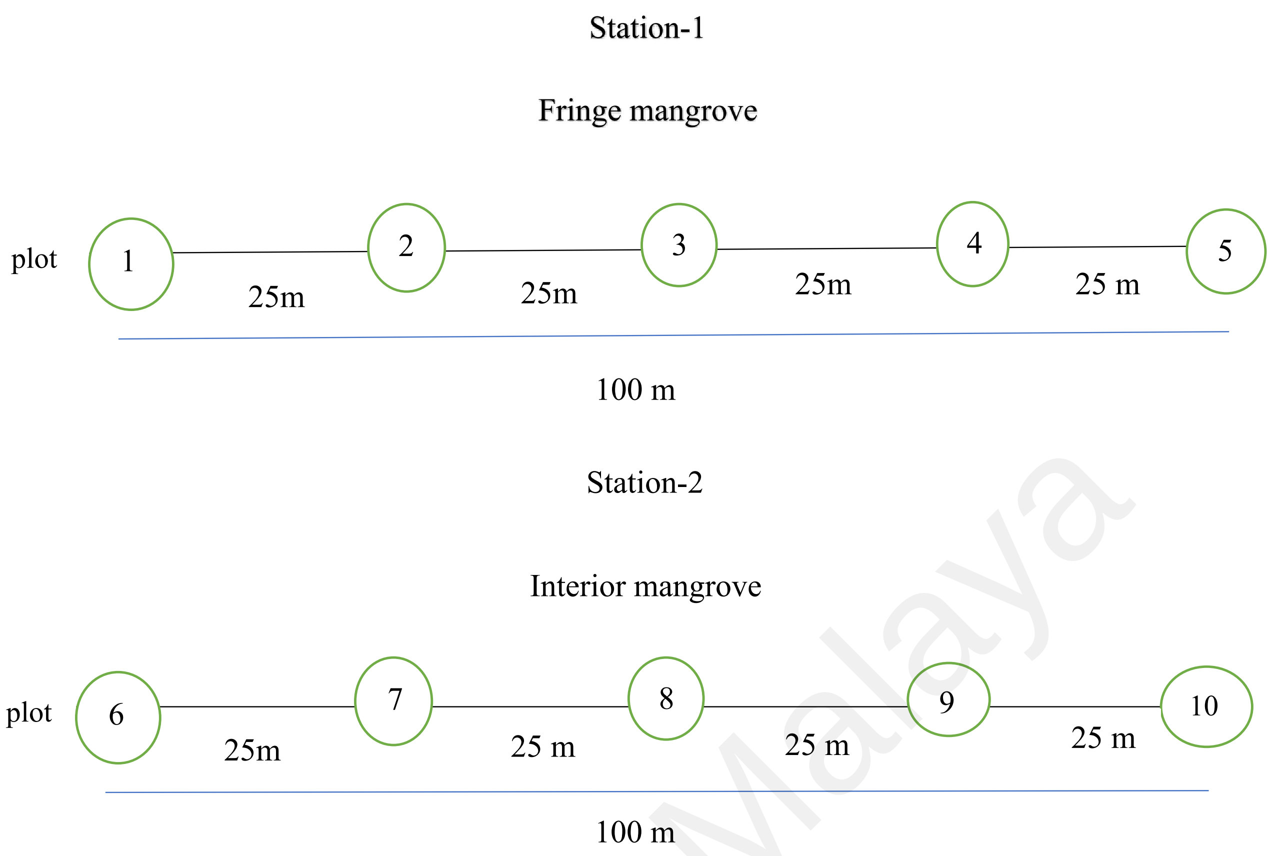


Figure 3.2: Establishment of 10 plots in two sites by following the protocol of Kauffman and Donato (2012)

3.3 Vegetation sampling (live and dead)

The radius of each plot was 7m and a center tree was tagged in each plot. Within this 7m radius plot, all trees with stem diameter > 5cm were identified and measured to determine DBH of the tree. The diameter was measured at 30 cm above the highest still root in case of *Rhizophora spp*. In addition, all trees with DBH<5 cm were being measured within 2 m radius nested subplots. Standing dead trees were categorized and measured into three classes according to their remaining biomass concentration: status 1 (97.5%), status 2 (80%), status 3 (50%) (Kauffman & Donato, 2012).

(a) Trees ≥ 5.0 cm were measured (b) DBH measured above the highest still root

Figure 3.3: Field Measurement

In each plot, saplings (height > 1.37 m and DBH < 5cm) and seedlings (height < 1.37m) within 2m radius were estimated. For saplings, the DBH was measured likewise trees. In case of seedlings, all the species within 2m radius were harvested and placed in a plastic bag and transported to the laboratory. They were dried in an oven at 60ºC until it reached constant weight.

3.4 Sampling of Dead and downed wood

Dead and downed wood was measured by using line intercept method (Kauffman & Donato, 2012). This is a common method to assess by laying down a transect and tallying up how much of woody pieces intersects the transect (Canfield, 1941). In each plot, two transects were set to determine dead wood. Dead and downed wood was divided into four size classes based on diameter, namely, fine (0 -0.64 cm), small (0.65-2.54 cm), medium (2.55-7.5 cm) and large (≥ 7.6 cm). All the wood pieces except large piece, were tallied according to the number of wood pieces crossing the transect tape. For the diameter of wood ≥ 7.6 cm, dead wood was again divided into two categories- sound and rotten.

3.5 Species composition and phytosociology- Important value index and diversity indices

To estimate the important value index of the species, the equation given by Cintron and Novelli (1984) were used:

IVI = Relative frequency+ Relative density+ Relative dominance

To estimate diversity index of species we used Shannon-Weaver index (Shannon & Weaver, 1949) which as follows-

$H' = -\sum_{i=1}^{n} Pi \ln Pi$ [Where ln is natural logarithm and Pi is proportion of individuals to the ith species]

To find the evenness of species in ten plots, following equation was used given by Pielou (1975).

Pielou evenness index, $J' = H'/ln(S)$

Here H' is Shannon-Weaver index and S is total number of species in a sample, across all samples in data set. The result ranges from 0 to 1 where the value of 1 indicates total evenness.

To know the similarity among the species of different sites, Sorenson's Index of similarity was followed (Sorenson, 1948) using this formula,

$$S = \frac{2j}{A+B}$$

Where J is the total number of common species I both samples, A is total number of species in sample A and B is total number of species in sample B. The result ranges from 0 to 1. If the result is 0 it indicates no similarity and 1 indicates complete similarity.

To know the number of species, present as well as the relative abundance of each species, Simpson's Diversity Index was estimated (Simpson, 1949) using following formula:

$$D = 1 - (ni/N)^2$$

Where n is the total number of organisms of a particular species and N is the total number of organisms of all species. The value of ***D*** ranges between 0 and 1. With this index, 1 represents infinite diversity and 0, no diversity.

3.6 Biomass and Carbon Calculation (trees & saplings)

Both aboveground and belowground biomass of trees was calculated using established species-specific allometric equations (Table 3.1). Allometric equations were used for widely acceptance that was established by several authors (Poungparn et al., 2002; Putz & Chan, 1986; Simpson et al., 1996; Zanne et al., 2009). It is also a non - destructive method that made the biomass calculation much easier. Aboveground and belowground biomass was mostly derived from DBH and wood density (Table 3.1). After getting the value of biomass we converted it into per ha. For that we divide total biomass of species with total sample area (0.0154 ha) of each plot.

$$\text{Biomass } (t\ ha^{-1}) = \frac{\text{Total biomass}}{0.0154 \text{ ha}}$$

The biomass of dead tree was calculated on the basis of its decay status as mentioned in (Murdiyarso et al., 2009). Aboveground carbon pools were estimated from the aboveground biomass values using the C conversion value 0.50 based on Kauffman and

Donato (2012). To estimate belowground Carbon stock, we multiplied total belowground biomass value by C conversion value 0.39 (Kauffman & Donato, 2012).

$$\text{Aboveground Carbon (Mg/ha)} = \text{Total Aboveground biomass} * 0.50$$

$$\text{Belowground Carbon (Mg/ha)} = \text{Total belowground biomass} * 0.39$$

Table 3.2: Allometric equations for biomass calculation (Tree and sapling)

Species	AGB equation	BGB equation	Wood density $\rho\ (g\ cm^{-3})$
Rhizophora mucronate	$0.1709\rho DBH^{2.46}$[a]	$0.199\ \rho^{0.899}DBH^{2.22}[a]$	0.867[b]
Bruguiera parviflora	$0.168DBH^{2.42}$[e]	$0.199\ \rho^{0.899}DBH^{2.22}[a]$	0.749 [a]
Xylocarpus granatum	$0.0823DBH^{2.59}$ [e]	$0.145DBH^{2.55}$[f]	0.567 [c]
Avicennia officinalis	$0.251\rho DBH^{2.46}[a]$	$\mathbf{0.199\ \rho^{0.899}DBH^{2.22}[a]}$	0.654 [b]
Avicennia alba	$0.251\rho DBH^{2.46}[a]$	$0.199\ \rho^{0.899}DBH^{2.22}[a]$	0.506 [a]
Sonneratia alba	$0.251\rho DBH^{2.46}[a]$	$0.199\ \rho^{0.899}DBH^{2.22}[a]$	0.475 [a]
Rhizophora apiculate	$0.1709\rho DBH^{2.46}$[a]	$0.199\ \rho^{0.899}DBH^{2.22}[a]$	0.770 [a]
Bruguiera gymnohoriza	$0.186DBH2.31$	$0.199\ \rho^{0.899}DBH^{2.22}[a]$	0.699 [a]

*References (in square parentheses): a = Komiyama et al. (2005), b = W. T. Simpson (1996), c = Zanne et al. (2009), d = Putz and Chan (1986), e = Clough and Scott (1989) and f = Poungparn et al. (2002)

3.7 Biomass and carbon Calculation (seedlings)

To estimate the biomass of seedlings, a destructive sampling was done in the forest. Where all the seedlings within 2m radius were collected. After that, all the seedlings were dried in an oven at 60ºC temperature until constant weight was found. Then the biomass was calculated using the dry weight by multiplying with the numbers of seedlings for each species. Carbon content was calculated using the same conversion factor 0.50 as aboveground tree.

3.8 Biomass and Carbon estimation for dead and down wood

To determine volume of down wood, following equation was used (Brown, 1971).

$$\text{Volume } (m^3 ha^{-1}) = \pi^2 * (\frac{N*QMD^2}{8*L})$$

Where,

N= the number of woody debris that intersect in each size class

QMD= quadratic mean diameter of each size class(cm) (Kauffman & Cole, 2010)

L= transect length (m)

According to the protocol of Kauffman and Donato (2012) wood biomass was estimated by multiplying wood volume with its mean specific gravity. Specific gravity was taken from the protocol (Kauffman & Donato, 2012) based on the size class of dead and downed wood. The biomass was then converted into carbon stock using the value of 50% for tropical forests.

3.9 Soil properties and C pool

Soil is one of the main important component and largest pool of belowground C in Mangrove ecosystem. The protocol derived by Kauffman and Donato (2012) was followed. To determine the soil carbon pool, we have measured three parameters which are- 1) soil depth; 2) soil bulk density; and 3) organic carbon concentration. The soil C pools were sampled at each of 10 plots. The soil core was taken with a stainless-steel open-faced cylindrical auger for organic and peat soils (Figure 3.3).

