A COMPARATIVE STUDY OF BIOMASS AND CARBON POOL BETWEEN NATURAL AND DEGRADED MANGROVE FORESTS IN PENINSULAR MALAYSIA

ZHILA HEMATI

THESIS SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

INSTITUTE OF BIOLOGICAL SCIENCES
FACULTY OF SCIENCE
UNIVERSITY OF MALAYA
KUALA LUMPUR

2015

ABSTRACT

The present study involves the assessment of biomass concentration and carbon pool potentials of two major mangrove forests in Peninsular Malaysia; natural mangrove (Kuala Selangor) and degraded mangrove (Sg. Haji Dorani) forests. Various approaches adopted on the study ranged from biodiversity assessment, biomass estimation, to physico-chemical characterizations and estimation of carbon pool potentials. Components of the mangrove assessed included litter production: leaves, stem, branch, propagules and roots across three (3) seasons of Peninsular Malaysia. Shannon- Weniner index (H') was used to assess the species diversity indices while Simpson's index (D_s) and Sorenson's Similarity index (S) were used to estimate the species richness indices of both mangrove areas. Statistical tools (SPSS & Ms Excel) were used to validate and analyze generated data. The forest trees distribution with the study areas gave a population count of 703 individual trees; 302 individuals for KSNP and 401 for SHD. Further investigation among the trees population revealed that species diversity was higher in SHD (5 species) than those found in KSNP (4 species). *Avicennia marina*, *Bruguiera cylindrica*, *Excoecaria agallocha*, *Xylocarpus mekongensis* characterized SHD, and *Avicennia officinalis*, *Bruguiera parviflora*, *Rhizophora mucronata* characterized KSNP, yet a tree species was common to both areas; *Sonneratia alba.* Both areas had a total above- ground biomass of 428.24 t ha^{-1} yr^{-1}; 305.46 t ha^{-1} yr^{-1} from KSNP and 122.78 t ha^{-1} yr^{-1} from SHD. The most pronounced above-ground biomass species were *B. parviflora* (266.74 t ha^{-1} yr^{-1})

for KSNP and *A. marina* (108.63 t $ha^{-1}yr^{-1}$ for SHD). Hence, when both species were further assessed, it was found that the highest percentage of above-ground biomass in tree components was recorded from the stem; 61.62 t ha^{-1} $yr^{-1}$for *B. parviflora* and 49.66 t ha^{-1} yr^{-1} for *A. marina.* In general, the rate of litter production individually ranged from 0.08 to 6.59 g m^2 day and 0.09 to 8.82 g m^2 day for SHD and KSNP, respectively. The maximum individual rate was found in propagules litter where 8.82 g m^2 day was recorded in KSNP and 4.36 g m^2 day found in SHD. Such development might depict an enriched nature of KSNP as an undisturbed mangrove forest. The carbon concentration in KSNP was pronounced in the stem of *B. parviflora* (31.87 t C ha^{-1} yr^{-1}) and *A. officinalis* (14.31 t C ha^{-1} yr^{-1}), and it directly influenced the corresponding carbon sequestration potential of the plant parts where 126.37 t C ha^{-1} yr^{-1} and 54.46 t C ha^{-1} yr^{-1} were found in *B. parviflora* and *A. officinalis*, respectively. Though the stem contained highest carbon concentration in SHD as well, yet it did not directly influence corresponding carbon sequestration potential trend as in the case of KSNP. The total carbon sequestration potential of the living plant parts of KSNP was 125.83 t C ha^{-1} yr^{-1}while SHD recorded 97.15 t C ha^{-1} yr^{-1}. Such variation in the organic carbon content, carbon concentrations and carbon sequestration potentials of different parts of the mangrove species can be due to biological activities of plants. Finally, the net primary productivity showed that KSNP (14.92 t ha^{-1} yr^{-1}) than SHD (13.87 t ha^{-1} yr^{-1}) despite the higher species diversity found in SHD. This may be due to species types and some other associated environmental factors.

ABSTRAK

Kajian ini melibatkan penilaian kepekatan biojisim dan potensi kolam karbon untuk dua hutan bakau utama di Semenanjung Malaysia; Hutan bakau semula jadi (Kuala Selangor) dan Hutan bakau merosot (Sg. Haji Dorani). Pelbagai pendekatan digunakan untuk kajian ini dan di antaranya ialah penilaian biodiversiti, anggaran biojisim, pencirian fiziko-kimia dan anggaran potensi kolam karbon. Komponen bakau dinilai termasuk pengeluaran sampah: daun, batang, cabang, propagul dan akar merentasi tiga (3) musim Semenanjung Malaysia. Indeks Shannon-Weniner (H') digunakan untuk menilai indeks kepelbagaian spesies manakala indeks Simpson (D_s) dan Persamaan indeks Sorenson (S) telah digunakan untuk menganggarkan indeks kekayaan spesies kedua-dua kawasan bakau. Penilaian statistik (SPSS & Ms Excel) telah digunakan untuk mengesahkan dan menganalisis data yang dihasilkan. Taburan pokok hutan dengan kawasan kajian memberikan bilangan penduduk daripada 703 pokok individu; 302 individu untuk KSNP dan 401 untuk SHD. Siasatan lanjut di kalangan pokok yang mendedahkan bahawa kepelbagaian spesies adalah lebih tinggi pada SHD (5 spesies) daripada yang terdapat dalam KSNP (4 spesies). Walaupun *Avicenna marina*, *Bruguiera cylindrica*, *Excoecaria agallocha*, *Xylocarpus mekongensis* dicirikan SHD dan *Avicenna officinalis*, *Bruguiera parviflora*, *Rhizophora mucronata* dicirikan KSNP, namun spesies pokok adalah sama bagi kedua-dua kawasan; *Sonneratia alba*. Kedua-dua kawasan mempunyai sejumlah biojisim tanah above- daripada 428.24 t ha^{-1} yr^{-1}; 305.46 t ha^{-1} yr^{-1} dari KSNP dan 122.78 t ha^{-1} yr^{-1} dari SHD. Spesies yang paling ketara dengan

biomass atas tanah adalah *B. parviflora* (266.74 t ha^{-1} yr^{-1}) untuk KSNP dan *A. marina* (108.63 t ha^{-1} yr^{-1}untuk SHD). Oleh itu, apabila kedua-dua spesies dinilai, didapati bahawa peratusan tertinggi biomass atas tanah dalam komponen pokok direkodkan daripada batang; 61.62 t ha^{-1} yr^{-1} untuk *B. parviflora* dan 49.66 t ha^{-1} yr^{-1} untuk *A. marin*a. Secara umum, kadar penghasilan sampah secara individu adalah antara 0.08-6.59 g m^2 day dan 0.09-8.82 g m^2 day untuk SHD dan KSNP masing-masing. Kadar individu yang tertinggi didapati di propagul di mana 8.82 g m^2 day dicatatkan pada hari KSNP dan 4.36 g m^2 terdapat dalam SHD. Ini mungkin KSNP dicirikan sebagai hutan bakau terganggu. Kepekatan karbon dalam KSNP dalam batang *B. parviflora* (31,87 C t ha^{-1} yr^{-1}) dan *A. officinalis* (14.31 t ha^{-1} yr^{-1}), dan ia langsung mempengaruhi potensi pemencilan karbon yang sepadan dengan bahagian-bahagian tumbuhan di mana 126,37 t ha^{-1} yr^{-1}dan 54.46 t ha^{-1} yr^{-1} ditemui pada *B. parviflora* dan *A. officinalis*, masing-masing. Walaupun batang di SHD mempunyai karbon kepekatan tertinggi, namun ia tidak langsung mempengaruhi corak potensi karbon sepadan seperti dalam kes KSNP. Jumlah potensi karbon daripada bahagian tumbuhan hidup KSNP adalah 125.83 t ha^{-1} yr^{-1} while SHD mencatatkan 97.15 t ha^{-1} yr^{-1}. Apa-apa perubahan dalam kandungan karbon organik, kepekatan karbon dan potensi karbon bahagian yang berlainan spesies bakau boleh disebabkan oleh aktiviti biologi tumbuh-tumbuhan. Akhirnya, produktiviti utama bersih menunjukkan KSNP (14.92 t ha^{-1} yr^{-1}) daripada SHD (13.87 t ha^{-1} yr^{-1}) walaupun kepelbagaian spesies yang tinggi terdapat dalam SHD.

ACKNOWLEDGEMENTS

First of all, I would like to express my sincere gratitude to my supervisor, Associate Prof. Dr. Rozainah Binti Mohamad Zakaria, for her continuous support in order for me to complete my Ph.D. I could not have imagined having a better advisor and mentor for my Ph.D study rather than her. I would like to express my deepest gratitude to my Co-supervisor, Prof. Dr. Mahmood Hossain, for his excellent guidance, caring, patience, and providing me with an excellent atmosphere for doing research.

I deeply appreciate the members of my thesis committee, for their knowledge and expertise in the field. Your constructive feedback and suggestions add great value to my work. I truly admire your dedication and scholarly attitudes as academicians and researchers.

Sincere thanks to all my friends especially, Dr. Emenike C.U., who as a good friend, was always willing to help and give his best suggestions and thanks to Jayanthi Barasarathi for her kindness and moral support during my study. Thanks for the friendship and memories.

Last but not least, my deepest gratitude goes to my beloved parents; Mr. Ebrahim Hemmati and Mrs. Akram Vosog for their unconditional support, both financially and emotionally throughout my studies, and also to my sisters for their endless love, prayers and encouragement. In particular, the patience and understanding shown by my mum, dad and sister during the honors year are greatly appreciated. They were always supporting me and encouraging me with their best wishes.

TABLE OF CONTENTS

CHAPTER 3: MANGROVE FOREST STRUCTURE AND BIOMASS

CHAPTER 4: CARBON POOL

List of Table

List of Figure

List of Plate

ABBREVIATION

AGB	Above-Ground Biomass
BGB	Below-Ground Biomass
BA	Basal Area
DBH	Diameter at Breast Height
FAO	United Nations Food and Agriculture Organization
GIS	Geographic Information System
GHG	Greenhouse gas
GPP	Gross Primary Production
H	Height
IVI	Importance value index
IUCN	International Union for Conservation of Nature
IPCC	Intergovernmental Panel on Climate Change
KSNP	Kuala Selangor Nature Park
Ln	Natural log
NPP	Net Primary Production
QM	Quarter Method
Pg	Petagram
SHD	Sungai Haji Dorani
VCM	Voluntary Carbon Markets
UNFCCC	United Nations Framework Convention on Climate Change
UNEP	United Nations Environment Progra

CHAPTER ONE

INTRODUCTION

1.1 Introduction

Climate change is no longer just a growing concern but rather a nature issue both at the global and local levels. Especially in the presence of the continued quest for growth in economy and military, a consequently raise in the atmospheric CO_2 levels is generating heated debates due to the environmental implications, global warming being the major impact. The foregoing have called for ameliorating steps or approaches typical of reducing atmospheric CO_2 to a reasonable levels, and ensuring a more sustained carbon cycle that will see carbon storage in a holding system for longer times. To this end, forest ecosystem with its beehive of green assembly is reported as the potential solution to the situation (Guerra *et al.,* 2011; Cerón-Bretón *et al.,* 2011). Therefore, understanding how relevant forest and wetlands ecosystem can be to our immediate environment has become extremely important just as the CO_2 in the atmosphere has shown a difference of 407 ppm between what was obtained in the pre-industrial era (280 ppm) and now (387 ppm) (Mcleod *et al.,* 2011), and even with the role of some nations in ensuring stability of greenhouse gas concentration in the system, the current climate system inertia will still avail global warming (Teodorescu, 2010; Cerón-Bretón *et al.,* 2011). The rapid increase in the atmospheric concentration of CO_2 has raised the

specter of severe climate change and much effort has gone into understanding the likely scale and implications of global warming. Today, it is generally accepted that doubling of the CO_2 in the atmosphere would create serious harm and an often-cited goal for stabilizing CO_2 in the atmosphere is 450 ppm, which at current rates of increase world be breached in about 30 years (Klaus, 2010).

Therefore a very important forest ecosystem that is of great interest is mangrove forest. Mangroves are woody plants that grow at the interface between land and sea on tropical and sub-tropical sheltered coasts. Therefore, mangrove trees grow in soil that is more or less permanently water logged (Peter, 1999). A wide diversity of aquatic and terrestrial species of different taxonomic groups resides in mangrove ecosystems (Dinerstein *et al.,* 1995). Mangroves provide timber, firewood and charcoal, fishing poles, pulp and tannin (Hamilton & Snedaker, 1984; Nagelkerken *et al.*, 2008; Barbier *et al.,* 2008). Mangroves reduce coastal erosion, flooding and run-off, and provide nutrients (Lugo & Snedekar, 1974; Mahmood *et al.,* 2003). They also play an important role in carbon fixation and stocking, control of the quality and quantity of water, and the flux of organic particles to the aquatic ecosystem (Dinerstein *et al.,* 1995). Mangroves are important to estuarine fisheries because of their contribution of detritus and dissolved organic carbon within the food webs, and their roots provide shelter for juvenile fish (Mahmood *et al.,* 2005; Mumby *et al.,* 2004; Husch *et al.,* 2003; Machiwa & Hallberg, 2002; Alongi *et al.,* 2001).