3.10 Soil depth

At first, we had removed the organic litter from the surface at the sampling site. Then insert the auger vertically into the soil until the top of the sampler is level with the soil surface. If the auger is not going to penetrate to full depth, we did not Push it, as it can be obstructed by any large root. We had tried in a different place. To collect the undisturbed soil samples, we twist the auger at depth a few times in clockwise direction to cut through any remaining fine roots.

The samples were collected near the center of each plot and the depth of soil core was 0-15 cm, 15-30 cm, 30-50 cm, 50-100 cm and 100-200 cm. the depth interval of soil was taken until 200cm due to get a well partitioning of the soil C pool suggested by previous studies in mangrove forest (Kauffman & Donato, 2012). From the 10 plots, total 50 soil samples were collected for laboratory analysis.

3.11 Soil salinity

After obtaining the depth of the soil, water was collected from the surface. Soil water was obtained by pressing soil with a plastic syringe to estimate interstitial water and its salinity was measured using a potable refractometer (Perera et al., 2013).

3.12 Soil bulk density and organic carbon concentration

The fresh weight of all soil samples was measured before drying. All the soil samples were processed by keeping in Oven at 60ºC to dry it thoroughly (Kauffman & Donato, 2012). The dry weight was measured until it reached the constant weight.

Bulk density was determined for each sample by dividing the oven-dry weight by the volume of sample interval (Kauffman & Donato, 2012).

$$\text{Bulk density } (gm\ cm^{-3}) = \frac{Oven\text{–}Dry\ weight}{Sample\ Volume}$$

All the 50 soil samples were then ground into fine texture using a mortar and pestle (Figure 3.5). To remove all the large roots, a 2 mm sieve was used and let the ground soil passed into it. Then the rest large roots were thrown.

Figure 3.4: collection of soil sample from an open face auger

Figure 3.5: Grinding soil samples in mortar and pestle(left), 2mm sieve(right)

The size and texture of soil particles was analyzed by using PSA (Particle-Size Analysis) analyzer which is LS 230 with Fluid Module (Figure 3.6). We followed the protocol of (Coulter, 2011) for this analysis. As it is a computer-based windows program, so it was easy to achieve both hardware monitoring and data management. The software enabled to view, print, store and export data, customizable on-screen and print files and to identify and assess the application profiles to simplify the most used application protocols.

Universal Liquid Module (approx. 1 mg to 10 g) was followed to measure the sample requirement. Run time was very short and about 30 to 90 seconds typical. After the run time, the data was displayed on the computer and hardcopy was printed out for further processing. Later the raw data was analyzed to get the particle texture and size.

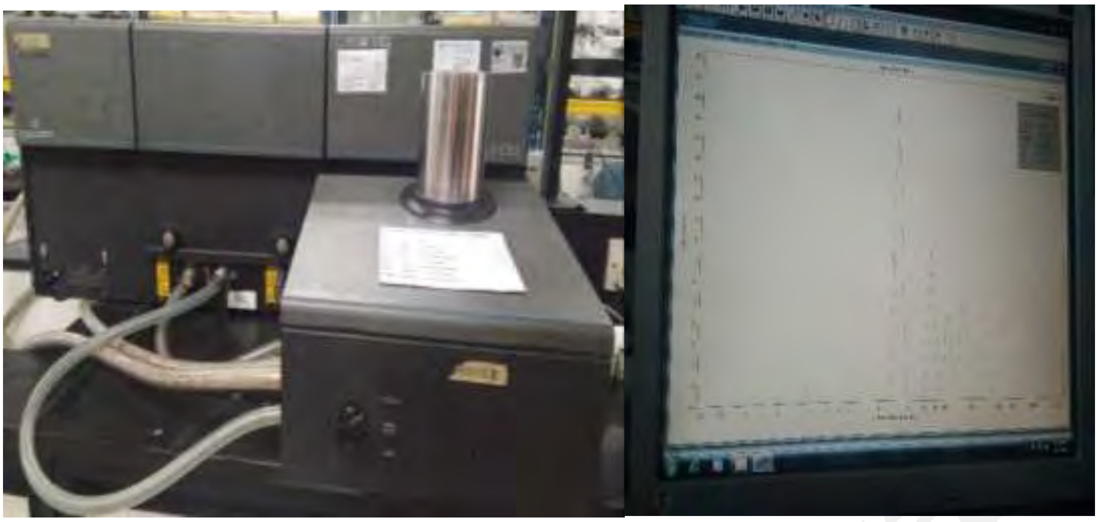


Figure 3.6: PSA analyzer (left), reading on computer (right)

Twelve major soil texture classifications defined by (USDA) was used. The twelve classifications are presented in the Figure 3.7 which are sand, loamy sand, sandy loam, loam, silt loam, silt, sandy clay loam, clay loam, silty clay loam, sandy clay, silty clay, and clay. We determined soil texture using soil texture triangle figure 3.7. According to the USDA soil taxonomy, clay particles are the smallest having diameters of less than 0.002 mm. The next smallest particles are silt with diameters between 0.002 mm and 0.05 mm. The largest particles are sand particles which are larger than 0.05 mm in diameter.

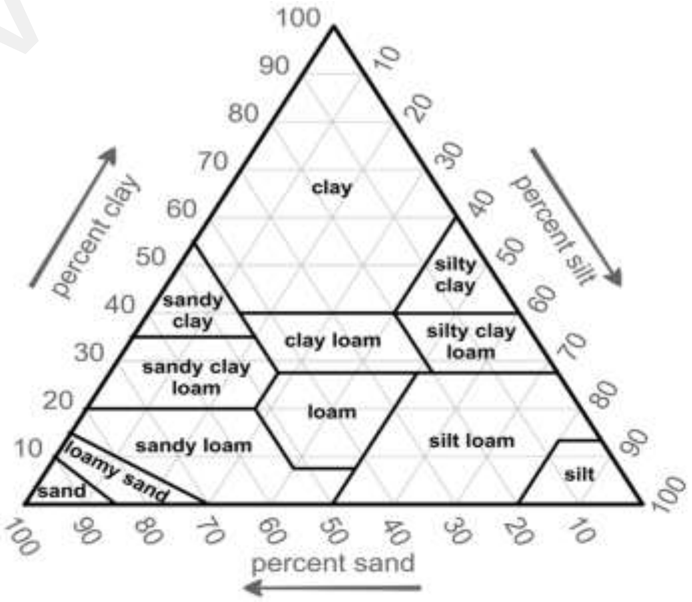


Figure 3.7: USDA Soil Texture Triangle

3.12.1 Organic carbon (OC) estimation by Loss on Ignition (LOI)

To estimate the organic carbon content of soil, we used LOI which is a common and most widely used method (Dean, 1974; Heiri et al., 2001). The procedure given by Nelson and Sommers (1996) was followed to determine OC. The crucibles were pre-heated at 150ºC and after cooling in room temperature, we took the weight of crucible. After that, the dried soil sample was weighed 5±0.001gm and placed in crucible. Then we measured this weight and it is pre-ignition weight.

Figure 3.8: Steps to measure Organic Matter by LOI method using muffle furnace

LOI was carried out by heating at 550ºC in a muffle furnace until combusted all organic matter which depended on the sediment type as stated by Wang (2011). After required time, the furnace was turned off, allowing the samples to cool to ~150°C. After cooling down and the samples were removed from desiccator and post-ignition weight was taken. The Organic Matter (OM) was calculated by the following equation-

$$\text{OM\%}= \frac{Pre\ ignition\ weight(g) - Post\ ignition\ weight(g)}{Pre\ ignition\ weight(g)} \times 100$$

Percentage of organic carbon (%OC) was calculated using the following formula given by (Adame et al., 2018).

$$\%OC = 0.37 * OM - 0.063$$

3.12.2 Soil carbon pools determination

To determine total carbon pool of soil, we followed the protocol of (Kauffman and Donato (2012)). At first the soil carbon was determined according to depth interval of soil horizon, i.e., 0-15cm, 15-30cm, 30-50 cm, 50-100 cm and 100-200 cm and the bulk density and carbon concentration (%C which is expressed as a whole number) that is measured at each layer.

Soil carbon (Mg ha^{-1})= bulk density (g cm^{-3})*depth interval of soil (cm)* % OC

After adding all the Carbon mass from each layer of soil depth interval, total soil carbon pool was estimated.

3.13 Total ecosystem carbon pool

By adding all component pools, total carbon pool or stock was estimated. First, the average value of each component pool was estimated for all plots. The average values are added to sum up the total (Kauffman & Donato, 2012). The equation is as follows-

$$\text{Total C stock } (Mg\ ha^{-1}) = \mathrm{C_{treeAG}} + \mathrm{C_{treeBG}} + \mathrm{C_{deadtree}} + \mathrm{C_{sap/seed}} + \mathrm{C_{sap/seedBG}} + \mathrm{C_{deadsap/seed}} + \mathrm{C_{woodydebris}} + \mathrm{C_{soil}}$$

Where,

$\mathrm{C_{treeAG=}}$aboveground carbon stock of trees, $\mathrm{C_{treeBG=}}$ belowground tree carbon pool, $\mathrm{C_{deadtree=}}$ dead tree pool, $\mathrm{C_{sap/seed=}}$ carbon pool of saplings and seedlings, $\mathrm{C_{woodydebris=}}$ carbon pool of downed wood, $\mathrm{C_{soil=}}$carbon pool of soil.

The equation for estimating total carbon stock of this whole study site was calculated as follow-

Total carbon stock of Pulau Pintu Gedong (Mg) = total carbon (Mg/ha) * Area (807 ha)

3.14 Carbon dioxide equivalents ($\mathrm{C}O_2$e)

Through multiplying carbon density or stock by 3.67, the total carbon density or stok can be converted to $\mathrm{C}O_2$e (Kauffman & Donato, 2012). It is because $\mathrm{C}O_2$ is the most common form of greenhouse gas of C and inventories of greenhouse gases are often reported in equivalents of $\mathrm{C}O_2$ or $\mathrm{C}O_2$e units. So, the equation used to estimate $\mathrm{C}O_2e\ is\ as\ follows -$

$$\mathrm{C}O_2e = \text{Total Carbon stock*3.67}$$

3.15 **Market value of Carbon**

The price of C in US$ was multiplied with the value of CO_2e that was estimated by converting the total C stock into CO_2e.

Market Value of C = CO_2e* price of C unit in US$

There are two essential market sources in terms of evaluating carbon emissions and these are voluntary market and regulated market (Ullman et al., 2013). To estimate market value of carbon, price of each sources was taken into consideration as stated in Table 3.3.

Table 3.3: Global Market of Carbon

Market sources	**Price of t/CO_2e (US$)**
Voluntary markets	6.00
EU emissions trading scheme	19.18
Clean development mechanism	15.68
Greenhouse gas initiative	9.69
Kyoto assigned allowance units	13.95

*Source:(Ullman et al., 2013)

Multilateral Development Banks (MDB) have played a major role in addressing climate change. An increased number are beginning to use internal carbon pricing to influence their investment decision-making and address climate risks. The following Table (3.4) reported by World Bank (2018) summarizes the current status of internal MDB carbon pricing, which is actively using in today's carbon price.

Table 3.4: Internal carbon pricing by Multilateral Development Bank (MDB)

Multilateral Development Bank (MDB)	**Price of t/CO_2e (US$)**
Asian Development Bank	36.3
European Bank for Reconstruction and Development (EBRD)	43
European Investment Bank (EIB)	47
The World Bank	40 – 80
The International Finance Corporation (IFC)	30

*Source: World Bank (2018)

3.16 Statistical analysis

The significant difference in above- and below-ground C stocks, sediment C pool and ecosystem C storage among forest types was tested using one-way ANOVA, Independent-samples T-Test and Nonparametric Spearman rank correlation coefficient. One-way ANOVA was also used to determine the differences in Soil organic carbon content within the different sediment depth intervals. The significance level was acknowledged at a p-value < 0.05 for all statistical tests. All statistical testing was carried out using IBM SPSS Version 24.

CHAPTER 4: RESULTS

4.1 Vegetation analysis

4.1.1 Species composition

Pulau Pintu Gedong Mangrove forest is composed of different species. Eight mangrove species was found in two different station and a total of 448 trees was identified (Table 4.1 & Table 4.2). In station 1, *Rhizophora mucronata* and *Bruguiera parviflora* were found as most abundant species. *Xylocarpus granatum* along with *Rhizophora mucronata* and *Bruguiera parviflora* were most abundant species observed in station 2. However, *Rhizophora mucronata* is the biggest tree (34.9m in station 1 and 36.9m in station 2) in both station 1 and 2 in terms of diameter at breast height. In terms of abundance, Station 2 (3117) has more tree density per ha than station 1 (2701). This variation in tree density was probably due to forest location. As station 1 was near seaside and station 2 was inland forest.

Table 4.1: Species composition, mean diameter at breast height (±SD), Total abundance (N) and tree density (ha^{-1}) of mangrove trees recorded in station 1 and station 2

		Station-1			
Plot	Species	Abundance	Mean DBH (cm)	Min DBH (cm)	Max DBH (cm)
1	*Avicennia alba*	7	14.64 ± 7.63	7	29
1	*Sonneratia alba*	8	26.15±11.32	6	41
	Total	**15**			
2	*Rhizophora mucronata*	40	9.82 ± 7.40	5	22.9
2	*Xylocarpus granatum*	5	8.9 ± 2.94	6.3	12.2
2	*Avicennia alba*	5	7.22 ± 1.28	5.6	8.5
	Total	**50**			
3	*Bruguiera parviflora*	18	9.12 ± 4.17	5.2	21.5
3	*Xylocarpus granatum*	2	5.75 ± 0.21	5.6	5.9
3	*Rhizophora apiculate*	26	9.74 ± 2.12	6.3	14.5
	Total	46			
4	*Bruguiera parviflora*	31	8.72 ± 2.31	5.3	13.5
4	*Bruguiera gymnohoriza*	3	8.70 ± 3.11	5.3	11.4
4	*Rhizophora apiculate*	11	13.23 ± 5.07	9.3	25.1
4	*Rhizophora mucronata*	17	10.46 ± 7.03	5	34.9
	Total	62			
5	*Sonneratia alba*	2	30.90±16.83	19	42.8
5	*Bruguiera parviflora*	10	7.15 ± 1.24	5	9.1
5	*Rhizophora mucronata*	22	10.95 ± 8.97	5.2	43.3
5	*Xylocarpus granatum*	1	5	5	5
	Total	35			
	Total abundance(N)	208			
	Tree density (ha^{-1})	**2701**			
		Station 2			
Plot	Species	Abundance	Mean DBH (cm)	Min DBH (cm)	Max DBH (cm)
1	*Rhizophora mucronata*	61	8.77 ± 2.90	5.2	17.5
	Total	**61**			
2	*Xylocarpus granatum*	23	9.26 ± 5.28	5	30.9
2	*Bruguiera parviflora*	1	5.3	5.3	5.3
2	*Rhizophora mucronata*	28	8.67 ± 2.70	5	16.1
	Total	**52**			
3	*Rhizophora mucronata*	19	11 ± 7.52	5	36.9
3	*Bruguiera parviflora*	11	8.98 ± 2.42	6.4	13
3	*Avicennia officinalis*	7	9.03 ± 2.22	6.3	12.1
3	*Xylocarpus granatum*	6	6.55 ± 1.49	5	8.7
	Total	**43**			
4	*Bruguiera parviflora*	47	8.70 ± 2.79	5.3	13.1
4	*Avicennia officinalis*	3	11.23 ± 9.60	5.1	22.3
4	*Rhizophora mucronata*	6	11.22 ± 1.14	9.8	12.8
4	*Xylocarpus granatum*	1	5.1	5.1	5.1
	Total	**57**			
5	*Rhizophora mucronata*	13	8.53 ± 2.48	5.2	13.5
5	*Bruguiera parviflora*	10	9.64 ± 4.34	5.4	17
5	*Avicennia officinalis*	3	6.2 ± 1.1	5.1	7.3
5	*Xylocarpus granatum*	1	6.3	6.3	6.3
	Total	**27**			
	Total abundance	**240**			
	Tree density (ha^{-1})	**3117**			

4.1.2 Sapling (height > 1.37 m and DBH < 5cm) and seedling (Height < 1.37)

The saplings didn't show much variation in terms of species composition. In station 1, *Rhizophora mucronata* had the biggest DBH but *Bruguiera parviflora* showed biggest DBH in station 2 (Table 4.2). But tree density was highest in station 1(2333 trees/ha) than station 2 (Table 4.2).

Table 4.2: Species composition, mean diameter at breast height (±SD), Total abundance (N) and tree density (ha^{-1}) of mangrove saplings (height > 1.37 m and DBH < 5cm) recorded in station 1 & 2

Station 1	Species	Abundance	DBH (cm)	Min DBH (cm)	Max DBH (cm)
	Rhizophora mucronate	5	3.48±0.81	2.5	4.5
	Bruguiera parviflora	6	3.16±0.91	2.3	4.4
	Xylocarpus granatum	3	2.73±0.90	1.8	3.6
	Total abundance	14			
	Tree density (ha^{-1})	2333			
Station 2	Species	Abundance	DBH (cm)	Min DBH (cm)	Max DBH (cm)
	Rhizophora mucronate	4	3.78±0.74	3.1	4.6
	Xylocarpus granatum	2	2.40±0.14	2.3	2.5
	Avicennia alba	1	2	2	2
	Bruguiera parviflora	1	4.2	4.2	4.2
	Total abundance	8			
	Tree density (ha^{-1})	1334			

In case of seedlings (Table 4.3), station 2 had more seedlings (43) than station 1 (18). Undoubtedly, tree density was very high for station 2 (7166/ha) in comparison to station 1 (3000/ha). *Xylocarpus granatum* dominated station 2 (21 species found) but in station 1 only one species of *Xylocarpus granatum* were found (Table-4.3). Most of the seedlings and saplings were *Rhizophora mucronata* in station 1 whereas *Xylocarpus granatum* were more dominant seedlings and saplings from station 2.

Table 4.3: Species composition and Total abundance (N) and tree density (ha^{-1}) of mangrove seedlings (Height < 1.37)

Station	Plot	Species	Count
1	2	*Rhizophora mucronate*	4
	3	*Xylocarpus granatum*	1
	4	*Bruguiera parviflora*	4
	4	*Rhizophora mucronata*	9
		Total abundance	**18**
		Tree density (ha^{-1})	**3000**
Station	**Plot**	**Species**	**Count**
2	1	*Rhizophora mucronata*	5
	2	*Rhizophora mucronata*	7
	2	*Xylocarpus granatum*	21
	3	*Bruguiera parviflora*	4
	3	*Bruguiera parviflora*	6
		Total abundance	43
		Tree density (ha^{-1})	7166

4.1.3 Phytosociological Parameters

Species Diversity and Important value index

In the following (figure 4.1), it shows diversity index and important value index of species in 10 sampled plots of two stations. Simpson's index showed that station 1 has more diversification of species compared to station 2 (Figure 4.1). Analyzation of shannon-weiner index indicated high diversity in station 1 (1.53, Figure 4.1). But the pielou evenness index suggested highly evenly distribution of mangrove species in station 2 (0.81, figure 4.1). The species composition found in two stations are not very similar as only 3 common species i.e., *Rhizophora mucronata, Bruguiera parviflora* and *Xylocarpus granatum* found in both sites. So, the Sorenson index of similarity suggested 55% similarity in both station (Figure 4.1).

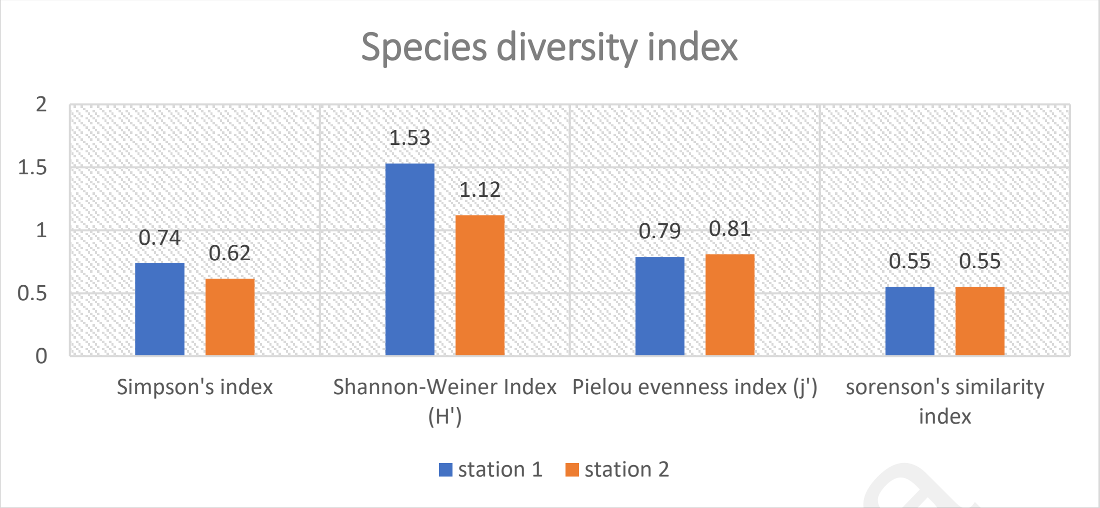


Figure 4.1: Species diversity index in the study sites

According to the value of IVI for trees presented in Table 4.4, *Rhizophora mucronata* was the most dominant tree species in both station 1 and station 2. In station 1, the less dominant species was *Bruguiera gymnohoriza* (Table 4.4). For saplings, *Bruguiera gymnohoriza* was most dominant species in station 1. But *Rhizophora mucronata* was dominant in station 2 (Table 4.5).

Table 4.4: Important value index (IVI) for mangrove tress sampled at two sites

Species	**IVI**	
	Station 1	**Station 2**
Rhizophora mucronate	70.65	135.67
Bruguiera parviflora	55.9	70.3
Xylocarpus granatum	32.64	54.34
Avicennia officinalis	_	39.69
Avicennia alba	25.56	_
Sonneratia alba	68.55	_
Rhizophora apiculate	37.91	_
Bruguiera gymnohoriza	8.8	_

Table 4.5: Important value index (IVI) for mangrove saplings sampled at two sites

Species	IVI	
	station 1	station 2
Rhizophora mucronate	94.47	163.89
Xylocarpus granatum	96.61	54.23
Avicennia alba	-	33.52
Bruguiera gymnohoriza	108.93	48.38

DBH range and Density

Figure 4.2 had shown the DBH size class distribution on two sampling plots (Station 1 & Station 2). It was clearly seen that both sites were mostly dominated by younger trees. The density of Plants with DBH <10 cm in station 1 was 1800 trees/ha whereas in station 2 there was around 2000 trees/ha. In station 1 all the size classes were present until DBH > 40.1 cm. But in Station 2 there was no trees that reached the size DBH > 40.1 cm. It was clear that the frequency distribution of both sites was similar, and it is L-shaped as the density was highest in the left side of the graph and gradually decreased. The distribution pattern of trees was almost similar up to the range of DBH 25 cm. The main difference between two stations started from medium to large size trees (DBH 25.1 up to > 40.1 cm). So, the population distribution in station 1 shows a continuous age structure where all DBH size classes were present.