Mangrove forests protect coastal communities from cyclone and storm damage, and this function may become even more important as climate change intensifies. Like all plants, mangroves take up carbon dioxide, and mangrove forests are net stores for carbon. Conserving and restoring mangrove forests may therefore play an important role in mitigating climate change. Mangroves further provide firewood, building materials and food for humans, as well as habitat and spawning grounds for fish.

Even at several meters of depth, mangrove ecosystems possess the ability to significantly store large amounts of organic carbon. Such property is often influenced because of the presence of an aquifer level near to the surface, just as the high productivity and the low decomposition rate are due to the slow diffusion of oxygen in these soils (Whiting & Chanton, 2001). Most coastlines of the world are dominated by mangroves (75%) and are adapted to areas characterized by high temperatures, fluctuations in salinity and anaerobic substrates (Day *et al.,* 1987). As reported in Cerón-Bretón *et al.* (2011), about 80% of total organic balance in Union Bays, Florids was obtained by export from the mangrove forest that surrounds the bay. It also gave insight into research by Xiaonan *et al.,* (2008) where in it showed that consequent upon the evaluation of carbon sequestration potentials for Chinese swamps, mangrove forest demonstrated about double carbon sequestration rate (444.27 g C m^{-2} a^{-1}) compared to coastal salt marsh (235.62 g C $m^{-2}a^{-1}$).

However, mangroves have been neglected as potential sinks. It is often viewed to constitute just a fraction of global forests since it covers only 200,000 km^2, yet they constitute the large percentages of forest in some countries and have the potential to expand. This might imply that evaluating carbon budgets for mangroves and exploring the roles of resident plant and animal species with a given location might yield explanation on the optimal drive for rapid carbon storage (Teodorescu, 2010).

Some countries that signed the Kyoto Protocol in a bid to reduce atmospheric CO_2 concentration are bent on generating inventories of carbon storage which are currently integrating the inventory by region and ecosystem. Mangrove forest in Malaysia covers about 645,852 ha (Azahar & Nik, 2003). There are often some disagreements in methods of estimating carbon storage, however paramount interest should be accorded the uncertainty about the factors that influence changes over time. Some mangrove forests in Malaysia remain undisturbed and as such are known to be natural whereas the need of infrastructural development and economic drive has increased anthropogenic activities on some of the mangrove forests; hence the term "degraded mangrove". Some countries have lost over 40% of their mangrove forests over a 25 year period, whereas the remaining ones are in degraded state (Van Lavieren *et al.,* 2012). Currently, Malaysia has some legislative that protect forests, yet the efforts and controls are not enough to check illegal cut down in the mangrove ecosystem.

In order to enhance or understand the mechanism of enriching the carbon stock of the environment, it means that organic matter input is very crucial. Hence different components of mangrove ecosystem cannot be avoided, especially biomass estimation, litter production, carbon pool assessment etc.

Trees remove carbon dioxide from the atmosphere through the natural process of photosynthesis and store the carbon in their leaves, branches, stems, bark and roots. Approximately half the dry weight of a tree's biomass is carbon. Growing trees on soil that has been depleted of organic carbon by regular cultivation or heavy grazing can increase soil carbon after several years.

Trees in forests (including plantations), if well-stocked, typically sequester carbon at a maximum rate that range from 10 to 30 years of age. For instance, at an average of 30 years, about 200 to 520 tonnes CO_2 are sequestered per ha in forests with productivity ranging from low to high (Australian Greenhouse Office 2001). After this age, if the trees are not harvested, the sequestration rate slows gradually until maturity at about 80 to 100 years of age, and flattens out from then on as growth is balanced by decay. Reforesting cleared areas will create carbon sinks to counteract greenhouse gas emissions, and will assist in other aspects of environmental improvement such as salinity control and creation of wildlife habitat.

It can be said that the carbon sequestration benefit from reforestation is determined by the difference in average carbon stock between the previous land use and the forest or plantation. Generalized predictions of the sequestration rate of reforestation projects cannot be made, since growth and sequestration depends on local climate, soil factors and management. For forests managed for timber production on a long-term plant–harvest–replant cycle, the maximum C stock achieved will not be maintained. In such cases it is more useful to consider the average sequestration benefit of each hectare across multiple rotations. A number of computer models have been developed over recent years to estimate the carbon sequestered by forests. Their levels of complexity and required input data vary greatly (Fortunaso *et al.,* 2008).

Measurement of above-ground biomass in forest ecosystem, especially mangroves, is important for Carbon Storage and cycling studies, mitigation of climate change and management of natural resources. Quantifying forest biomass is of crucial importance for climate change studies and forest conservation and management. By quantifying the amount of the above and below-ground biomass and consequently carbon stored in forest ecosystems, we are able to derive estimates of carbon sequestration, emission and storage which help in closing the carbon budget. Mangrove forests, in addition to providing habitat and nursery grounds for over 1300 animal species, are also an important sink of biomass (Alongi, 2002; Hemati *et al.,* 2014a).

Saenger and Snedaker (1993), in a review of many studies described the above-ground biomass of mangrove forests around the world. However, those studies were all based on small-scale, plot-based studies and may be affected by site selection biases. The particular growth form of tidally inundated, high-density forests, with dense aboveground roots has made it difficult to assess mangrove structure and biomass on a large scale in the field (Alongi, 2002; Ellison, 2002).

Several studies have estimated the aboveground biomass density of forests in South-East Asian countries using various approaches. Iverson *et al.,* (1994) developed a geographic information system to estimate total biomass and biomass density of tropical forests in South and South-East Asia. This will be potentially useful to C stocks accounting in the region since available data from forest inventories were insufficient to extrapolate biomass density estimates across the region. The study predicted the potential biomass density of tropical forest without human intervention or natural disturbances. This value was derived from overlaying data on elevation, soils, slope, rainfall and an integrated climate index using geographic information system (GIS).

Similarly, litter production is fundamental to ecosystem process due to its importance to organic matter production and decomposition cycle. From global view point, mangrove is a major productive ecosystem that is not only known for its primary productivity but is as well recognized for export of organic matter and support for variety of aquatic life (Woodroffe, 1992). Litter fall is highly required

in energy and nutrients cycle in the woodland ecosystem (Guo *et al.,* 2006). It mitigates nutrient depletion by tree harvesting and as such do affect sustainability of land use. Whereas obtaining direct methods of measuring primary productivity in mangrove forests are technically difficult Duke *et al.,* (1981) utilized the extrapolation of litter production data for the generation of net primary production.

This is to infer that litter from mangrove swamps potentially represents a significant organic input into the sea, especially where the swamps are extensive, such as on the west coast of the Peninsular Malaysia (Sasekumar & Loi, 1983). Geographical location is even found to influence mangrove productivity. This is because litter production and breakdown rate do not only vary with species but also varies geographically (Guo *et al.,* 2002). In fact in the tropics, mangrove swamps achieve their highest structural and floristic diversity; hence litter production rates in the temperate region are less than what is obtained in the tropical setting (Woodroffe, 1992). Estimates of litter production have been reported for some mangrove forest around the global. Leaf litter production in Florida and Central America was 2 g dry wt. m^{-2} day^{-1}, (Lugo & Snedaker, 1974), the total litter was 2.4 g m^{-2} day^{-1}(Heald, 1971) ; in Queensland it ranged from 1.04 g m^{-2} day^{-1} to 5.26 g m^{-2} day^{-1} (Duke *et al.,* 1981); and Sasekumar and Loi (1983) recorded 3.5 g m^{-2} day^{-1} to 6.72 g m^{-2} day^{-1} in mangrove forest zones of Peninsular Malaysia. Despite the importance of mangrove forest, little has been published on litter production. Similarly, none of the literature has viewed litter

production from the angle of evaluating both natural and degraded mangroves. While some mangrove forests have been left untouched; hence natural, some have experienced alterations and disturbances due to anthropogenic activities like building resorts, fishing etc., thereby making them degraded mangrove forests. Both mangrove forest types characterize Peninsular Malaysia. Therefore this study presents data on the litter production in both natural and degraded mangrove forests of Malaysia, and also aimed to determine the pattern of litter production across the months of seasons.

Understanding the importance of mangrove to the costal ecosystem is very important. Though a number of studies have documented forest diversity, structure and biomass, yet little has been related to its role in carbon pool as it pertains to the productivity of mangrove trees. Moreover, a comparative scenario of natural and degraded mangrove is expected to correct the negligence on mangrove management, wherein some changes go on within mangrove eco-diversity without clear detection (Hemati *et al.,* 2014a). The impact of such losses goes beyond a decrease in carbon sequestration.

1.2 Problem Statement

Economic drive in developing countries is gradually becoming antagonist to environmental protection, and to this end mangrove forests are gradually disappearing (Hemati *et al.,* 2014b). Mangroves are disappearing from all over the world at an alarming rate. Estimates indicate that the mangrove area worldwide

fell below 15 million ha by 2000, down from 19.8 million ha in 1980. The world has thus lost about 5 million ha of mangroves over that 20-year period, or 25 % of the extent found in 1980. Estimates also indicate that mangrove deforestation continued, on a slightly lower rate in the 1990s (1.1% per annum) than in the 1980s (1.9% per annum) (FAO, 2003). About 90 % of global mangroves are growing in developing countries, and they are critically endangered and nearing extinction in 26 countries. Malaysia contributes approximately 12 % of Southeast Asia's mangrove area, along the coasts of Sabah (57%), Sarawak (26%) and Peninsular Malaysia (17%). However, about 1% of the mangrove area in Peninsular Malaysia is being lost each year since 1990 due to conversion to aquaculture, agriculture, deforestation and urban land uses (FAO, 2003; Ong, 1982). With the intention that such conversions enhance economic empowerment, enable infrastructural development and create conducive recreational environment as desired by present day lifestyle, little is known on the magnitude of what is lost.

Carbon sequestration is one of many valuable environmental services that forests provide. Traditionally, society has enjoyed the benefits of environmental services such as clean air, nutrient cycling, and watershed protection without any payment. Such free-riding often leads to underinvestment in management and protection of environmental and natural resources, and result in their degradation. These concerns have generated reason for enquiries into the carbon sequestration capacity and carbon storage rate in forests and other associated terrestrial and

wetlands ecosystems. With most previous studies concentrating on forest ecosystems and crops, little information still exist on the carbon sequestration potential of wetlands. This is to imply that while wetlands act as the main carbon sink, interests focus on carbon storage studies relating to terrestrial ecosystems (Hemati *et al.,* 2014b). Global warming due to unchecked emissions of GHG into the atmosphere is a case in point.

Between 1400 and 1600 Petagram (Pg) of carbon are stored as organic matter in typical tropical soils and wetlands; hence serving as important carbon reservoirs. However limitations on the degree at which soil can act as either source or reservoir of atmospheric CO_2 is highly dependent on factors that range from climatic, textural and topographic conditions to land use practices (Zhang *et al.,* 2007). Wetland of significant importance is mangrove. It has a capacity of carbon sequestration per unit area of approximately one order of magnitude greater than other systems of wetlands (Cerón-Bretón *et al.,* 2011) and can store carbon with a minimum emission of greenhouse gases due to inhibition of Methanogenesis due to sulphate (Bridgham *et al.,* 2006).

1.3 Research Hypothesis

- Anthropogenic activities can affect the state of mangrove forest, hence natural and degraded, and biomass estimation is a distinguishing factor.
- Degree of carbon sequestration will be higher in a natural mangrove forest than in degraded one.

1.4 Objective

- To describe the structure of forest among the selected natural and degraded mangrove forests of Malaysia.
- To estimate above-ground and below-ground biomass of common/ dominant mangrove species that exist in the selected mangrove forests using published allometric equations.
- To estimate the litter standing crop and litter production in the selected natural and degraded mangrove forests of Malaysia.
- To estimate the carbon pool in both vegetation and soil of the selected natural and degraded mangrove forests of Malaysia.
- To estimate carbon sequestration by mangrove plants in the selected natural and degraded mangrove forests of Malaysia.
- To estimate biomass increment and net primary productivity of the selected mangrove forests of Malaysia.