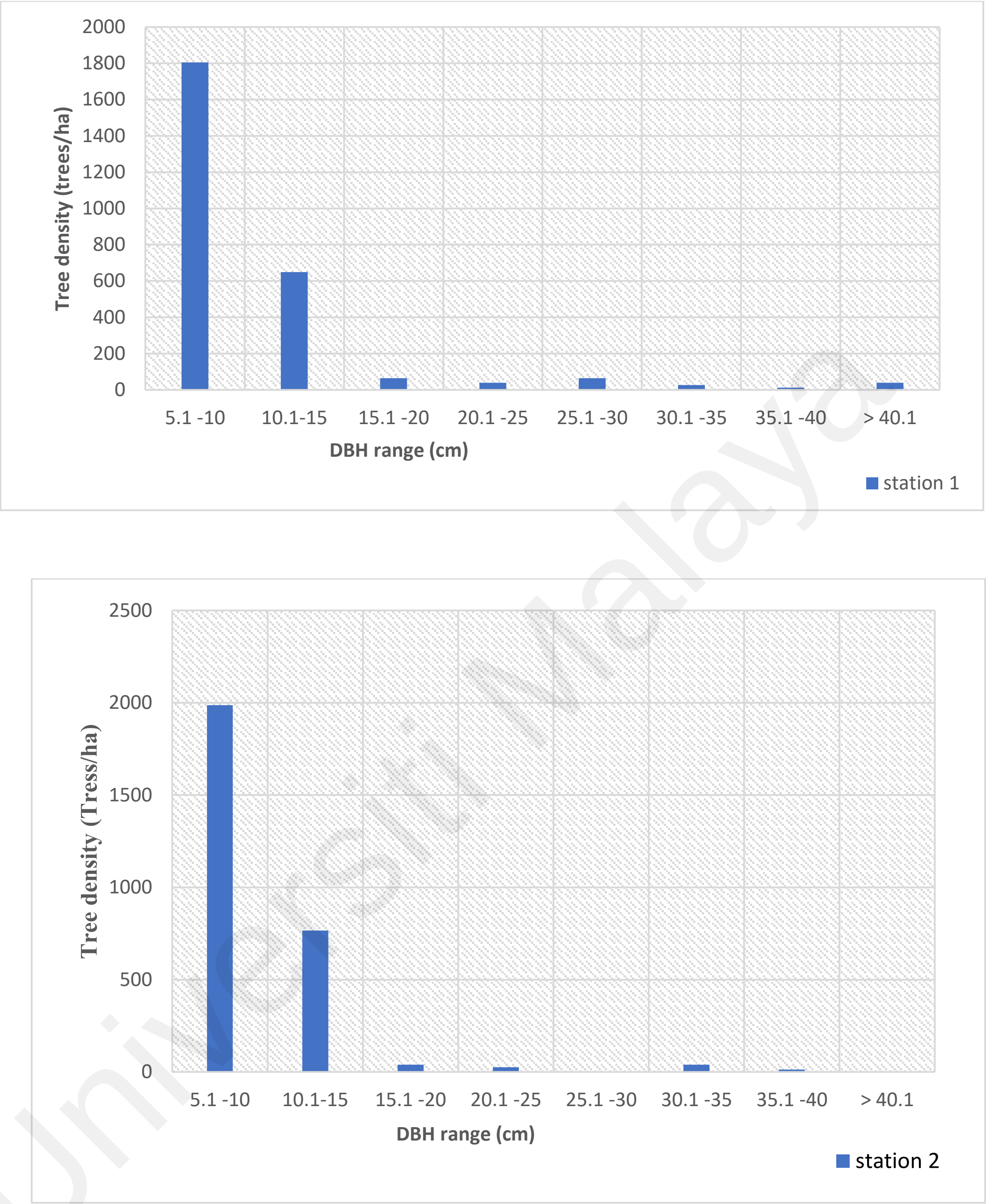


Figure 4.2: Density distribution in different DBH size classes at two stations

4.1.4 Biomass estimation

4.1.4.1 Tree with diameter > 5cm

Aboveground and belowground biomass for trees were compared between two stations in Pulau Pintu Gedong Mangrove forest (Table 4.6). The highest aboveground and belowground biomass accumulation was noticed for *Rhizophora mucronata* (111.60 and 58.60 t/ha, respectively) in station 1. Similarly, the highest aboveground and belowground biomass accumulation was found in *Rhizophora mucronata* (82.00 and 49.80 t/ha, respectively) in station 2. But the lowest biomass was recorded for *Xylocarpus granatum* (2.00 and 3.40 t/ha, respectively) in station 1. For station 2, *Avicennia officinalis* showed the smallest accumulation of biomass (9.00 and 4.00 t/ha, respectively). In total station 1 showed the highest biomass (both aboveground and belowground) accumulation (378 t/ha).

Table 4.6: Estimated Aboveground (AGB) and belowground (BGB) biomass (t/ha)

Species	Station 1		Station 2	
	AGB	BGB	AGB	BGB
Avicennia alba	12.90	5.60	-	-
Sonneratia alba	66.90	24.50	-	-
Xylocarpus granatum	2.00	3.40	15.20	24.30
Rhizophora mucronate	111.60	58.60	82.00	49.80
Bruguiera parviflora	28.60	16.10	35.20	20.00
Bruguiera gymnohoriza	0.40	0.80	-	-
Rhizophora apiculate	29.50	17.10	-	-
Avicennia officinalis	-	-	9.00	4.00
Total	251.90	126.10	141.40	98.10
Total Biomass(t/ha) (AGB+BGB)	378		239.50	

4.1.5 Sapling (Height > 1.37, DBH<5cm) and Seedling (Height < 1.37) biomass

The Aboveground and belowground biomass for single species of saplings were estimated (Table 4.7). The AGB of *Xylocarpus granatum* (0.60 t/ha) was significantly higher in High intertidal zone of station 1 compared to the mangrove stands of station 2. Moreover, the AGB was higher in station 2 for *Rhizophora mucronata* (2.5 t/ha). However, the total biomass (both AGB & BGB) was higher in station 1 compared to station 2.

Table 4.7: Estimated AGB and BGB (t/ha) for saplings

Species	Station 1		Station 2	
	AGB	BGB	AGB	BGB
Rhizophora mucronata	2.6	2.3	2.5	2.1
Xylocarpus granatum	0.6	1	0.3	0.5
Bruguiera parviflora	2.9	2	0.8	0.57
Avicennia alba	-	-	0.1	0.08
Total	6.1	5.3	3.7	3.25
Total biomass (t/ha) (AGB+BGB)	11.4		6.95	

The highest aboveground and belowground biomass were recorded in station 1 in comparison to station 2 (Figure 4.3). In contrast, the biomass was highest in station 2 (0.16 t/ha) for seedlings in comparison to station 1 (0.05 t/ha) (Figure 4.4).

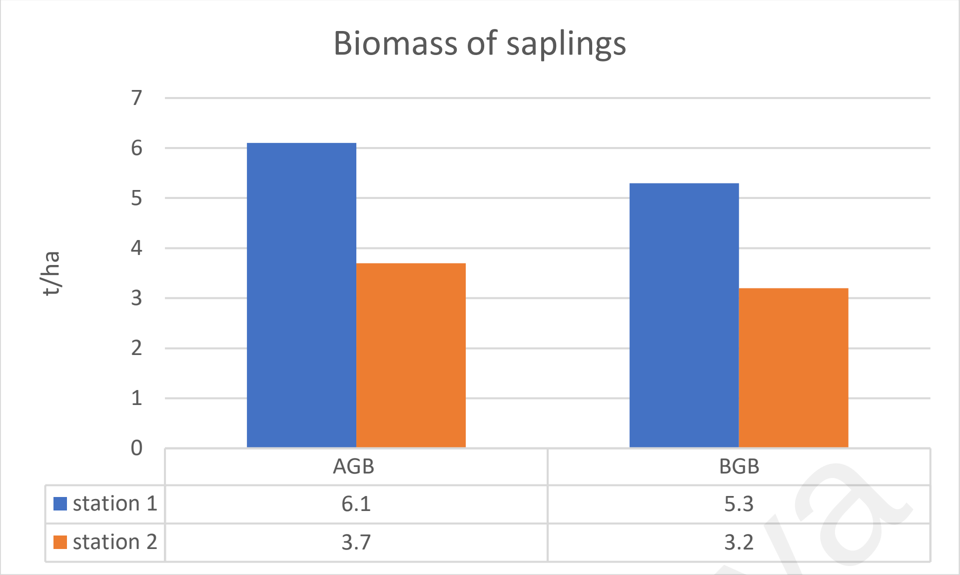


Figure 4.3: Biomass of saplings in two stations

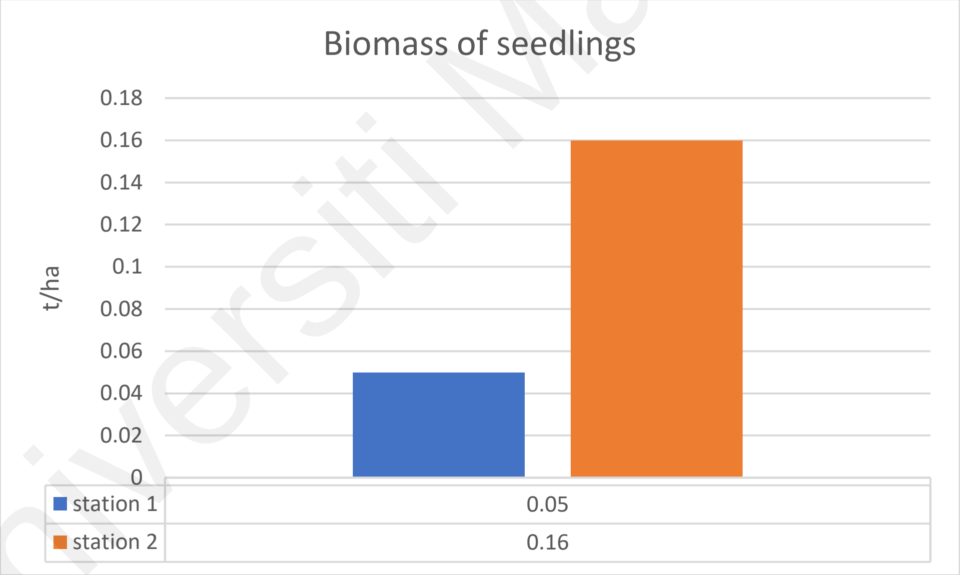


Figure 4.4: Biomass of seedlings in two sites

4.1.5.1 Dead & downed wood

The biomass of dead & downed wood was estimated according to the size class in both stations. In total, station 1 has more biomass content than station 2 (Table 4.8). We had got more dead wood in station 1 than station 2. This is probably due to their location.

Table 4.8: Biomass of dead & downed wood in two stations

Dead & downed wood (size class)	Station 1 (Biomass t/ha)	Station 2 (Biomass t/ha)
Large (> 7.6cm sound) (diameter in cm)	1.69	0.15
Large (>7.6 rotten) (diameter in cm)	0.07	0
Medium (2.5-7.6cm) (count)	0.39	0.58
Small (0.6-2.5cm) (count)	0.13	0.40
Fine (<0.6cm) (count)	0.01	0.05
Total Biomass (t/ha)	2.29	1.18

After calculating all the individual parts of vegetation biomass, it had been clearly noticed that station 1(389.45 t/ha) has more biomass than station 2 (246.61 t/ha) (Table 4.9). Station 1 has the largest biomass in all terms (trees and saplings) except for seedling biomass. But station 2 had only highest biomass in terms of seedlings (Table 4.9).

Table 4.9: Total biomass estimation in station 1 and station 2

Sites	Tree biomass (t/ha)	Sapling biomass (t/ha)	Seedlings biomass (t/ha)	Dead & downed wood biomass (t/ha)	Total biomass (t/ha)
Station 1	378	11.4	0.05	2.29	389.45
Station 2	239.5	6.95	0.16	1.18	246.61

4.1.6 Estimation of aboveground and belowground C content

Carbon allocation in individual species was very much similar in both study sites (Figure 4.5). For trees, the organic carbon content in *Bruguiera parviflora* was found to be higher in station 1 whereas *Rhizophora mucronata* was highest in station 2, even though both sites were not significantly different (P > 0.05). Similarly, *Bruguiera* *parviflora* and *Rhizophora mucronata* showed the highest C stocks in station 1 but *Rhizophora mucronata* was only found to be higher in station 2. But there was no significance difference ($P > 0.05$) between two sites in terms of individual species of sapling C content.

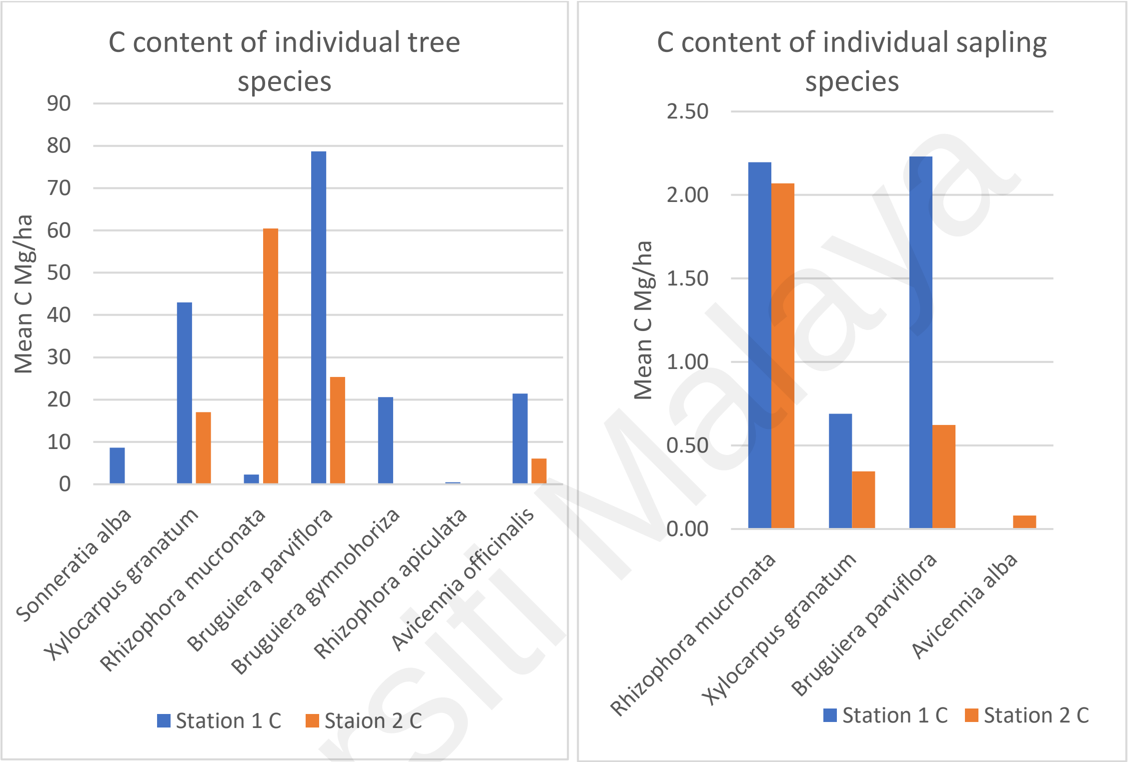


Figure 4.5: Carbon content according to Mangrove species (left = Tree, right = Sapling)

Carbon (C) storage capacity for trees in two different stations were compared and the amount of C stored in both aboveground and belowground were presented in Figure 4.6. For trees, the total aboveground carbon sequestration in station 1 and station 2 were 125.96 Mg/ha and 70.67 Mg/ha respectively (Figure 4.6). So, station 1 has more C storage capacity than station 2. Similarly, Station 1 has the largest belowground C content than station 2 (49.14 Mg/ha for station 1 and 38.26 Mg/ha for station 2). Though station 2 has more tree density per ha (3117 trees/ha) than station 1 (2701 trees/ha), the C storage capacity was higher in station 1(Figure 4.6).

For saplings, total amount of aboveground carbon stored in station 1 was higher than station 2. Likewise, station 1 (2.07 Mg/ha) had higher belowground carbon content that station 2 (1.25 Mg/ha). However, total amount of belowground carbon was less in both stations compared to aboveground carbon storage capacity (Figure 4.7).

Moreover, belowground carbon content for trees and saplings was perfectly correlated with aboveground carbon in two study sites ($r_s = 1.00$, $P < 0.0001$) which was estimated by Nonparametric Spearman rank correlation coefficient.

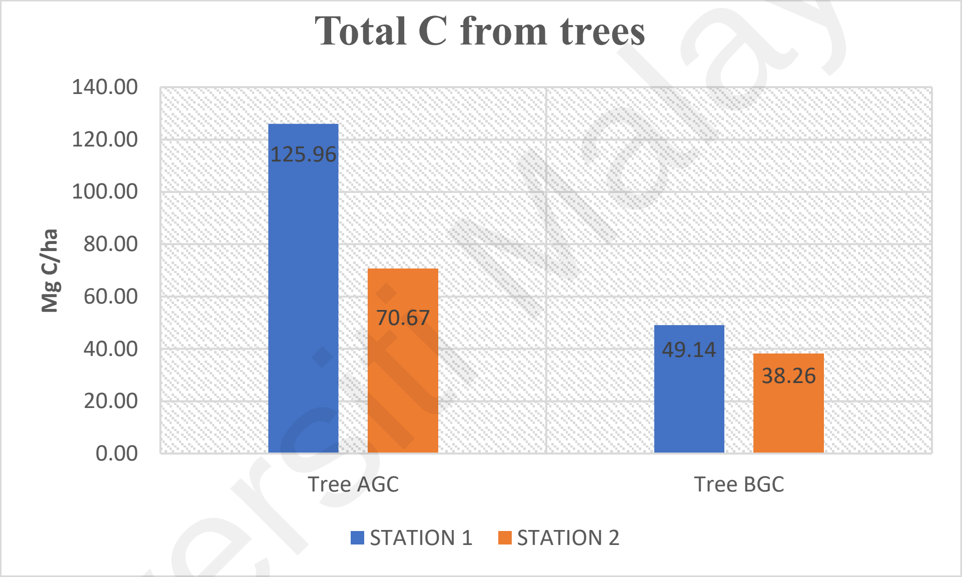


Figure 4.6: Amount of C stored in trees in the study sites

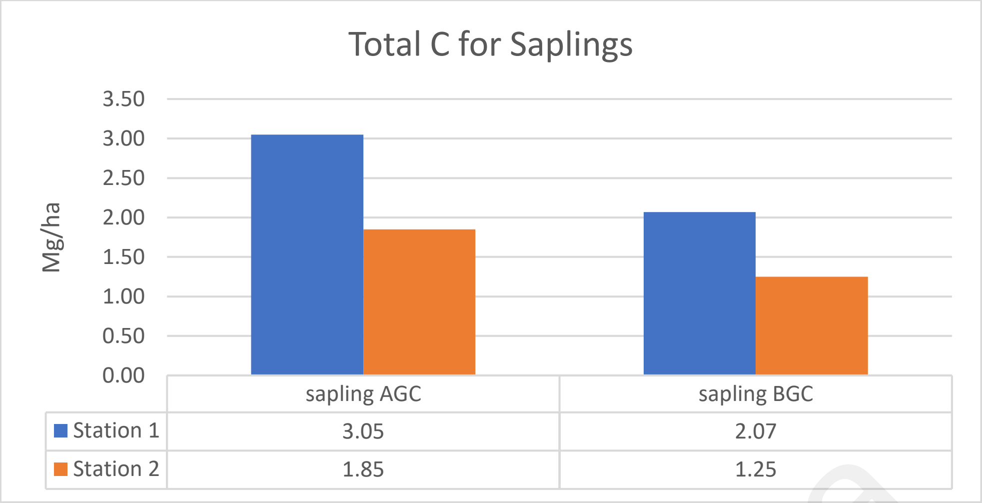


Figure 4.7: Carbon stock of saplings stored in two stations

In case of seedlings, the total amount of C content was much higher in station 2 than station 1 (Figure 4.8). Dead & Downed wood also showed the same pattern as seedlings because station 1 has more C content than station 2 (Figure 4.9).