In general, this work has been subdivided into chapters in order to aid easy understanding and conceptualization of the study. Chapter one has formed the introductory part with an overview of mangrove forest ecosystem and carbon-associated components, while pointing out the research hypothesis and objectives. Detailed review of literature characterized F wherein the factors influencing mangrove forest distribution, carbon components estimation and sequestration potentials will be overtly elucidated. Chapter three will capture the biodiversity distribution and estimation of biomass within the natural and degraded mangrove

forests of Peninsular Malaysia as standard methodology will be considered alongside discrete discussion on the results. Furthermore, chapter four will explain the methodology, result and discussions on the carbon pool assessment on the aforementioned mangrove forests. Chapter five will show case the general summary of the findings, while the conclusions and recommendations on the study will be found in chapter six.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Tropical plants that are located along the tropical coasts of the world are referred to as mangroves, and are known to thrive in wet and loose soils, salty water, and sometimes submerged by tidal flows. Certain factors such as climate condition, water salinity, tide imbalance, soil types and even exploitation of tidal wetlands for socio-economic developments, highly influence the global distribution of mangrove (Duke *et al.*, 2007).

Therefore, mangrove forest is viewed to exist partly in two worlds at the same time; it grows within the intertidal portion and estuary mouths that are situated between land and sea. Mangrove trees are often salt-tolerant trees and easily survive in intertidal zones of sheltered tropical shores, islands, and estuaries. This is because of the trees characteristics that range from possession of specially adapted aerial and salt-filtering roots to salt-excreting leaves; hence they survive in saline wetlands that are vulnerable to other plant species. According to Duke *et al.*, (2007), what constitute mangroves are any tree, palm, shrub and even ground fern, as long as the height exceed one half meter, and can grow above mean sea level in the intertidal zone of marine coastal environments, or estuarine margins.

In fact it is considered as one of the most threatened ecosystems (Farnsworth& Ellison, 1997; Valiela *et al.*, 2001; Alongi, 2002; Duke *et al.*, 2007). Only few of the mangrove trees are listed in the Red List of Threatened Species by International Union for Conservation of Nature (IUCN), as a result of the vast distributions of most mangrove tree species (Polidoro *et al.*, 2010). However, this does not mean that most mangrove species and its associated ecosystems are very much intact, rather they are more threatened locally regardless of their many goods and services.

Mangrove ecosystems do not only serve as habitats for many animals and birds, but also for microbes which closely interact with the mangrove vegetation (Cannicci *et al.*, 2008; Nagelkerken *et al.*, 2008; Bouillon *et al.*, 2004; Kristensen *et al.*, 2008). The protection of coastal populations and zones is another significant function of mangrove forests (Badola & Hussain, 2005; Dahdouh-Guebas *et al.*, 2005b; Olwig *et al.*, 2007; Walters *et al.*, 2008; Kaplan *et al.*, 2009) while other forest products abound such as timber and non-timber (Bandaranayake, 1998, 2002; Walters *et al.*, 2008).

Some retrospective research methods have shown evidence of mangrove degradation across the world (Dahdouh-Guebas & Koedam, 2008; Ellison, 2008). Degradations of mangrove forests can be due to anthropogenic degradation (Farnsworth & Ellison, 1997; Alongi, 2002) which is considered a direct form, or cryptic ecological degradation (indirect form) (Dahdouh-Guebas *et al.*, 2005a).

'Cryptic ecological degradation' (Dahdouh-Guebas *et al.,* 2005a) signifies mangrove species such as *Acrostichum aureum* which is minor mangrove plant or an introgressive mangrove-associated vegetation type, can gradually start to dominate a forest to the detriment of the actual, important and functional true mangrove species (qualitative degradation) while still maintaining an intact spatial extent (no change or an increase in area). Also, climatic factors such as rise in sea-level cause global threat to mangrove ecosystems (Gilman *et al.,* 2008). Therefore, it is paramount to have background knowledge to the early drivers in mangrove dispersal (Di Nitto *et al.,* 2008; Triest, 2008), mangrove establishment (Krauss *et al.,* 2008), eventual growth and development of adult mangrove (Komiyama *et al.,* 2008), regenerative constraints (Bosire *et al.*, 2005), and dynamics of mangrove vegetation (Berger *et al.,* 2008) so as to constrict a mangrove recovery plan (Kairo *et al.,* 2001; Bosire *et al.,* 2008).

Mangroves are extraordinary ecosystems, located at the interface of land and sea that offer a considerable array of ecosystem goods and services. They are vital for food security and protection of coastal communities; they provide a wide diversity of forest products, nurseries for aquatic species, fishing grounds, carbon sequestration, and crucial natural coastal defences that mitigate the impact of erosion and storm action. Global climate change and the associated risks of sea level rise and extreme weather events have increased their importance. Calls for conservation have also increased in recent years with growing evidence that

mangroves may have an important role as natural buffers in protecting coastlines from the impacts of storms and extreme wave action.

2.2 Mangrove Distribution and Requirements

2.2.1 Geographical Distribution of Mangroves in the World

According to the International Society for Mangrove Ecosystem, there is about 14 million hectares that serve as habitat for the world's 243 mangrove species including its 30 genera and 62 families. Mangroves are mostly distributed along the coastal zone of the Indian Ocean and Western Pacific; for example Vietnam, Thailand and Malaysia and as such these harbour almost 20% of the world's mangrove forests. Similarly, mangrove forests are geographically distributed on both sides of the equator between latitudes of zero to 25 degrees, comprising of 55 species in 16 genera and ten families. In fact, Bengal possesses largest mangrove forest in the world, covering about one million hectares, while the second largest that covers about 700 thousand hectares can be found within the Nile Delta of Africa (Giri *et al.*, 2011) (Figure 2.1).

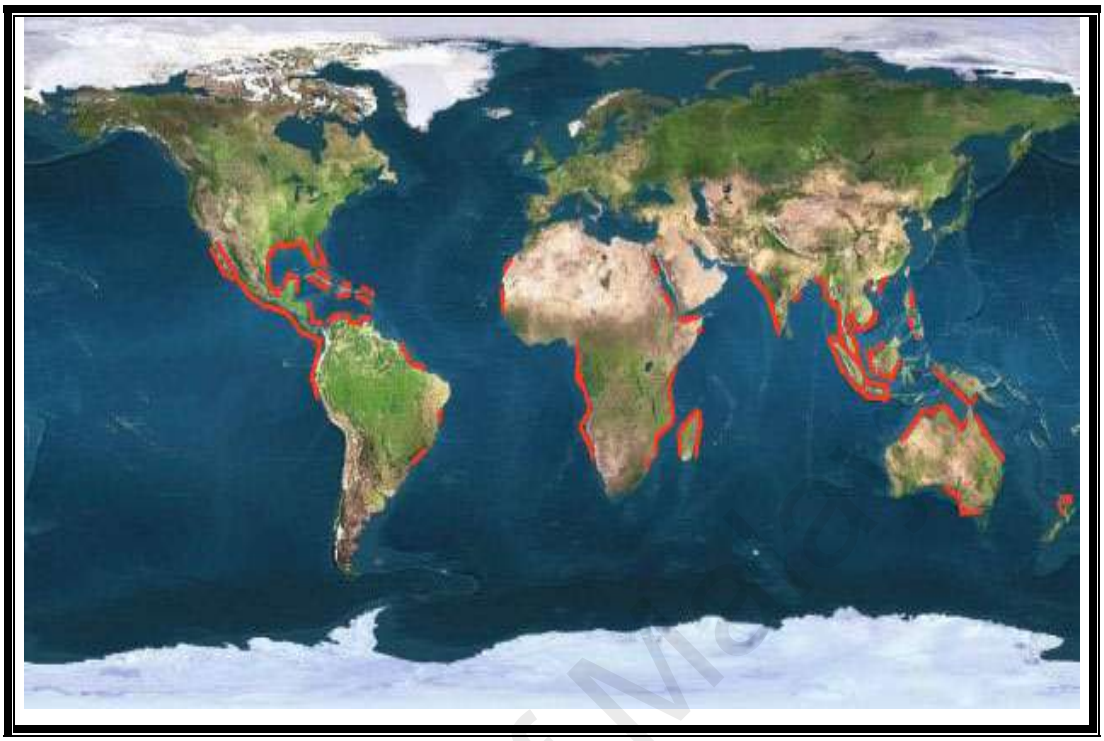


Figure 2.1: Global Distribution of Mangrove Diversity (Chapman, 1977)

2.2.2 Mangrove Distribution in South-East Asia

Southeast Asia harbour a significant size of world's mangrove forest, hence as at 1980, about 34-42% (6.8 million ha) of world's mangrove was found in this region. Unfortunately, it reduced to 5.7 million ha by 1990, which implied about 15% reduction or loss of 110,000 ha per year. Between 1990 - 2000 the annual loss was limited to13.8% (79,000 ha). Hence, according to Giesen *et al.,* 2006, the largest mangrove areas found in Southeast Asia are Indonesia (almost 60% of Southeast Asia's total), Malaysia (11.7%), Myanmar (8.8%), Papua New Guinea (8.7%) and Thailand (5.0%).

With, mangroves now disappearing globally at disturbing rate, estimate indicates that the global mangrove area has now fallen below 15 million ha, down from 19.8 million ha in 1980 (Cuong *et al*., 2005; Nazli & Hashim, 2010; Donato *et al*., 2011, Spalding *et al.*, 2010). Hence, about 5 million ha of this mangrove has been lost within the last twenty years, which is 25% of the existing mangrove in 1980. However, it might imply some degree of reduced deforestation though on a slightly lower scale; the 1990s (1.1% per annum) than in the 1980s (1.9 % per annum) (FAO, 2007). Suffice to state that nearly 90% of mangroves around the world are growing in developing countries and the state of mangroves in 26 countries is too critical in terms of being endangered or nearing extinction (Duke *et al.*, 2007).

There is gross mangrove forest reduction in South-east Asian; in Philippines and Thailand mangrove forest areas reduced from 4,000 km^2 to 1,600 km^2, and 5,500km^2-2,470km^2, respectively within 1961-1986 (Spalding *et al.*, 1997). Kongsanchai (1994) reported that before 1991, almost 50% of mangrove area in Thailand was converted to other land utilization purposes. Similarly, Malaysia has about 12% (5,053 km^2) of its vast mangrove forest with 1980-1990, and such is highly evident in almost all the Malaysia provinces except Malacca (Chan *et al.*, 1993). A major set-back with mangrove assessment in the data inadequacy which most times make it impracticable to estimate the mangrove depreciation/loss within the Asian region. It is worthy to mention that the coasts of Peninsular Malaysia, Sarawak and Sabah harbour 17%, 26% and 57% respectively of

Malaysia mangrove forest. Yet about 1% of the mangrove forest is being lost yearly since 1990, especially in Peninsular Malaysia due to land uses for agriculture, aquaculture and other socio-economic/ urban development (FAO, 2003). Most times little concern is accorded the loss in mangrove areas due to the supposed social-economic and recreational benefits.

2.3 Mangrove Vegetation Structure

Assessing the structure of mangrove vegetation is considered an important part of studies that pertains to ecological dynamics. Therefore, such understanding is pivotal and serves as baseline information for any mangrove management and conservation. Hence, it becomes necessary to understand the core beginning and the ecological dynamics of a mangrove in any particular area before getting on to the levels of protection, afforestation, re-afforestation and management for the purpose of regeneration (Lee *et al.*, 1996; Caloz & Collet, 1997).

Local geomorphology and some other related environmental factors determine the degree of mangrove growth and distribution (Cintron & Novelli, 1984). Hence, regional and localized differences as sometimes exhibited by mangrove stands in terms of structural characteristics are significantly influenced by pronounced environmental factors that differ markedly across geographical regions. This is important as it is considered that forest structure is a core factor when analyzing and managing forest ecosystems (Zenner & Hibbs, 2000). According to James and Shugart (1970), in order to define and assess the spatial heterogeneity and

temporal dynamics of understory vegetation, the understanding the structural characteristic is fundamental.

2.4 Zonation of Mangrove Area

Mangrove forest species are often arranged in zonation patterns as each one occupies its own niche along the coast. The species variation is often related to degree of salinity, quantity of sediments and their distance from the shoreline. Hence, three zones of mangrove habitats can be found in Malaysia mangrove forest, namely; *Sonneratia/Avicennia*, *Rhizophora* and *Bruguiera*. They are mostly domiciled along canals and estuaries, and go on to form islands (Sasekumar & Chong, 2012; Mendelssohn & McKee 2007) **(**Figure 2.2**).** Appendix A shows all the mangrove species found in Malaysia.