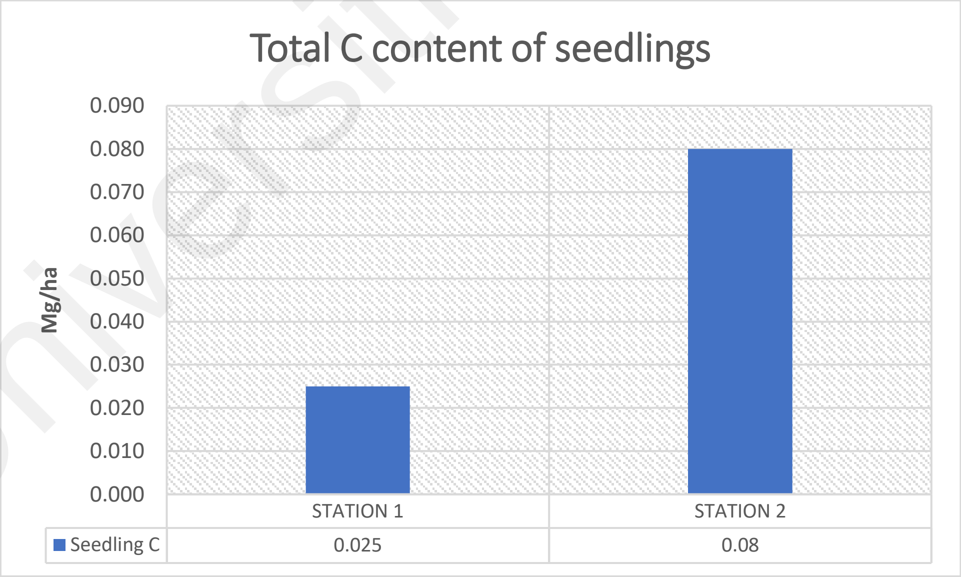


Figure 4.8: Carbon stock of seedlings in two stations

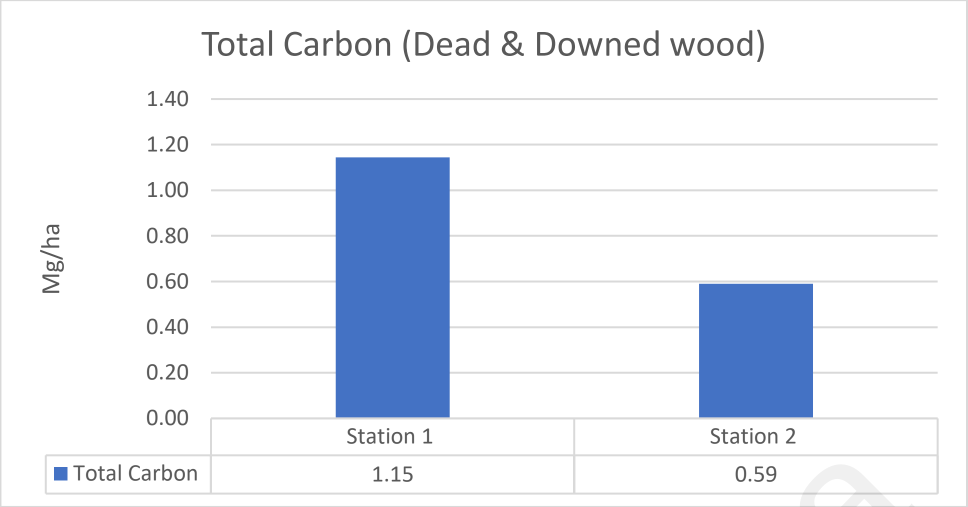


Figure 4.9: Carbon stock of dead & downed wood in two stations

4.1.7 Vegetation functional attributes and carbon stock

The total carbon stock for individual species was plotted against functional characteristics of vegetation such as DBH. Figure 4.10 showed that DBH had a strong positive relationship with ecosystem C stock in both study sites ($R^2 = 0.82$ for station 1 and $R^2 = 0.75$ for station 2 with $P < 0.05$).

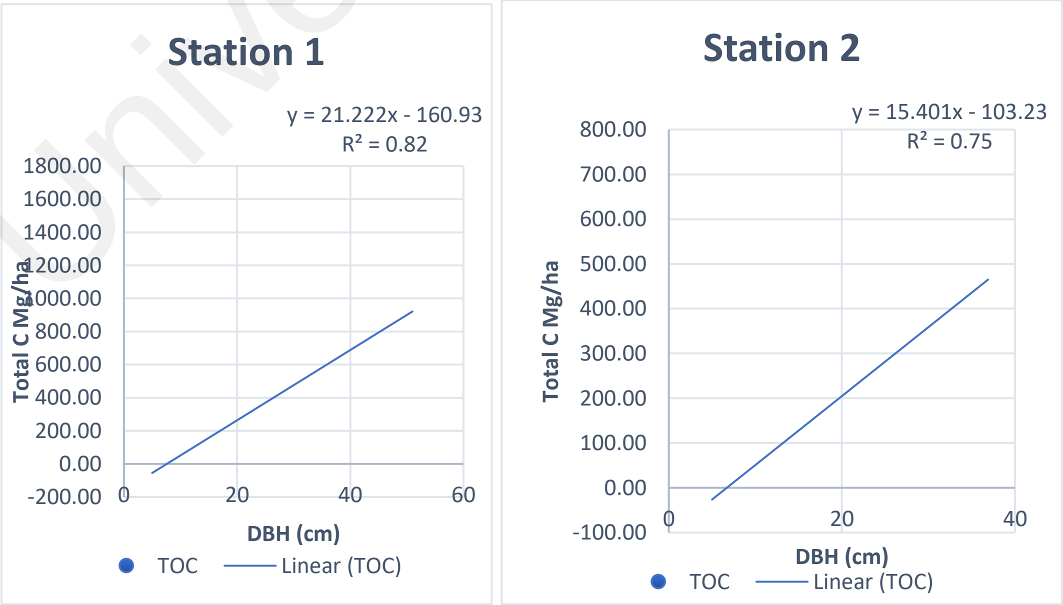


Figure 4.10: Relationship of ecosystem carbon stock (Mg/ ha) to DBH in both sites

4.1.8 Soil analysis

The salinity level was measured from 10 plots of two sites and comparatively station 2 had more saline water (e.g., PG 6 in station 2 reach up to 40 ppt) than station 1(Table 4.10).

Table 4.10: Soil salinity in 10 plots of station 1 & 2

Plot ID	Salinity (ppt)	Soil depth (cm)
PP 1	30	200
PP 2	27	200
PP 3	27	200
PP 4	30	200
PP 5	27	200
PG 6	40	200
PG 7	30	200
PG 8	34	200
PG 9	33	200
PG 10	32	200

Table 4.11 and Table 4.12 shows the sediment texture in Station 1 and station 2, in terms of sand, silt and clay. Soil type was distinguished by the percentage of silty loam, silty clay and silty clay loam present in soil. In station 1, silt loam and sandy loam dominated the soil texture (Table 4.11). Similarly, in station 2, sandy loam and silt loam was revealed most dominant (Table 4.12). For station 1, plot 1 and 2 dominated the texture of silt loam as percentage of silt was more (Table 4.11 and Table 4.12). In contrary, plot 5, showed the dominancy of silt loam in station 2 (Table 4.12).

Table 4.11: Soil texture in 5 plots in station 1

soil depth	%clay	% silt	%sand	soil type
0-15	1.58 ± 0.99	47.50 ±7.13	50.93 ± 7.54	sandy loam
15-30	0.28 ± 0.57	50.60 ± 6.33	49.12 ± 6.09	silt loam
30-50	0.07 ± 0.12	50.71 ± 4.12	49.22 ± 4.04	silt loam
50-100	0.25 ± 0.55	48.13 ± 5.17	51.62 ± 4.79	sandy loam
100-200	0.24 ± 0.53	53.48 ± 6.21	46.28 ± 5.81	silt loam

Table 4.12: soil texture in 5 plots in station 2

soil depth	%clay	% silt	%sand	soil type
0-15	1.07 ± 0.83	46.44 ± 4.85	52.49 ± 4.23	sandy loam
15-30	0.67 ± 0.77	47.26 ± 4.27	51.79 ± 4.07	sandy loam
30-50	0.38 ± 0.68	52.38 ± 10.07	47.22 ± 9.76	silt loam
50-100	0.95 ± 1.22	50.69 ± 5.21	48.36 ± 4.15	silt loam
100-200	0.36 ± 0.62	55.69 ± 4.16	44.14 ± 3.68	silt loam

4.1.9 Soil Organic Matter (SOM), Bulk Density (BD) and Carbon Content

The amount of OC was highest in the depth of 15-30 cm in station 1 whereas the amount of OC was highest for the depth of 0-15 cm in station 2 (Table 4.13). However, station 1 showed decreasing of OC content with the increase of depth and station 2 fluctuates (Table 4.13). Maybe the setting is the reason behind it. Station 1 was at seaside and station 2 was in inland. Bulk density was higher in 0-15 cm depth for station 1 but totally different from station 2 as the highest bulk density was for the depth of 100-200 cm (Table 4.13). There was a significant relationship ($p < 0.0001$ in station 1 and $p < 0.01$

in station 2) between bulk density and organic carbon in both stations (Figure 4.11). So, there was a high percentage of OC even in relatively low bulk density.

Table 4.13: Soil organic carbon (%OC), bulk density (g cm^{-3}) and organic carbon stocks (Mg ha^{-1}) up to 2m

Station 1	Depth (cm)	Bulk Density	%OC
	0-15	0.90±2.87	4.48±2.55
	15-30	0.71±0.11	5.81±1.50
	30-50	0.80±0.12	4.38±1.37
	50-100	0.68±0.07	5.11±1.76
	100-200	0.85±0.19	4.38±1.56
Station 2	Depth (cm)	Bulk Density	%OC
	0-15	0.81±0.12	4.15±0.79
	15-30	0.79±0.04	3.86±0.61
	30-50	0.78±0.08	3.55±1.77
	50-100	0.88±0.08	3.29±0.49
	100-200	1.03±0.17	2.75±0.39

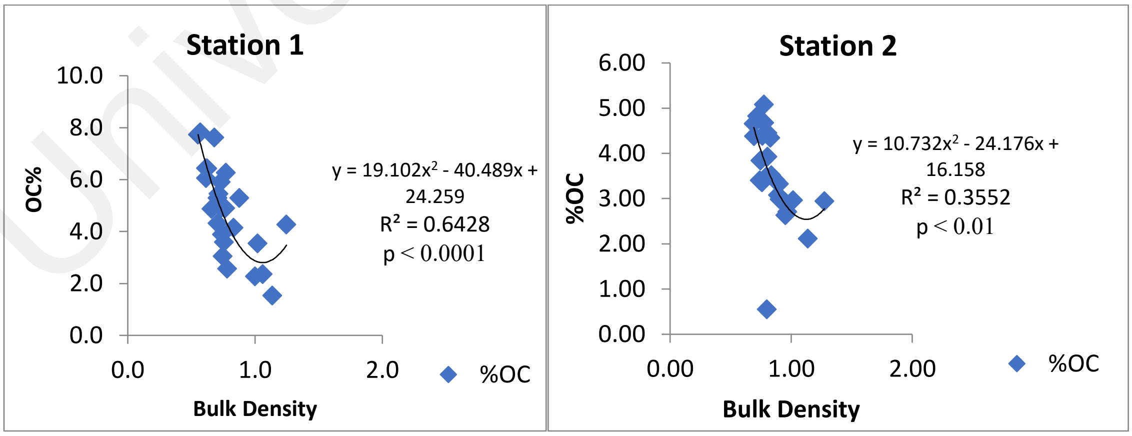


Figure 4.11: Association between Soil Organic Carbon (%OC) And Bulk Density (g cm^{-3})

4.1.10 Soil Organic Carbon Stock

The mean soil organic carbon content in station 1 was 698.32 ± 130.77 Mg/ha and 574.78 ± 64.07 Mg/ha in station 2 (Table 4.14). This indicates that station 1 was not significantly higher in soil organic carbon than station 2 (P value > 0.74) which was confirmed by the Independent-Samples T test.

Table 4.14: Soil organic carbon stocks (Mg ha^{-1}) up to 2m depth

Station 1	Soil carbon (Mg ha^{-1})	Station 2	Soil carbon (Mg ha^{-1})
plot 1	481.24	plot 1	525.75
plot 2	668.28	plot 2	606.76
plot 3	777.21	plot 3	658.69
plot 4	782.67	plot 4	498.24
plot 5	782.22	plot 5	584.45
Mean Soil C	698.32 ± 130.77	Mean Soil C	574.78 ± 64.07
Mean Soil C for two stations	636.55±87.36		

The findings based on soil depth showed that soil organic carbon (%C) content was significantly different ($P < 0.007$) within the depth interval and the highest value was found for the depth of 15-30 cm for station 1 and 0-15 cm for station 2 (Figure 4.12). In both study sites, One-Way ANOVA indicated that there was a significance difference between two stations in terms of soil organic carbon content for each depth interval until 2m ($P < 0.05$, P= 0.01; Figure 4.12).