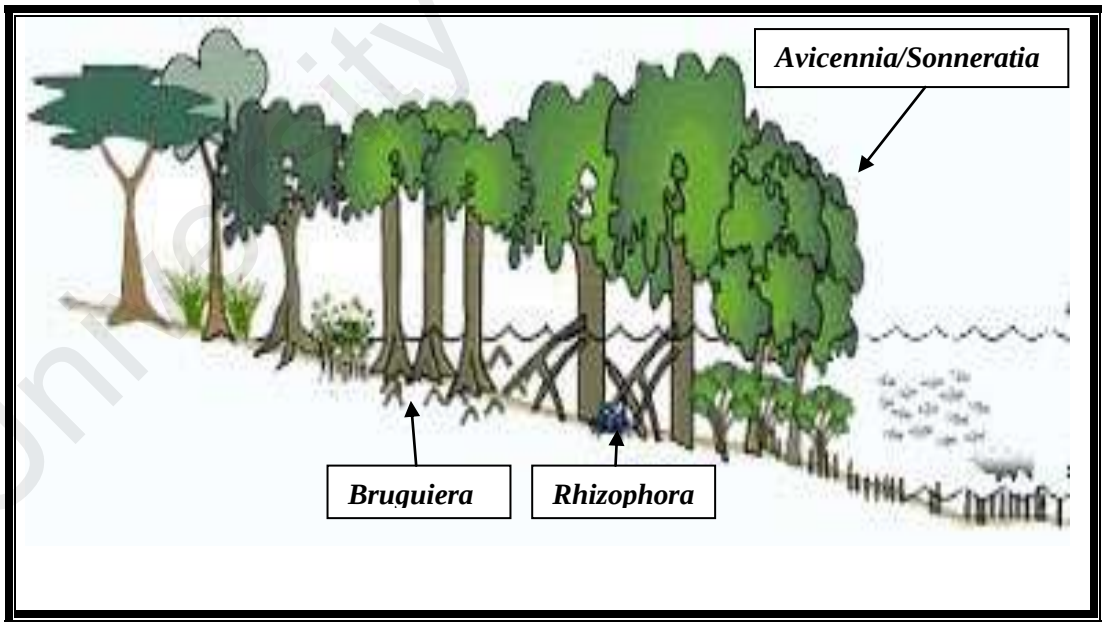


Figure 2.2: Zonation of Mangrove in Malaysia (lighthouse-foundation.org)

2.4.1 *Sonneratia /Avicennia* Zone

Sonneratia and *Aviennia* species are located in first zone of mangrove forest in Malaysia in a mixed pattern and shows high proximity to the water whereby it grow at seaward edge of the mangroves and can be found in almost all mangrove environments (Mitsch *et al.,* 2002). While *Avicennia* species' bark is often smooth, grey-white to green bark that is sometimes flaky, the *Sonneratia* species have thick cone- shaped pneumatophores. Also the bark of *Sonneratia* is covered with a layer of wax, which often protects it against water loss and attacks from creatures (Peter & Sivasothi, 1999; Colin, 1995; Michael, 1997). *Avicennia* species best grow on soils that are open to the air at low tide but covered by high tide. Trees in this zone are usually large and can tower up to 20-25 m and 40 cm in height and diameter at breast height (DBH), respectively. This implied that amongst the other species types, species in this zone are often the largest and tallest due to age. Similar to *Rhizophora* species, they possess roots that are well adopted to enhance oxygen in- take (Figure 2.3). However, they do not have prop roots, yet the root system is characterized of tubular bristles that project vertically and trap the need oxygen for oxygen-deprived (Sasekumar & Chong, 2012; Houck & Neill, 2009; Peter & Sivasothi, 1999; Colin, 1995; Michael, 1997). Both *Sonneratia* and *Aviennia* can tolerate high salinity levels while the trees grow in isolated groups pattern or woodland structure.

Figure 2.3: Roots of the *Avicennia* Species

Generally, seeds of *Avicennia* species do germinate on the parent tree, yet the growing shoot does not penetrate the seed coat while the fruit is still on the tree (known as cryptovivipary). Hence, the shoots appear after the fruit falls off. Germination takes place once the seed falls into water, since the seedlings are small, they can be carried farther into the forest by tides. They are also form entangled network of detritus mats at the roots. It produce seeds all through the year in abundance, and the seeds undergo germination while still attached to the parent tree (viviparous nature) (Figure 2.4). *Avicennia* species have good regeneration ability and coppicing them is very commonly feasible (Sasekumar & Chong, 2012; Houck & Neill, 2009; Peter & Sivasothi, 1999; Colin, 1995; Michael, 1997).

Figure 2.4: Seed of the *Avicennia* Species

The leaves which are often 5-10 cm long have dark green appearance and also silvery and hairy at the undersides. Salts that were absorbed by the roots while taking in water are eventually excreted through the leaves. The flowers are small, and have pale orange flowers that are pollinated by ants and other insects (Figure 2.5).

Figure 2.5: Leaf and Flower of the *Avicennia* Species

2.4.2 *Rhizophora* Zone

Just immediately behind the *Avicennia* species is another mangrove zone called the *Rhizophora*. This species are located in the intertidal zone, where its roots are submerged during high tides. This zone exhibits the highest level of tolerance to salinity more than other mangrove types. Often an evergreen tree, *Rhizophora* species grows to about 25 meters in height and 40 centimeters in diameter at breast height. Such are easily identified with the very visible and pronounced prop and aerial root system that give stability to the trees. The waxy content in the root prevents salt penetration and even the salt that seeps through, it is absorbed in the older leaves which are shed by the tree (Menezes *et al.,* 2003). Structurally, the mangrove tree is often seen as "Walking Tree" (Figure 2.6) because its appearance as it grows in deepest water looks like a tree walking on stilts as its arching prop roots are very visible and support the plant above water. The prop roots have wart-like lenticels for the movement of oxygen through its openings into the system of the underground roots in fact, *Rhizophora* species have a close growth pattern, the roots become entangled and impenetrable, hence forming a network that can slow down the water movement under the tree. Such obstruction allows for the deposition of sediment and traps large quantities of debris and under optimal conditions, such deposits (sediments and debris) form thick layers of organic peat. Similarly the ability of the trees to thrive in brackish water owe to the fact that trees are capable of adapting to its environment by expelling 99% of the salt available in the absorbed water via the roots. Analyzed tissue samples of

Rhizophora species have shown that its water content in terms of salt level has 1/100th of the salt from the habitat water.

Figure 2.6: Root System of the *Rhizophora* Species

Even the seedlings of *Rhizophora* species possess an unusual reproductive adaptation within the watery environment which gives them the survival ability. While the seed is still attached to the parent tree, it germinates from the fruit, and the seedling eventually breaks from the fruit and falls into the water only when it is mature (also known as vivipary). Some can be found at the soft mud within the base of the parent tree and grow from there, while a large number of them float with the tide. It floats only for a short period of time and then it will begin to sink as the pointed end absorbs water. Seedling can grow up to 30 cm in length before

detaching from the parent tree and about 16 to 30 months maturation period is required to obtain mature seedlings from flower bud.

Furthermore, *Rhizophora* species possess leaves that are shiny deep green, lighter on the underside, broad but blunt at the tip and can measure up to 2.5-12 cm. The leathery evergreen leaves also form a dense canopy which effectively converts sunlight to organic molecules. The leaves have yellow flowers (Figure 2.7). However, *Rhizophora* species does not withstand cutting and are sensitive, hence easily die if about 50% or half the leaves are plucked or removed from it. *Rhizophora mucronata* has larger leaves and a propagule about twice the length (Sasekumar & Chong, 2012; Houck & Neill, 2009; Peter & Sivasothi, 1999; Michael, 1997) (Figure 2.8).

Figure 2.7: Leaf and Flowers of the *Rhizophora* Species

Figure 2.8: Fruit of *Rhizophora* Species

The benefits derived from mangrove cannot be ever emphasized as it is a source of fuel, timber, tannin and even railroad ties in the tropics. *Rhizophora* species are most preferred for posts and poles in Malaysia forest management because it has short crop rotation period. Similarly, in Asia, construction of boats, furniture and houses is aided by commercial mangrove production. The calorific value of *Rhizophora* mangrove tree is quite high, hence making it the most prioritized wood for charcoal in Indonesia, Thailand and Malaysia. In fact, mangrove

charcoal is one of the heaviest charcoals, and can be food source (mangrove-derived honey, vinegar, salt and cooking oil), provide drink (alcohol and wine) and have medicinal value (Lovelock, 1993).

2.4.3 ***Bruguiera* Zone**

Farther upland after the *Rhizophora* species is another zone known as the *Brugueria* species, and often characterized of the largest genus in the Rhizophoraceae (Hou, 1958; Tomlinson, 1986; Hogarth, 1999; Saenger, 2002; Sheue *et al.*, 2005) and all six described *Bruguiera* species belong to the "Indo Malayan" group of mangroves, which extend from East Africa to Australia and the West Pacific. With the exception of *Bruguiera exaristata* which is found in Northern Australia and Southern New Guinea (Hou, 1958), the remaining five *Bruguiera* species could be found in Malaysia (Watson, 1928; Wyatt-Smith, 1953; Kochummen, 1989) while four *Bruguiera* species were previously recorded in Singapore (Keng, 1990; Turner and Yong, 1999). Based on flower size and the pollinating agent, various authors (Tomlinson, 1986; Noske, 1993) generally divided *Bruguiera* into two groups. *Brugueria* species with large, recurved flowers (*B. gymnorhiza, B. sexangula, B. exaristata, B. hainesii*) are considered to be bird-pollinated, while the remaining two species (*B. cylindrica, B. parviflora*) with comparatively smaller and erect flowers are probably insect-pollinated.

This species may grow to 25 m tall. Having buttressed at the base of the trunk and knee roots, its species normally grow in sandy soils found at the landward edge of mangrove forests along rivers of the wet tropics where there is substantial freshwater influence. Flowers are red and remain attached to the propagule when it falls. The propagules are green and cigar- shaped, between 10 and 20 cm long, while the leaves are large (10-20 cm) which occur in clumps at the end of branches, the bark is dark and rough bark (Figure 2.9 - 2.10).

Figure 2.9: Leaf and Propagules of the *Bruguiera* Species

Figure 2.10: Roots of the *Bruguiera* Species

2.5 The Functions of Mangroves

In the past, there was no recognition for the relevance of thick weed-like mangrove forests, and need for industrial development, fish rearing and farming, lead to disregard for mangroves. In fact the discharge of wastewater and dumping of rubbish into the estuaries, also lead to the degradation of coastal environments and the eventual loss of most mangrove forests. However, environmental awareness in recent times has risen and people now understand the value placed on wetlands when preserved. Hence the global view on the mangrove forests and the associated significance has changed tremendously to the positive sense (Shing *et al.,* 2014). Therefore the following had been identified as the core functions of mangroves:

2.5.1 Ecological Relevance

Mangroves wetlands are known to be reservoir of accumulate rich organic matter and salt that are deposited from the upstream river and ocean. Considering the fact that mangroves are sited on muddy beaches that serve as point of intersection for river and sea sizable quantity of organic nutrients generated via the biological breakdown of mangrove litter; hence the ensuring nutrients become food source for the phytoplankton found only the coastal waters (especially during the rise and fall of tides). Similarly, aquatic organisms such as fishes, shellfishes, shrimps, crabs and even birds obtain food from the large deposits of organic sediments in the wetlands. It is a good habitat for the aforementioned organisms. Therefore, excluding the fact that mangrove forests enhance the ecological balance of the river estuaries, it creates a formidable detritus food chain in the ecosystem and at the same serve as an intermediate medium linking terrestrial (land) and aquatic (sea) environments(Ong, 1995).

2.5.2 Environmental Protection

Mangroves are good at intercepting silt and using such to develop beaches. Such does not only provide defense for the riverbanks and seashores, but can serve as be barriers that minimize the colossal impact of strong winds and waves. Mangroves use the well adapted silt and aerial roots to enhance water and soil retention. In fact, previously, mangroves were planted along fish pond's shore by fishermen in order to protect the quay and supply food for the fish which in turn reduces costs.

Also, research had shown that mangroves do not stop at providing food and shelter for living organisms, but can filter various degrees of poisonous substances. Hence, it can be inferred that wetlands provide the optimal and pure water treatment system for the sea and estuary. As such, destruction or removal of mangrove forests cause loses of water and soil retention, and the water purification capacity. In absence of mangrove forest, the stability of ecosystem may be affected as a result of erosion of the shoreline by sea waves (Ong, 1995).

2.5.3 Academic and Educational Function

There is same degree of diversity across the components of mangrove forest ecosystem. Among the living components is not just the mangrove plants, but algae and fungi are part of the microbial flora that can be found on the surface of mangrove leaves, whereas birds, arthropods, fish and mollusks are not left out. Therefore mangrove ecosystem is a world of great diversity of combined species. Studying mangrove wetland and ecosystem is of high academic research value as it gives room to evaluate the interdependency of food chains in such and similar environments. It offers a better understanding of a natural environment, just as can be found in Guandu mangrove forest where an integration of migratory birds with natural ecological attributes had established a comprehensive wetland conservation that enables students and tourists alike the opportunity to have a clear introduction and evaluate of wetlands (Marquardt & Trevena, 2009).

2.5.4 Economic Function

Mangroves have a lot of economic benefits among which are the provision of wood for building materials and fuel, which in most cases, the tree bark can serve for denim refinement and extraction of dye. It is used as a windbreaker for fish breeding in the coastal areas of Southeast Asia. Consequently upon the formation of mangrove forest, production of leaf litter becomes imminent and this is good food source for fish which is also very economical.

Species of *Rhizophora*, *Kandelia*, *Bruguiera* and *Ceriops* possess high specific gravity and are therefore preferred for firewood. Also *Rhizophora* species and *Avicennia* species are suitable for brick-burning, while *E. agallocha* is important for boat making. Furthermore, *Bruguiera* species is well adopted for making poles, whereas in honey production *A. rotundifolia* and *C. ramiflora* produce high quality. For human consumption and production of animal feed, *Avicennia* species *S. caseolaris* and *P. paludosa* are useful. Mangrove estuary is characterized of unique scenery that serves as spots for leisure, tourism and recreation. In some Asian countries, mangrove ecotourism is now an increasing trend; such as in Matang, Tg. Piai, Johor (Malaysia), Hong Kong and Thailand (Sathirathai, 2003).

2.5.5 Their Unique Way of Survival

Despite the fact that plants require oxygen in large volume for growth, it is necessary to note that mangrove trees are tolerant to the hypoxic condition of the swamp wetlands found in intertidal zone of the sea and river.

Considering the nature of mangrove surrounding which can be seen as being poor, the mangrove seedlings unlike most plants in the plant kingdom, have developed a viviparous germination to maintain survival. Mangrove fruits do not drop off upon maturity, but they will rather remain attached to the parent tree and develop pencil-shaped viviparous seedlings as it absorbs nutrients. Further survival is enhanced as it ages the lenticels found a the radicle to exchange air, and upon maturity it will drop into the soft mud below which is then carried among by tides to any place conducive for its growth. It survives the search time (time taken to locate a good spot for growth) by photosynthesis using the within the hypocotyl of the viviparous seedlings.

2.6 Natural and Human Stresses on Mangroves

Salt accumulation and/or cyclic storms are often the major forms of natural stress on mangrove system. They cause damages such as loss of foliage, uprooting and erosion. It takes many years for the mangrove to recover from such damage, however, the presence of the mangrove propagules makes regeneration easier. Similarly, dryness can hinder the development of mangrove and when this leads to hyper-salinity (accumulation of salt in soil when the degree of evaporation is higher than amount of rainfall) the resultant effect is the death of mangrove.

Another form of stress to mangrove ecosystem is human stresses which can be as a result of anthropogenic activities whether deliberate or direct. It takes a very long time for mangrove to recover from such stress and may not even recovery in

some cases. Reason behind such detrimental impact is because human activities transform the physico- chemical properties of the place which impairs mangrove development and regeneration. Activities that are sources of human stress to mangrove are overfishing, charcoal production, land reclamation, coastal development, conversion to agricultural lands, waste disposal and pollution (Figure 2.11) (Kathiresan & Bingham, 2001).

Figure 2.11: Shrimp Farms Cover the Area Where Mangrove Forests Once Stood, Bulungan, Indonesia (Copyright: Audrie Siahainenia)

2.7 Mangrove Management Strategy

Mangrove is characterized of diverse, rich and complex ecosystem that is generally a productive resource base. However, poor management practices in general have lead to significant global degradation of this resource base. Some countries had earlier embarked on mangrove forest management with the objective of generating wood, thatching materials and fuel wood which are forest

products, and silvicultural systems were commonly adopted for management of the natural or planted mangrove due to its widespread acceptability. Furthermore, "sustainable management" is another approach added to the mangrove forest ecosystem management in general, while "integrated management" is used to handle the resource component. However, in as much as it is a fact that many countries are seriously thinking or encouraging the adaptation of the latter management approaches, yet no record has shown its successful adoption (Melana *et al.*, 2000).

2.7.1 Mangrove Management in Malaysia

In Malaysia, it is the jurisdiction of the Forest Department in the discrete states to oversee mangrove forests, and as such there are some variations across the states on mangrove management practices. It is interesting to note that one of the best managed mangrove forest in the world is the Matang mangroves which under the management of Forest Department, Perak state, Malaysia (Goessens *et al.*, 2014). The main objective of this mangrove management is to maximize the sustained production of wood for charcoal generation. At present, the management utilizes a 30 year rotation approach as against the 25-40-year method used in the past. For its silvicultural system, trees are cut in alternate strips with a retention standard rate of seven trees per hectare for regeneration with additional artificial planting in depleted areas.

Rhizophora apiculata and *Rhizophora mucronata* are used for Supplementary planting at 1.2 m x 1.2 m and 1.8 m x 1.8 m spacing respectively (FAO, 2003). A narrow belt with 3 m width is maintained as an unworkable area along the banks of the rivers and creeks and the coast so as to mitigate erosion. Major products of Malaysian mangroves include charcoal, firewood, poles, Nypa and wood-chips. About 43000 t/a of charcoal is generated from Matang mangrove forest, and the charcoal kilns generate one ton of charcoal from five tons of green wood. The poles come from thinning process. In fact about three to four million poles are produced from the thinning of 2000 ha of Matang. Most firewood generated from Matang are from *Bruguiera parviflora* that cover about 100 ha/a. Wood chips exported to Japan from Malaysia are mostly obtained from Sabah and Sarawak mangroves that covers about 4000 and 600 ha, respectively and such raw material is used for rayon production (FAO, 2003). Most Nypa leaves that are generated are used for thatching and the young leaves serves as wrapping for tobacco while the Nypa tree is tapped of its alcohol (Goessens *et al.*, 2014).

2.8 Climate and the Mangrove Ecosystem

Climate had direct impact on mangrove ecosystem, and major climatic conditions often associated to mangrove ecosystem are rainfall, light, wind and temperature. These climatic conditions do not limit their roles to plants and animal development, but do influence changes in the abiotic components namely soil and water.

2.8.1 Temperature

The body temperature of plants is influenced by the temperature of its environment; hence they are exothermic. Plant metabolic processes are often affected by extreme temperatures and in some cases it can lead to death of the entire plant or its parts. The most affected parts of plants when temperature is high are the flowers and seedlings. As an adaptive mechanism, mangroves orient their leaves to minimize the amount of light they receive, hence avoiding damage by heat. Some reflective properties of plant can deflect the sunlight away. Temperatures can be reduced by the presence of cool and shaded habitats. Mangrove communities often exist in locations where the average temperature of the coldest month is not less than 20 $^{\circ}$C and the seasonal change will not be more than 10°C. Very low temperature (less than 5°C and frost) also limit mangrove distributions (Tomlinson, 1986). Temperature just like light plays important role in photosynthesis and respiration. Different species have varying temperature requirements. In general, the optimal temperature range for mangrove species growth is from 18 $^{\circ}$C to 26 $^{\circ}$C. This implies that higher temperature (above 26 $^{\circ}$C) as obtained in some tropical mangrove forests may influence mangrove species growth, though depending on plant species. In most cases, the temperature range may not consistent throughout the year as seen in the Figure 2.12.

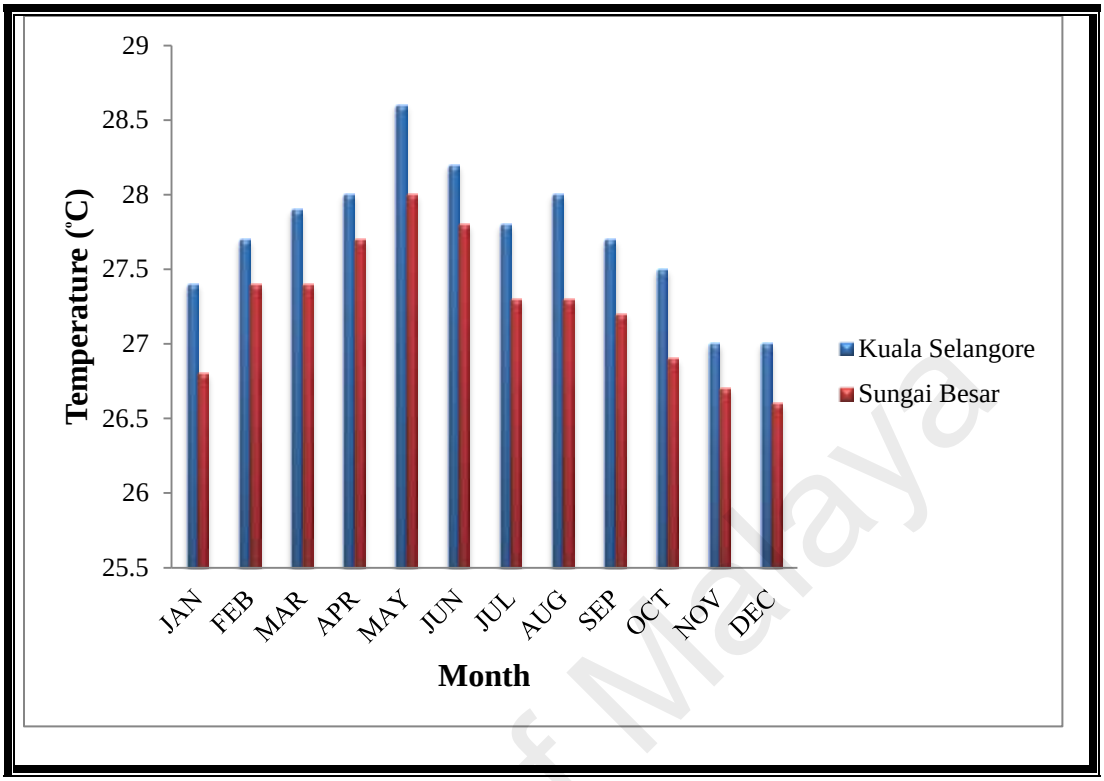


Figure 2.12: Temperature from 2003-2012 for Kuala Selangor (Subang) and Sungai Besar (Sitiawan)

2.8.2 Light

Light is vital for photosynthesis and growth processes of green plants. At the same time, it is important for some other metabolic processes such as respiration, transpiration, and the physiological composition of plants. Mangrove plants need much of sunlight intensity because they are characterized of long-day plants. This is why coastal zones within the tropics are ideal mangrove habitat. About 3000-3800 kcal /m^2 /day of light is the optimum light requirement for mangroves.

Considering the fact that light is very necessary in plant environment, excess or extremely low light intrusion alters plant processes and triggers temperature variations. This is because excess light inhibits important cellular activities in the

plant while very low light causes plant starvation. Light reflection can be enhanced by the tiny hairs on plant's leaves or leaves color. Similarly, some plants chemicals or pigments have the potential to absorb part of the solar radiation. This helps to reduce the possible impacts of excess light intrusion. In situation of inadequate light penetration, mangroves expand their leaves to absorb more light (Ong and Gong , 2013).

2.8.3 Rainfall

Mangrove species are more distributed along coasts that experience high rainfall, heavy run off and water flow into the intertidal zone from the hinterland. Such areas experience high sedimentation, and as such diverse range of substrate types and nutrients abound which favour mangrove growth (Tomlinson, 1986). Rainfall conditions in terms of duration, amount and distribution influence the distribution and development of plants and animals. Air and water temperature, and salinity of the soil are affected by rainfall, hence influencing survival of mangrove species. The optimum rainfall range for mangroves falls between 1500-3000 mm annually. However, amount of rainfall in any given mangrove forest, especially with the tropics, tend to vary across the month (Figure 2.13).