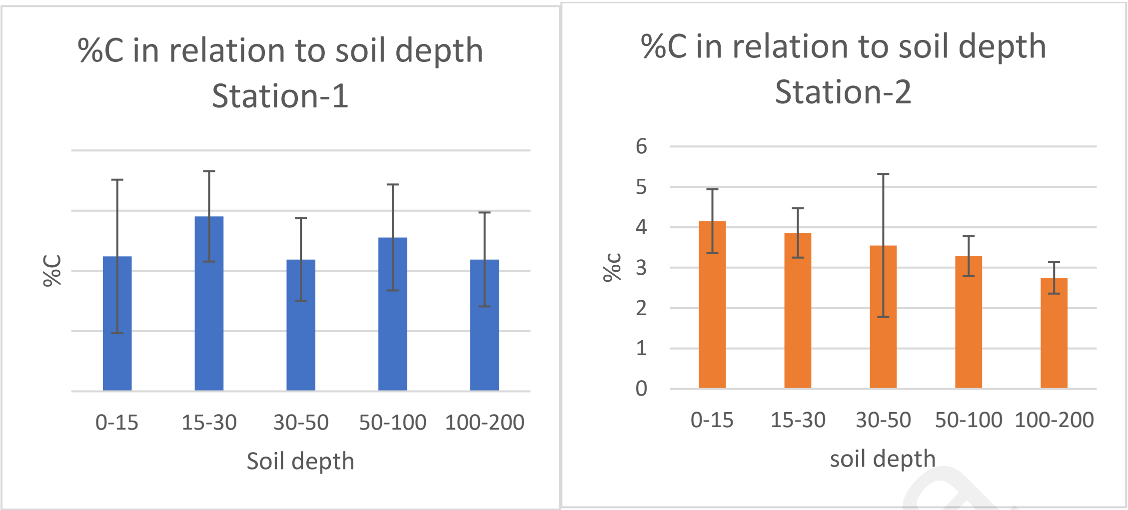


Figure 4.12: Distribution of %C according to soil depth in two stations

In both study sites, One-Way ANOVA indicated that there was no significance (P > 0.29) difference between two stations in terms of bulk density for each depth interval and the highest bulk density was noted for the depth of 100-200 cm (Figure 4.13).

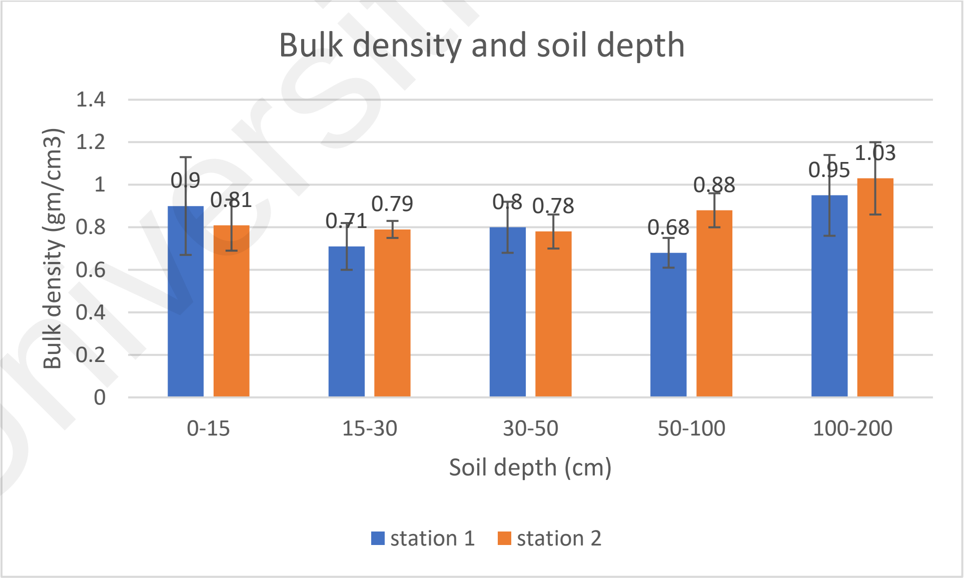
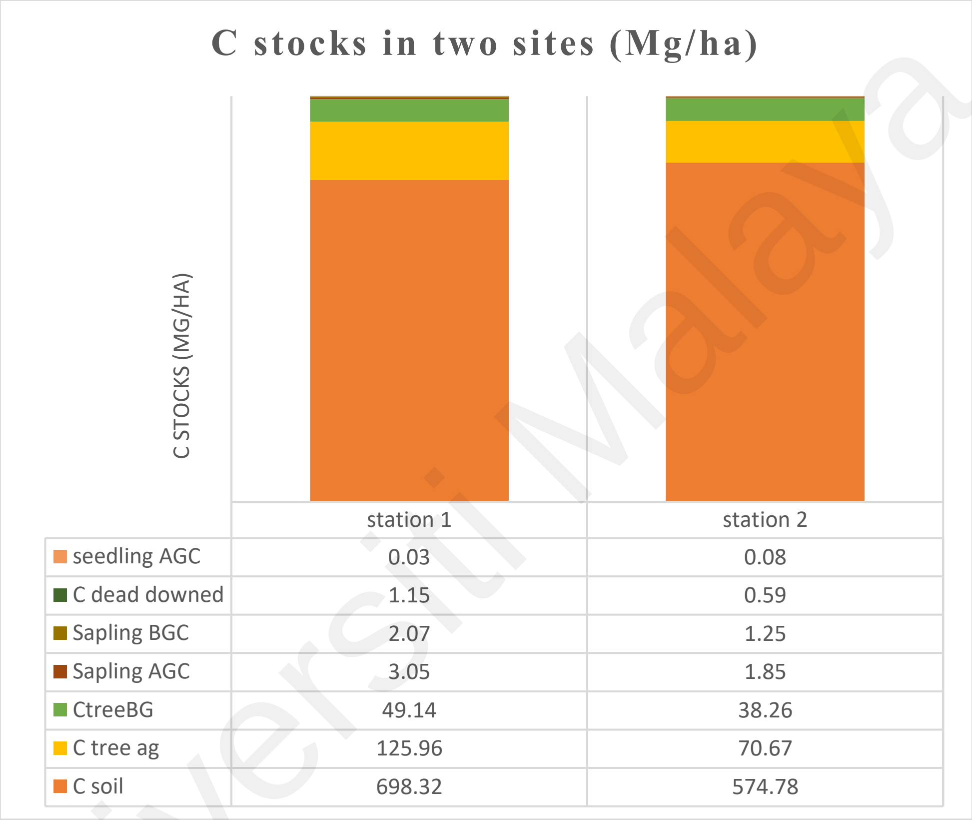


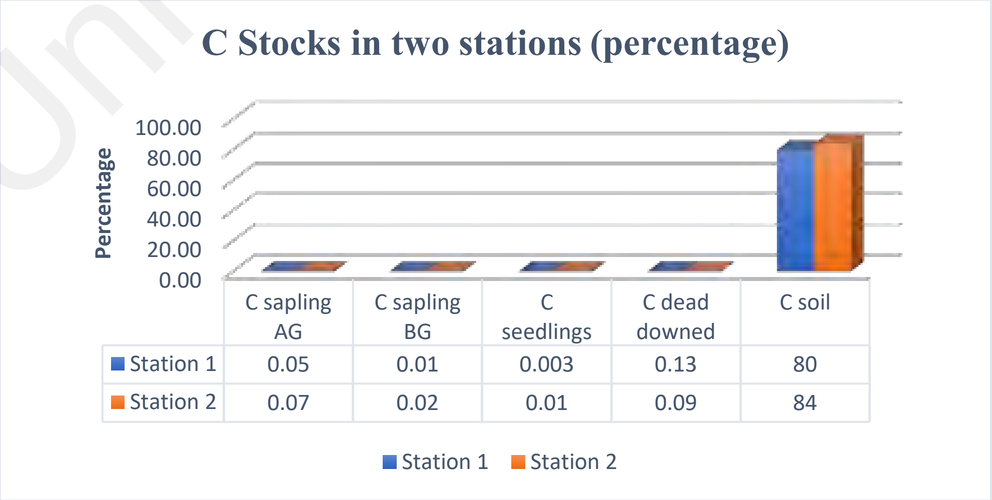
Figure 4.13: Bulk density (gm/cm^3) according to soil depth in two stations

4.2 Total ecosystem carbon pool & CO_2e

As represented in Figure (4.14), the total ecosystem carbon stock in both sites was not significantly different (df = 12, P > 0.79) at 879.70 Mg/ha and 687.46 Mg/ha carbon in station 1 and station 2 respectively. Soil carbon stock dominated 80% of the total ecosystem carbon stock in station 1 and 84% of total carbon stock in station 2.



	station 1	station 2
seedling AGC	0.03	0.08
C dead downed	1.15	0.59
Sapling BGC	2.07	1.25
Sapling AGC	3.05	1.85
CtreeBG	49.14	38.26
C tree ag	125.96	70.67
C soil	698.32	574.78



	C sapling AG	C sapling BG	C seedlings	C dead downed	C soil
Station 1	0.05	0.01	0.003	0.13	80
Station 2	0.07	0.02	0.01	0.09	84

Figure 4.14: Carbon stocks in terms of Mg/ha and percentage at Station 1 and Station 2 in Pulau Pintu Gedong

Total ecosystem for the Pulau Pintu Gedong was estimated by multiplying the average value with project area 807 ha. Finally, the ecosystem C stock for the Pulau Pintu Gedong island mangrove forest was determined which had shown a huge value i.e., 632349.06 Mg C (Table 4.14). Based on the calculations, 632349.06 Mg C × 3.67 = 2320721.05 Mg CO_2e was recorded for whole study area. It means that every hectare of mangrove forest in Pulau pintu Gedong Island is equal to 2875.74 CO_2. There was a significance difference between two stations in terms of total carbon stock and CO_2e value as $P<0.05$ ($P=0.03$).

Table 4.15: Total Ecosystem C stock and CO_2e in whole project area ($P<0.05$)

Sites	**Total carbon stock (Mg/ha)**	**CO2 e (Mg/ha)**
Station 1	879.70	3228.50
Station 2	687.46	2522.98
Average value	783.58 ± 135.93	2875.74± 498.88
Total ecosystem C stock of Pulau pintu Gedong (Mg) [780.08 Mg/ha*807ha]	632349.06	
Total CO_2e of Pulau pintu Gedong (Mg)	2320721.05	

4.3 Potential Market value of Carbon

Voluntary and regulated markets are two such important market that evaluates the amount of C emissions. Before participating, the regulated market needs implementing policies and is more structured than the voluntary market (Ullman et al., 2013). Table 4.15 indicates the market value of carbon based on different sources which includes Voluntary and regulated markets. EU Emissions Trading Scheme (EU ETS), the Clean Development Mechanism (CDM), Greenhouse Gas (GHGs) initiative and Kyoto Assigned Allowance are under the regulated markets. The estimated carbon price based on study area ranges from 13.86 million to 44.31 million in US$ (Table 4.15). The highest market value was estimated from regulated market (44.31 mill) and lowest from voluntary market (13.86 mill).