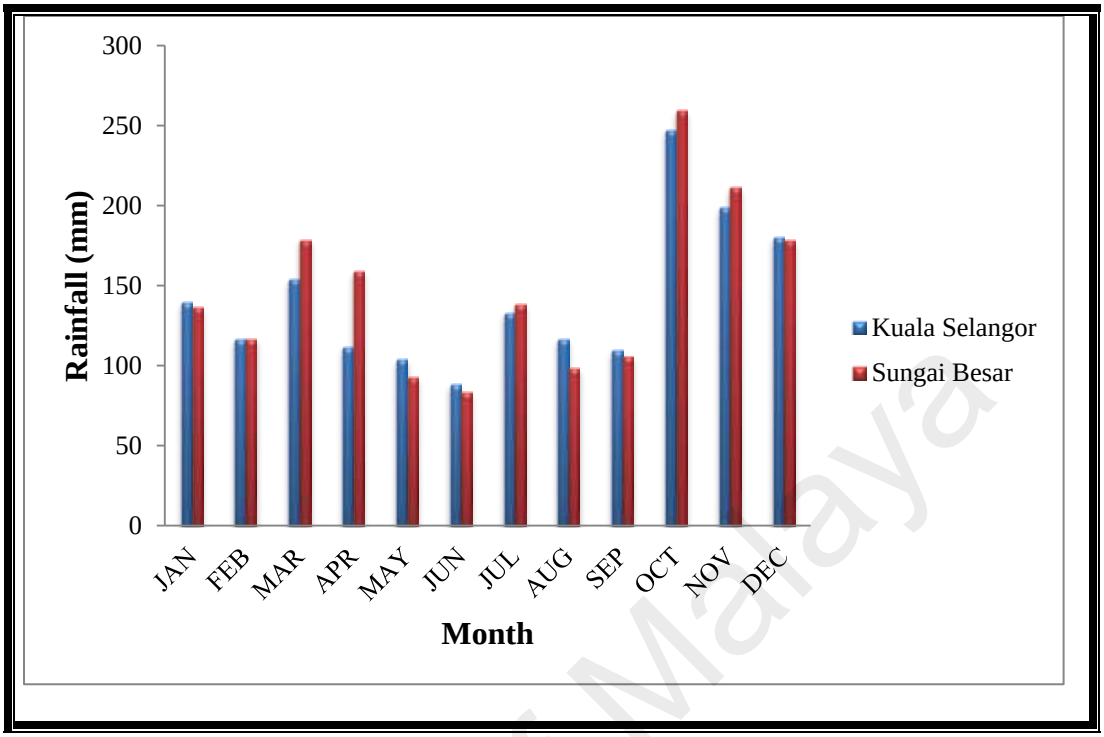


Figure 2.13: Rainfall from 2003-2012 for Kuala Selangor (Mardi Tanjong Karang station) and Sungai Besar (Mardi Hilir Perak station)

2.8.4 Wind

Wind is much needed for plant pollination, dissemination of seed and even the evapo-transpiration that occur in plants. However, plant growth can be affected by strong winds and in some cases it can cause abnormal physiology.

2.9 Ecosystem Structure

2.9.1 Factors Affecting Natural Distribution

Mangrove development depends on abiotic conditions that include tropical climate, shores free from wind and tidal action, fine-grained alluvium, salinity and large tidal range. These conditions affect the distribution of mangrove in terms of

size, species distribution, population and zonation, and some other structural characteristics, including the functional ecosystem (Ong and Gong , 2013).

2.9.1.1 Geomorphic Factors

Sandy beaches, rocky shores and mangrove are pthe core divisions found along tropical coast lines. However, mangroves stretch way farther to the sea and the upper part of river, hence the role tides is significant.

2.9.1.1.1 Tidal Flooding/Inundation

2.9.1.1.1.1 Tidal and Wave Action

The impact of waves and tides within coastal areas is not only felt on the flora and fauna, but significantly affect water salinity as well. Salinity of water varies between spring (highest tidal range period) and neap tides (minimum tidal range period). The infiltration of saline water into the mangrove zone is higher during the spring tides (Ong and Gong , 2013).

Both low and high tidal ranges (Figure 2.14) affect root systems of mangroves. Generally, mangroves experience large tidal range with little undercurrent wave action.

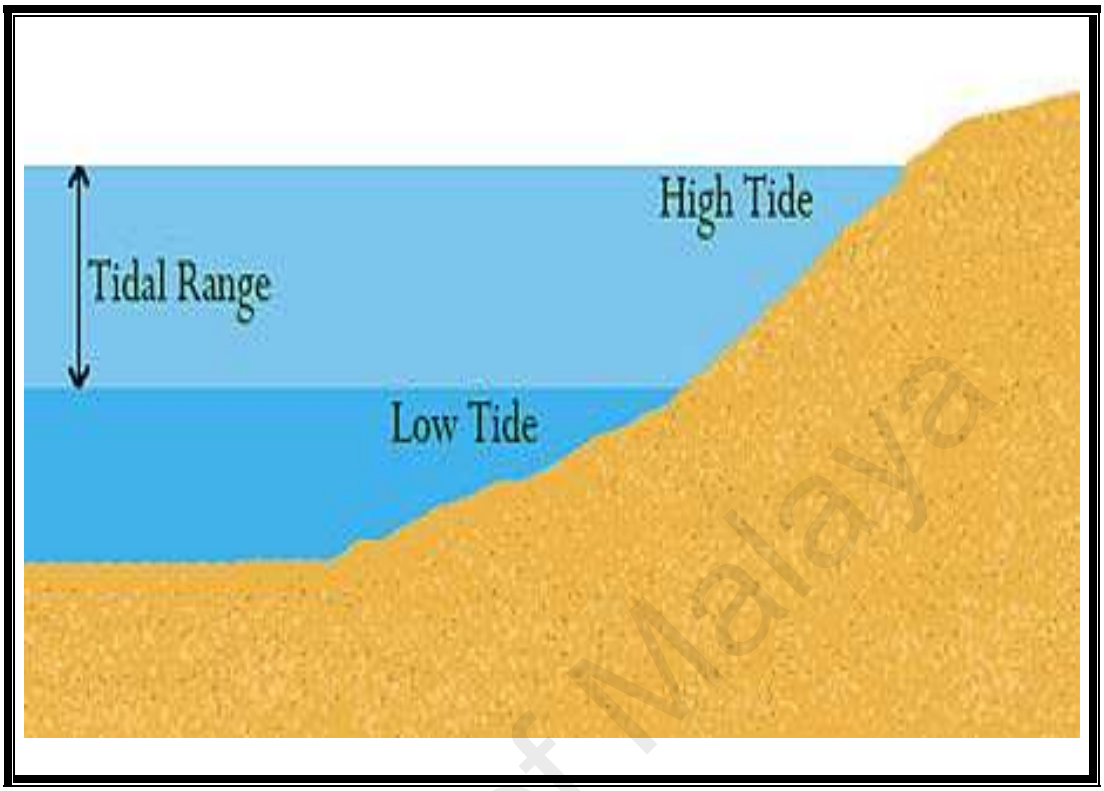


Figure 2.14: Tidal Range (en.wikipedia.org)

In most cases the zonation, distribution and composition of mangrove forest species are determined by the frequency and total time tidal flooding. Considering the fact that mangrove is subdivided into tidal regions in terms of high, mid and low-intertidal areas, comparisons between areas of different tidal regimes is often difficult. Therefore, Watson (1928) introduced an approach by dividing mangrove areas into five inundation classes (Table 2.1). The approach was able to align each inundation class with discrete mangrove species found in the area (Ong and Gong, 2013).

Table 2.1: Tidal Inundation Classes of Mangroves and Common Tree Species Found

Inundation class	**Common species**
1. All high tides inundation (AHTI)	Only *R. mucronata* found on banks of streams
2. Medium high tides inundation (MHTI)	*A. alba, A. marina, S. alba*., and *R. mucronata* predominates areas bordering rivers
3. Normal high tides Inundation (NHTI) (usually the greatest part of the mangrove area)	Allow for the growth of most mangroves. Species like *R. apiculata*, *B. parviflora* and *Ceriops* achieve optimal growth here.
4. Spring tide inundation	Often a day zone for *Rhizophora* species, yet it allows for optimal growth of *Bruguiera* species especially *B. parviflora, B. cylindrical* and *B. gymnorhiza* and the undergrowth ferns. Also found in this area are *A. aureum* and *A. speciosum*, *Lumnitzera* species, *Xylocarpus* species, *E. agallocha* and *F. microcarpa.*
5. Exceptional or equinoctial tides inundation (EETI) (occurs occasionally)	This area is often characterized of the highest species diversity, especially the class 4 species. Most common are pure stands (dotted with *Xylocarpus* species, *Heritiera* species and *I. bijuga*) of *N. fruticans* and *O. tigillarium.* The zone also harbours *B. sexangula* and *B. gymnorhiza,* epiphytes and other mangrove associates.

Most times, these classes of inundation are quantified based on the frequency of tidally inundation per month in a given area. However, there are some limitations with Watson's classification, and as such it is mainly used in Malaysia since it was originally devised for this region. Hence, it is necessary to develop more quantitative and precise description of the classes of tidal inundation which are hydrologically and ecologically meaningful when used across wide (Ong and Gong, 2013).

2.9.1.1.2 Sedimentation and Erosion

Mangroves, as mentioned earlier, are often situated on coasts characterized of fine sediments. Such fine sediments were once eroded by rivers before being deposited in estuarine deltaic plains. For example, Sundarbans which areas about 6,000 km^2 is the biggest single continuous area of mangroves, and this vastly vegetated deltaic plain was formed as result of the dumping of sediments by the giant rivers (Ganges and Brahmaputra) that flows through India and Bangladesh. Mangroves grow do not become saturated with C because sediments accrete vertically in response to rising sea level, assuming ecosystem health is maintained (McKee *et al*. 2007). The rate of sediment C sequestration and the size of the sediment C sink may therefore continue to increase over time (Mcleod *et al*., 2011; Chmura *et al*. 2003).

Both erosion and sedimentation activities often occur simultaneously on every coast, hence it is common to see that while certain area experience eroding affect,

another area will be accreting, even when there is an established mangrove there. Knowledge of and understanding this geomorphological process is very vital and should be properly noted, rather than spending heavily to mitigate natural erosion processes by employing exorbitant hard engineering solutions. Therefore, creating buffer zones that will limit tides to certain areas is often the most efficient and effective solution. Also land run- off and stabilization of sediments in mangrove ecosystem can be enhanced encourage dominance of intertidal salt-tolerant vegetation (Mcleod *et al*., 2011).

2.9.1.1.3 Sea Level Change

Interest in sea level change has been brought forward in accordance with climate change. It is certain that sea level will always change, however, uncertainty surrounds the rate at which it will occur (e.g. millimeters per year) and the direction of change (rise or fall). Hence many factors influence change in sea level in terms of rate and direction of change.

These include:

- The expansion $^{+}$ (increased temperature) or contraction $^{-}$ (decreased temperature)
- Rise $^{-}$ or fall $^{+}$ of tectonic plates
- Melting $^{+}$ of glacial ice (but not free-floating ice such as icebergs)
- Coastal erosion^{-} and sedimentation^{+} rates
- Extraction $^{+}$ of subterranean freshwater

The superscripts $^{-}$ and $^{+}$ indicate relative fall and rise in sea level, respectively. Therefore, the aforementioned factors make change to sea level to be relative and as such site specific. Sometimes the expansion and contraction of seawater in conjunction with melting and growth of glaciers cause the fluctuation in seawater volume. Such change in seawater volume is called eustatic change. Recently, use of satellite-based measurements appears more reliable though measurements are in very short-time series unlike when tidal gauge is used for measurement (Ong and Gong, 2013; Gilman *et al.*, 2006).

2.9.1.1.4 Soil

Mangroves survive and live in brackish water and salty environment characterized of tidal regimes, such as deltas, estuaries and deposited sediments in open coasts. Though they may take over the corals and sandy shores, yet clayey deposits are the most pronounced soil substrates (GFC, 2001). Formation of mangrove soils took place when there is accumulation of sediments originating from river coastal bank erosion or due to deposition of soils eroded from higher areas along canals and rivers.

Among various soil substrates, mud allows optimal growth of mangrove, though its true sense, it may be difficult to classify mud as soil since it lacks enough visible structure. Mangrove ecosystem is a typical example of an edaphic tropical forest type, where the 'soil' is mud. Similarly, beach vegetation or strand where the soil is sand can also be seen as another edaphic type.

Mud is basically a mixture of minerals gotten from rocks due to weathering. It lacks sufficient organic matter, but with mangroves growth on it, more organic matter is added as leaves and root litter decay on it. Hence it is normal to find high organic matter content in mature mangrove forest soil than in other soils which is partly due to the fact that the plant parts are buried in anoxic or low oxygen soil which does not the organic matter to decompose easily. Therefore this property of mangrove soils makes it an effective carbon sink (Ong and Gong, 2013).

The anoxic conditions enhance the presence of anaerobic sulphur bacteria that easily produce hydrogen sulphide in the deeper anoxic mud. In most cases, the odour of hydrogen sulphide goes unnoticed in the mangrove except where the surface soils have been disturbed significantly. Similarly, methane, also referred to as swamp gas, is produced by anaerobic bacterial as well, but the sulphate rich nature of seawater that inundates mangroves cannot allow it to form there (Kristjansson & Schonheit, 1983).

Mangrove soils that are dominated by *Bruguiera* are characterized of less sand and more clay for a lower bulk density than fringe forest soils. Such soils possess more humus, higher cation exchange capacity and lower phosphate absorption potential than those of the fringe forests. Despite the low nutrient concentrations within the surrounding waters, the fringe mangrove communities are known to be

highly productive. Hence, one can infer that the prop root community may be a metabolic 'hot spot' for nutrient regeneration and oxygen consumption within the fringe mangrove ecosystems.

Nutrient mobility significantly varies with nutrient content within different soil zones, hence making sampling depth an important aspect. The following depths are recommended during sampling (Table 2.2):

Table 2.2: Nutrient Content in Different Soil Depth

Depth	To measurement
0-15 cm	P, K, Cl, S, Ca, Mg, Zn, Fe, Mn, Cu, soluble salts
15-60 cm	soluble salts, NO_3 N^-, S, Cl (in addition to 0-15 cm depth)
60-120 cm	NO_3 N (in addition to 0-15 cm and 15-60 cm depth)

Source: (Kristjansson & Schonheit, 1983)

2.9.1.1.4.1 Soil Texture

Crop production and field management are highly influenced by soil texture. Soil texture determines the rate at which water drains through a saturated soil; water moves easily through sandy soils than when passing through clayey soils. Once field capacity is reached, soil texture also determines the extent to which water is available to the plant; the water retention capacity of clay soil is higher than with sandy soils. Also a much drained soil often have good soil aeration which is similar to atmospheric air contain, and is a healthy environment for root growth,

and thus a healthy crop. Based on texture, soils can also differ in erodibility: erodibility is higher in a soil with a higher percentage of silt and clay particles than a sandy soil within the same conditions (Wei *et al.*, 2006).

Also, soil texture influences organic matter contents. For example, in sandy soils the organic matter breaks down faster than in fine-textured soils under same environmental conditions because increased oxygen level abound in the light-textured sandy soils for decomposition. The content exchange capacity of the soil increases with percentage of clay and organic matter and the pH buffering capacity of a soil (its ability to resist pH change upon lime addition), is also largely depend on clay and organic matter content (Adekayode and Akomolafe, 2014).

2.9.1.1.4.2 Classification of Soil Texture

The textural classification of soil is done by assessment of combined portions of sand, clay and silt soils. Size ranges for sand, silt and clay soil fraction are 0.05–2.0 mm, 0.002–0.05 mm, and less than 0.002 mm in diameter, respectively. However, rocks or gravel of more than 2 mm in diameter are not considered when determining texture. The textural triangle is used to identify the textural class of any given soil sample as long as the sand, silt, and clay percentages are known (Figure 2.15). Therefore the four major textural classes of soil are sands, silts, clays, and loams (Saglam and Dengiz, 2012).

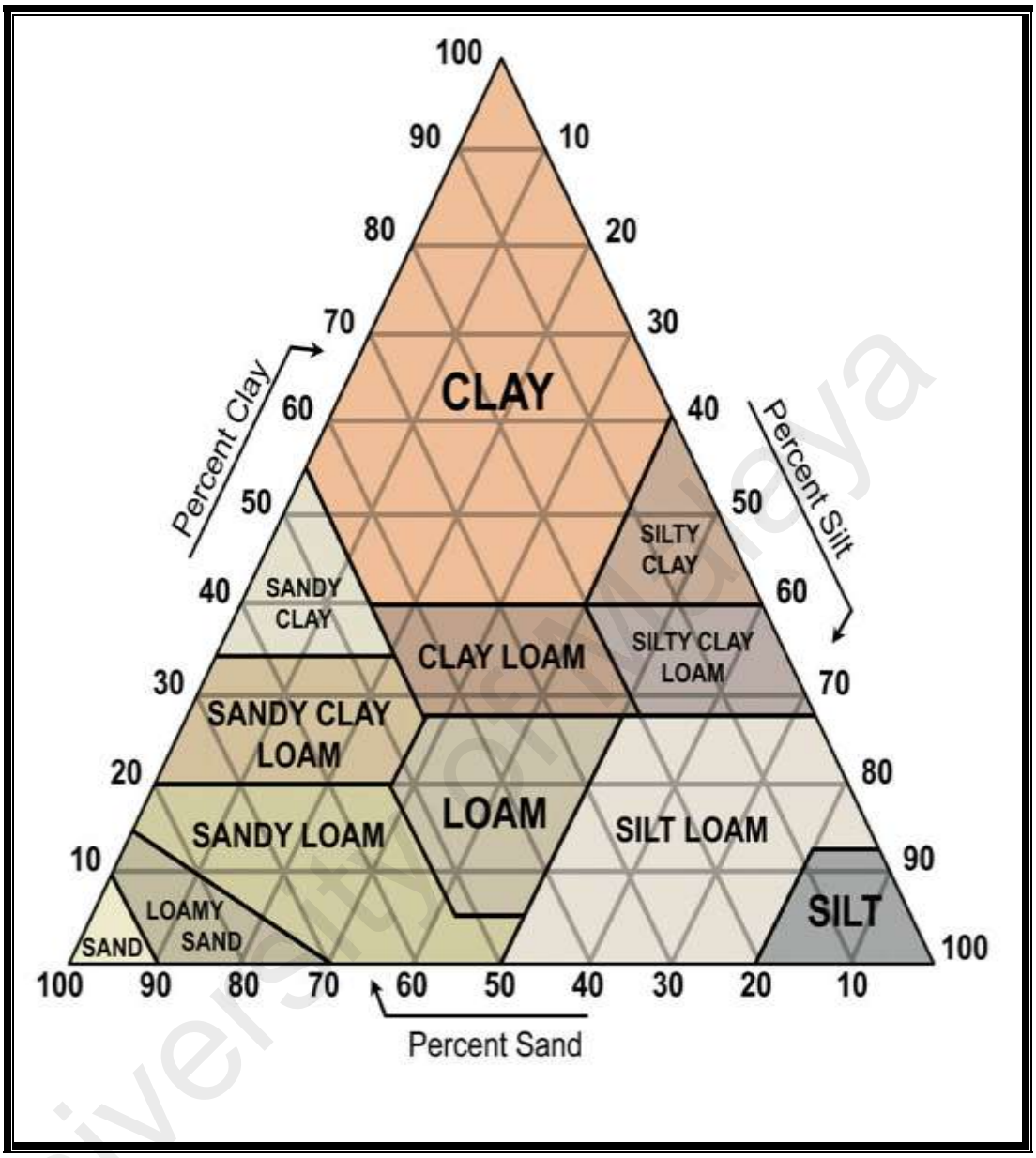


Figure 2.15: Soil Textural Triangle (soilsensor.com 2007-2011)

It is necessary to note that soil texture should not be confused with soil structure, as the latter represents the pattern at which soil particles are aggregated together. Best management practices such as reduced tillage can be used to improve soil structure, but such can be expensive and is not easily advisable to modify soil texture (Wayne *et al.*, 2007).

2.9.1.1.4.3 Methods for Soil Texture

Sieving of soil is one of the methods used to determine its texture. This can be done by adopting the dry or wet (washing type) method. Sieve method is not without limitation; the nature of the particle to be sieved, the number of particles at a particular size, the properties of the sieve and shake time determine the probability of a particle passing through the sieve (Gee & Bauder, 1986).

Figure 2.16 A shows the top view of selected sieve often used for USDA/USGA particle size analysis, while Figure 2.16 B is shake of nested sieves that was loaded on to a mechanical shaker. In a nested stack of sieves, the arrangement of the sieves is in the ascending order of sieve holes starting from the bottom (implies the largest holes size is at the top).

A B

Figure 2.16: Sieving Equipment

2.9.1.1.5 Salinity

Due to the toxic effect of Sodium (Na^+) and Chloride (Cl^-) ions on plants, salty environment (often involve the two ions) is often a stress to mangroves. Similarly, mangrove roots find it difficult to take up water from salty soil. Hence, mangroves deal with salt by adopting different strategies; these include shedding of salt via the roots or excreting salt via leaves and stem, while in some cases the salt is stored as ions in the plant. Despite the stress impact of salty environment to mangroves, it is pertinent to note that mangroves thrive over salty environment compared to other group of plants. However, mangrove tolerance to saline environment varies across species. There is no stipulated limit of interstitial water salinity which mangrove species can tolerate, but 28-34 ppt is the optimal range (Aksornkoae, 1993).

2.10 Forest Biomass

Forest ecosystem is very important in the global carbon cycle. About 80% and 40% of all above-ground and below-ground terrestrial organic carbon, respectively are stored in the forest ecosystem (IPCC, 2001). Vegetation often takes up CO_2 from the atmosphere during the productive season and is stored up as plant biomass (Losi *et al.*, 2003; Phat *et al.*, 2004). Hence the role of forests in carbon sequestration became recognized by UNFCC. In fact, forest is termed as potential carbon storage in Article 3.3 and 3.4 of the Kyoto protocol (Brown, 2002; United Nations, 1998).

Decomposition of vegetation allows the release of carbon into the atmosphere, and additional carbon is often returned to the atmosphere (more than amount used for photosynthesis) as both natural and anthropogenic activities take place within the forest ecosystem (Brown, 2002). Therefore, in order to make forest a carbon storage rather than source, it is imperative to encourage sustainable management approaches over forest ecosystem.

The state of tropical forest has continued to deteriorate. Conversion of land for other development uses account for the 93.4% cause of yearly net forest loss, while the other 6.6% is due to conversion to plantation forest. Forest mismanagement is the cause of land conversion, especially the execution of illegal forest practices and inadequate of well-structured and implementable policies and regulations that will ensure sustainable forestry (FAO, 2001).

Therefore, "biomass" according to FAO (2004), is "*organic material both above-ground and below-ground, and both living and dead, e.g., trees, crops, grasses, tree litter, root etc".* Hence, all living biomass above the soil such as stem, branches, seeds, stump, bark and foliage are grouped under the above-ground biomass. On the other hand the below-ground biomass including all living roots with the exception of fine roots which are often less than 2mm in diameter. Two biomass units, namely fresh weight (Araujo *et al.,* 1999) and the dry weight (Aboal *et al.,* 2005; Ketterings *et al.,* 2001; Montagu *et al.,* 2005; Saint-Andre *et al.,* 2005) are the two forms used in biomass estimation. However, the dry weight method is preferred over the fresh weight for the estimation of carbon

sequestration potential because it avails 50% of its carbon (Losi *et al.,* 2003; Montagnini & Porras, 1998; Montagu *et al.,* 2005). Also most studies on biomass assessment often focus on the estimation of the above-ground forest biomass (Aboal *et al.,* 2005; Brown, 1977; Losi *et al.,* 2003; Laclau, 2003; Kraenzel *et al.,* 2003; Segura & Kanninen, 2005) since it accounts for the majority of the total accumulated biomass in the forest ecosystem.

Lu (2006) mentioned three approaches to biomass assessment. These are field measurement, remote sensing, and GIS- based approach. The field measurement is considered to be accurate (Lu, 2006) but proves to be very costly and time consuming (de Gier, 2003). In any of these approaches, ground data is important for validation. In the case of remote sensing, ground data is needed to develop the biomass predictive model. This means, it is always necessary to have a field measurement of biomass for predictive modeling or validation purposes. Typically, the procedure is to randomly select sample trees, measure the tree variables (such as DBH or tree height) and the tree biomass, then develop biomass equation using these measurements. The developed biomass equation is used to estimate the tree-based biomass.

Two methods of measuring sample tree biomass are available (1) destructive and (2) non- destructive. The conventional destructive method is done by felling the sample tree and then weighing it. Direct weighing can only be done for small trees, but for large trees partitioning is required. Partitioning is necessary so that the partitions can fit into the weighing scale. In cases where the tree is large,

volume of the stem is measured. Sub-samples are collected, and its fresh weight, dry weight, and volume are measured. The dry weight of the tree (biomass) is calculated based on the ratio of fresh weight (or volume) to the dry weight. This procedure requires considerable amount of labour and cost, and the use of ratio is often biased (Cochran, 1963).

A new destructive method proposed by Valentine *et al.,* (1984) and later adapted by de Gier (2003) uses the principle of randomized branch sampling and importance sampling. In the randomized branch sampling, a "path" is determined starting from the butt and ending at the terminal bud. The segments (nodes) comprising the "path" is selected with probability proportional to size (pps). Unconditional probability of selection for each section is calculated. Along the path, the various points and places where a change of taper occurs, are often located. The inflated area of points measured along the path is calculated by dividing the diameter squared by its unconditional probability. The calculated inflated area is used to calculate the volume of the segment, say by Smalian's formula. The unbiased woody tree volume is the sum of these segment volumes (de Gier, 2003).