Table 4.15: Estimated price of Carbon in Pulau Pintu Gedong Island based on different market sources

Market	Price/T (US$)	Total Market value of C for whole Mangrove (Million US$)
Voluntary	6	13.86
EU ETS	19.18	44.31
CDM	15.68	36.23
GHGs initiative	9.69	22.39
Kyoto assigned allowance	13.95	32.23

While most financial organizations use only internal carbon pricing of GHG emissions from their power usage or company travel, certain financial organizations use internal carbon pricing to evaluate their investment portfolio, such as the World Bank and the International Finance Corporation. Table 4.16 summarizes the market value of carbon based on different Internal carbon pricing by Multilateral Development Bank (MDB). The estimated price of carbon was made based on the total mangrove area (807 ha) of Pulau Pintu Gedong Island with a range of 69.62 mill – 109.07 mill (USD). This indicated magnitude of economic value that can be earned through mangrove conservation.

Table 4.16: Estimated price of carbon by Multilateral Development Bank (MDB)in Pulau Pintu Gedong Island

Multilateral Development Bank (MDB)	Market value of C for whole Mangrove (Million US$)
Asian Development Bank	84.24
European Bank for Reconstruction and Development (EBRD)	99.79
European Investment Bank (EIB)	109.07
The World Bank	92.82
The International Finance Corporation (IFC)	69.62

CHAPTER 5: DISSCUSSION

5.1 Mangrove vegetation structure and Biomass

In this study, total of 8 species were recorded out of the 41 mangrove species found in Malaysia (FAO, 2007). The species diversity for this study had similarity with the mangroves nearby for Pulau Indah, Pulau Che Mat Zin, Pualu Ketam and Pulau Klang (Norhayati et al., 2009; Rozainah et al., 2018). Another study showed differences in terms of species composition where two times more mangrove species (e.g., 16 species) were recorded compared to this study as our site had 8 species (Saraswathy et al., 2009). In station 1, 8 different species were recorded while in station 2 there were 4 species recorded. So, this study covered a good number of species in station 1 compared to station 2. As station 1 was near seaside so the variation of species composition was probably more than the inland forest at station 2.

For this study, the most dominant species came from Rhizophoraceae family which is *Rhizophora mucronata* and *Rhizophora apiculata.* This similarity in terms of abundance has also been recorded by other authors for other mangrove forests such as Sibuti and Awat-Awat in Sarawak, Malaysia (Chandra et al., 2011; Shah et al., 2016), and Andaman and Nicober Islands in India (Ragavan et al., 2015). According to previous reports, Rhizophoraceae is the most extensive family as it has the ability to withstand in extreme mangrove environments (Tomlinson, 2016).

The mean DBH for *Rhizophora apiculata* for subplot 4 in station 1 (13.23 ± 5.07 cm) was similar with the previous study in Awat-Awat (14.40 ± 0.40 cm) by Chandra et al. (2011). Figure 4.2 represents the high percentage of young mangrove trees with a DBH less than 15 cm in both study sites. According to Rozainah et al. (2018), the plenty of young individuals in a mangrove forest indicates a healthy population as it will create a suitable environment for sustainable mangrove growth.

According to a study conducted by (Rahman et al., 2015), Basal Area (BA) holds a strong positive relationship with ecosystem C stock in mangrove forest of Bangladesh. Another study suggested that the density of organic carbon in a forest depends on its biomass growth and forest age of mangroves which has a parallel relationship (Wang et al., 2013). Similarly, tree size and density are the main contributor of biomass and wood density highly affects the carbon content of plants (Wilson, 2010). The result of this study suggests significant differences ($P < 0.05$) in carbon stock with DBH of different mangrove vegetation's. Figure 4.10 showed that DBH had a strong positive relationship with ecosystem C stock in both study sites ($R^2 = 0.82$ for station 1 and $R^2 = 0.75$ for station 2 with $P < 0.05$) of Pulau Pintu Gedong mangrove forest. In this study, *Rhizophora mucronata* was the most dominant species in both sites of Pulau Pintu Gedong mangrove forest that was found through IVI value for trees (70.65 for station 1 and 135.67 for station 2; Table.4.4) and for saplings (IVI 94.47 for station 1, and 163.89 for station 2; Table:4.5). This happens because of highest tree density of *Rhizophora mucronata* which was also estimated in Kien Giang Province, Vietnam by Wilson (2010).

Simpson's index showed that station 1 has more diversification of species compared to station 2 (Figure 4.1). The shannon-weiner index values in station 1 and station 2 were 1.53 and 1.12, respectively (Figure 4.1) which was less than Pulau Ketam mangrove forest but almost similar with Teluk Gong mangrove forest (Rozainah et al., 2018). But the pielou evenness index were highest in station 2 (0.81, Figure 4.1) that was similar with the findings at Pulau Ketam and the value for station 1 (0.79, Figure 4.1) was matched with the Teluk Gong (Rozainah et al., 2018). There are similarities between the past and present research findings in terms of species diversity. This could be because of the same geographical location in Malaysia as well as tropics. In tropical ecosystems, climate and other edaphic variables such as soil pH, nutrients, organic matter and tidal inundation do not influence the rate of fluctuation much (Hoque et al., 2015).

Hutchison et al. (2014) presented and assessed the very first worldwide map of potential mangrove AGB. In that study, the total AGB of Malaysian Mangrove forests was estimated with a mean AGB of 252.5 t/ha. The estimated total AGB for our study was ranged from 141.40 t/ha to 251.90 t/ha which was very much supported with the study by Hutchison et al. (2014). Again, the estimated AGB for our study site was higher than other studies done by Rozainah et al. (2018) (AGB range from 108.27 t/ha to 155.58 t/ha) and Tan et al., 2012 (AGB range from 133.90 to 206.93 t/ha). The BGB for our study ranged from 98.10 to 126.10 t/ha which was greater than Pulau Klang, Pulau Ketam and Teluk Gong which was ra nged from 53.66 to 65.06 t/ha (Rozainah et al., 2018). The higher biomass for our study site is due to higher tree density and larger trees compared to other forests such as Pulau Klang, Pulau Ketam and Teluk Gong. Another reason is that Pulau Pintu Gedong mangrove forest is fully intact and not disturbed and degraded forest like Sungai Haji Dorani and it had notably lower AGB (Zhila et al., 2014) in comparison to our study site. So, it is visible that biomass of mangrove vegetation differs in terms of forest condition (such as disturbed, undisturbed) and land us types. In Vietnam, restored and intact mangrove forest was compared, and no significance difference was found (Hong Tinh et al., 2020).

5.2 **Carbon pool**

The two biggest source of carbon pools in a forest ecosystem are the aboveground and belowground biomass of vegetation and organic matter stored in the soil (Chen et al., 2012). Compared with other subtropical forests, the comparatively large vegetation biomass and carbon-rich soils resulted in high ecosystem carbon stocks in the mangrove forest (Kauffman et al., 2011; Wang et al., 2013). In our study site, the highest vegetation carbon stock was recorded for station 1 that was near sea shore compared to station 2 that was near creek (Figure 4.14).

Mangrove derived OC had been generally the major supply of the carbon collected in mangrove soils (Jennerjahn & Ittekkot, 2002). The soil organic carbon (SOC) was disproportionally high in our both study sites in compared to other parts such as trees, saplings, seedlings and dead wood (Figure 4.14). The average soil organic carbon ranged from 698.32 ± 130.77 to 574.78 ± 64.07 Mg C ha^{-1} for both study sites which was comparatively lower than the mangrove in the Mekong Delta (Nam et al., 2016) and Indonesian mangrove (Murdiyarso et al., 2015) but higher than mangrove in Chek jawa (Phang et al., 2015). The total ecosystem carbon stock in Pulau Pintu Gedong mamgrove forest was much higher than mangrove at Chek jawa (Phang et al., 2015) but lower than Montecristi wetland complex that is a mosaic of mangrove (Kauffman et al., 2014). In station 1, the mean soil C was 698.32 ± 130.77 whereas in station 2 the mean soil C was 574.78 ± 64.07 that was recorded in our study.

This high SOC made the total ecosystem carbon stock in mangrove forest higher than any other forest and intertidal habitats (such as seagrass, mudflat and sandbar habitats) estimated by Phang et al., (2015). Our findings, however, indicate that overall carbon concentration in the mangrove forest of Pulau Pintu Gedong is higher than that of other mangrove forests in Sofala Bay (73%) and Hinchinbrook Channel (56%) (Alongi, 1998;

Sitoe et al., 2014). Our study has a range of 80-84% C presented in soil (Figure 4.14) and it confirmed the results from other studies that soil contains between 72%–99% of the total forest carbon of mangrove forest (Gonneea et al., 2004; Sitoe et al., 2014). Again, the OC contribution found in present study was very similar to the study of Chen et al. (2018). The amount of high organic carbon in mangrove comes from the deposition of autochthonous materials such as mangrove roots and detritus, which contribute significantly to mangrove sediment organic carbon (Alongi et al., 1998; Kristensen et al., 2008). Due to their stem morphologies and comprehensive root systems, mangroves are also efficient in trapping and binding sediments (Krauss et al.,2003; Krauss et al., 2014).

5.3 Carbon Dioxide Equivalents and Its Economic Evaluation

Carbon Dioxide Equivalents or CO_2e is used to express ecosystem C losses and to facilitate comparison among other assessments. The estimated amount for GHG emissions is also reported as CO_2 (Howard et al., 2014). Our estimations of CO_2e ranged from 3228.50 Mg/ha in station 1 and 2522.98 Mg/ha in station 2. The total CO_2e for the whole study area was estimated 2.32 million Mg CO_2e which was lower than Dominican Republic (3.8 million Mg CO_2e) reported by Kauffman et al. (2014) but higher than Carey Island, Malaysia (Ashokri & Rozainah, 2015). The reason is probably due to relatively lower land area than Dominican Republic and higher land coverage than Carey Island.

Jerath et al. (2016) estimated the valuation of total organic carbon from \$2–\$3.4 billion and the value of estimated unit area was \$13,859/ha–\$23,728/ha in Everglades mangrove forests, South Florida, USA. The valuation of this mangrove was based on- Eco geomorphic features, Socio-economic geographic climate and the forest status. In terms of voluntary and regulatory market value, our study supports Jerath et al. (2016) which is 13.86 to 44.31 million (USD). The voluntary carbon market offers opportunities for the growth of appropriate protocols and good practice case studies for small-scale mangroves, which will affect greater enforcement services in the future (Locatelli et al., 2014). But our estimated price of carbon was from 69.62 million – 109.07 million (USD) based on Multilateral Development Bank. There is still no single optimal economic value for carbon that vary considerably based on the political and economic environment of the natural resource. Therefore, mangrove restoration programs are increasingly needed because of human and natural impacts in mangroves.

CHAPTER 6: CONCLUSION

In this study, we presented carbon stocks at Pulau Pintu Gedong mangrove forest of Malaysia. The estimated carbon stock in the mangrove forest was 783.58 ± 135.93 Mg/ha and about 80%-84% of which was contained in the soil. The soil carbon proportions to the total carbon ecosystem suggest that mangrove soils are the richest in carbon compared to upland ecosystems. The variation may be because of differences in forest structure, distribution of species, conservation status, depth of soil, concentration of soil carbon, and bulk density. Variations in allometric functions used in the different studies for calculating above-ground biomass can be another factor of variations. Though a moderate carbon stock was found in this study, there should be always given special attention and taken conservation initiatives in carbon sequestration projects of mangrove forests.

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