After the path is selected, importance sampling come in to randomly locate the sample disk. The whole path is viewed as consisting of infinitely many thin disks, of which one is selected with probability proportional to its diameter squared. To determine the location of sample disk, the tree woody is multiplied with a random

number and the segment where this volume is reached is identified. The exact location of the sample disk within the identified segment is determined by interpolation. The weight per unit thickness of the disk is determined and divided by the unconditional probability assigned to the segment from where it is removed. Multiplying this value with the estimated tree woody volume, and dividing it by the square of the disk diameter gives the woody fresh weight. The woody dry weight is calculated in the same manner as the fresh weight (de Gier, 2003). The determination of path reduces much of the work as those tree segments not included in the path are not measured. Furthermore, there is no need weight the whole tree; hence, it is efficient in terms of time and cost. However, the procedure uses considerable amount of computation that decent computing equipment (e.g. HP LX200 palmtop computer or iPaq equipment) is necessary.

The non-destructive method does not require the trees to be felled. Measurement can be done by climbing the tree and measuring its various parts and computing the total volume. Tree density which can be found from literature is used to convert the measured volume into biomass estimate (Aboal *et al.,* 2005). This procedure takes even more time and cost to perform. Another procedure is taking of two photographs of the tree at orthogonal angles. Then the scale of the photograph is calculated so that the volume of each tree components (stem, branch, foliage) can be calculated. Density of the different tree components is calculated and used to convert the volumes into biomass (Montes *et al.,* 2000). However, the calculated biomass from these procedures cannot be validated unless the sample tree is felled and weighted.

Once sample tree variables and biomass data are obtained, and the biomass equation is developed, it is then applied to each tree in the sample plots to obtain the plot biomass. The forest biomass is then estimated by the corresponding sampling design formula for the mean and total estimator or by predictive modeling using remotely sensed spectral data.

Studies by Parresol (1999) and Zheng *et al.,* (2004), had demonstrated two key objectives of biomass assessment, which were; 1) for the purpose of resource use, and 2) environmental management. For example, it is necessary to know or quantify the extent of timber or wood that is available for use. Hence, it becomes imperative to assess how much of biomass is available at a particular time. Quantification of biomass is very important in environmental management because it shows the degree of productivity biomass quantification is important to assess the productivity and the sustainability potential of the forest. For carbon sequestration, biomass is an important indicator, hence estimation of both accumulated and lost biomass over time is necessary (Losi *et al.,* 2003). In fact, Kyoto protocol advocates for a transparent reporting of forest removal and accumulation (biomass change). This implies the use of precise procedure to quantify forest biomass and its uncertainty.

Precise and properly quantifying forest biomass is essential in conducting research climate change and forest conservation. The quantification of both above-ground and below-ground biomass invariably quantifies the forest

ecosystem's stored carbon, hence one can derive estimates of carbon sequestration, emission and storage, and even help close the carbon budget (Alongi, 2002; Lucas *et al.*, 2007). In addition, mangrove helps to increase ocean's dissolved organic carbon (10%) by exporting litter and leaves into offshore areas (Dittmar *et al.*, 2006). For the above-ground biomass of forest, two major scales adopted are; 1) on –the- plot scale (means field measurements of biomass), and 2) derivation of allometric equation and measurements of forest plots. In order to obtain a wider or regional estimation of biomass, careful calibration of the remotely sensed data from field is carried out.

Mangrove forests are very productive ecosystems and most cases, the carbon is either buried in sediments locally and in adjacent systems or stored in forest biomass as the trees grow. Three different global estimates for carbon burial within mangrove systems all concur on a value equivalent to 18.4×10^{12} g C yr^{-1} when applying a global area of 160,000 km^2 (Chmura *et al.,* 2003). When compared to tropical forests, mangroves have shown higher carbon sequestration efficiency (Laffoley & Grimsditch, 2009). Yet, it is rather unfortunate to note that above 50% of globle's original mangrove forests is no more (Valiela *et al.,* 2001) at the rate of 2% every year (Spalding *et al.,* 2010).

2.10.1 Biomass Increment

The biomass the plant puts on in a year is part of the net primary production. In the mangrove forest, the annual increment in above-ground biomass ranges from 4 t ha^{-1} yr^{-1} in an *Avicennia* mangrove forest in Mexico (Day *et al.,* 1996) to 26.7 t ha^{-1} yr^{-1} in a *Rhizophora* forest in Thailand (Christensen, 1978). Very little has been done on below-ground biomass increment in mangrove ecosystems. Considering that the below-ground root biomass could be up to 57% of the biomass as in the case of *B. exaristata* (Comley & McGuinness, 2005), it is possible that the below-ground biomass increment could be a significant contributor to the total biomass increment. Ong *et al.,* (1995) estimated below-ground root productivity of a *R. apiculata* stand to be 0.42 t ha^{-1} yr^{-1}. In the same stand, the canopy (leaves and branches) productivity was 0.52 t ha^{-1} yr^{-1}. Thus, the below-ground productivity is almost as high as the productivity of the canopy although the below-ground biomass is only about half that of the canopy in this mangrove stand.

2.10.2 Allometric

When trying to measure DBH of mangrove species, allometric relationships among stem, biomass, leaf, total above- ground biomass and branch are estimated. Allometric relationships include determining the relationship between the whole trees biomass, or their different parts, and other existing measured parameters especially as the DBH. For example, reported works are limited to *R. apiculata* (Ong *et al.,* 1985; Putz & Chan, 1986) and *B. parviflora* (Mahmood, 2004, Ong *et*

al., 1985) unlike other common species as relates to allometric relationships that involve DBH and above ground biomass. Basically, the measurement of tree's DBH is taken at above the 1.3 m height of the tree or somewhere at the peak of the prop-root of the tree such as *Rhizophora* species (Figure 2.17).

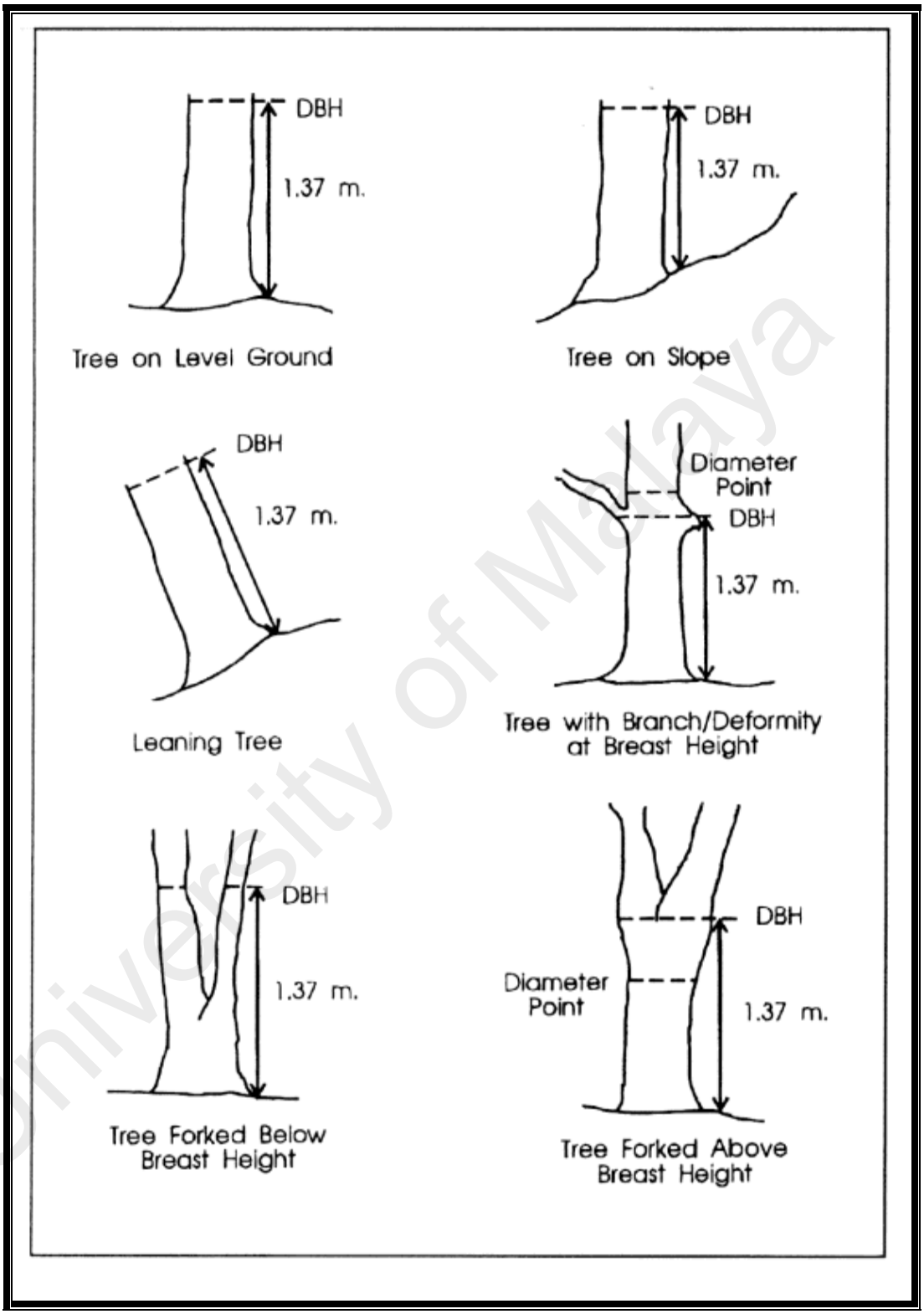


Figure 2.17: Measurement of DBH

2.10.2.1 Measurement of Biomass in the Field

To calculate the biomass of an entire forest stand, the biomass of individual trees in the field must be calculated and summed. There are three main methods used to calculate stand biomass:

- The harvest method is a technique where all of the trees in are felled, cut into sections and components (such as trunk, bark, leaves, branches), dried and subsequently weighed. This method is very labor intensive when dealing with trees that weigh several tons (Brown, 1997; Komiyama *et al.*, 2005, 2008) and cannot be reproduced on a large scale because all of the trees within a set area have to be felled.
- The 'mean tree method' consists in the weighing of one or several trees considered to be average, and extrapolating the biomass to that of the entire stand. This method can only be used in plantations or other stands with trees of a homogeneous size.
- The most common method of stand biomass retrieval is using allometric equations. The allometric equations are derived from selective sampling of trees that are representative of the size-classes found in a forest. These equations then estimate the whole or partial weight of the trees relative to the tree metrics, such as DBH and tree height. These equations have to be both site and species-specific, as seen within-species biomass allocation can vary greatly depending on the location.

2.10.2.2 Deriving Allometric Equations of Mangrove Trees

Allometry implies that the size and the rate at which a part of the living organism grows are proportional to the size and growth rate of another. In the case of trees, allometric equations correlate tree diameter with height, leaf, root, branch, biomass, etc. For several decades, allometric equations that can determine growth and biomass of mangroves have been introduced. These equations are available and applicable for all of the structural forms of mangroves including dwarf trees (Ross *et al.,* 2001) single–stemmed and multi-stemmed tree forms (Komiyama *et al.*, 2008, Clough *et al.,* 1997; Dahdouh-Guebas & Koedam, 2006). In allometry equations on mangrove, Komiyama *et al.,* (2008) describe the current state of knowledge on mangrove biomass and productivity equations based on 72 published studies in great detail. Saenger and Snedaker (1993) also reviewed 43 above-ground biomass equations of mangroves worldwide, to derive a single, global height-biomass and height-productivity equation. Studies by Soares and Schaeffer-Novelli, 2005; Ong *et al.,* (2004) and Comley and McGuiness (2005) describe the available species and site-specific equations extensively. As opposed to the site and species specific equations, Chave *et al.,* (2005) and Komiyama et al. (2005) had projected for the application of commonly generated allometric equations which are not site–and species–dependent. These equations depend on wood density, pipe model from Shinozaki and static plant from model (Shinozaki *et al.,* 1964; Oohata & Shinozaki, 1979). These common equations are of the form:

Komiyama *et al.,* 2005:

AGB = 0.251ρDBH 2.46 r^2 = 0.98, with n = 104, D_{max} = 49 cm, Relative error between 3.99 % and 30.1 %

(1)

Chave *et al.,* 2005:

$AGB = \rho \times \exp [-1.39 + 1.980 \ln (DBH) + 0.207(\ln(DBH))^2 - 0.02081(\ln(DBH))^3]$; standard error of 19.5 % (2)

or

$AGB = \exp (-2.977 + \ln (\rho DBH^2H)) = 0.0509 \times \rho DBH^2H$; standard error of 12.5 % with n = 84, D_{max}= 50 cm (3)

Where AGB is the Above-ground biomass, ρ represents the wood density, DBH is the diameter at breast height and H is the height of the tree. Figure 2.18 shows the allometric equations developed by Chave *et al.,* (2005) and Komiyama *et al.,* (2008) for *A. marina* mangrove trees. When comparing the common equations to site and species specific equations, Komiyama *et al.,* (2008) found that the average error was within 10%, thereby showing that wood density may be a more important factor in the determination of biomass than site or species.

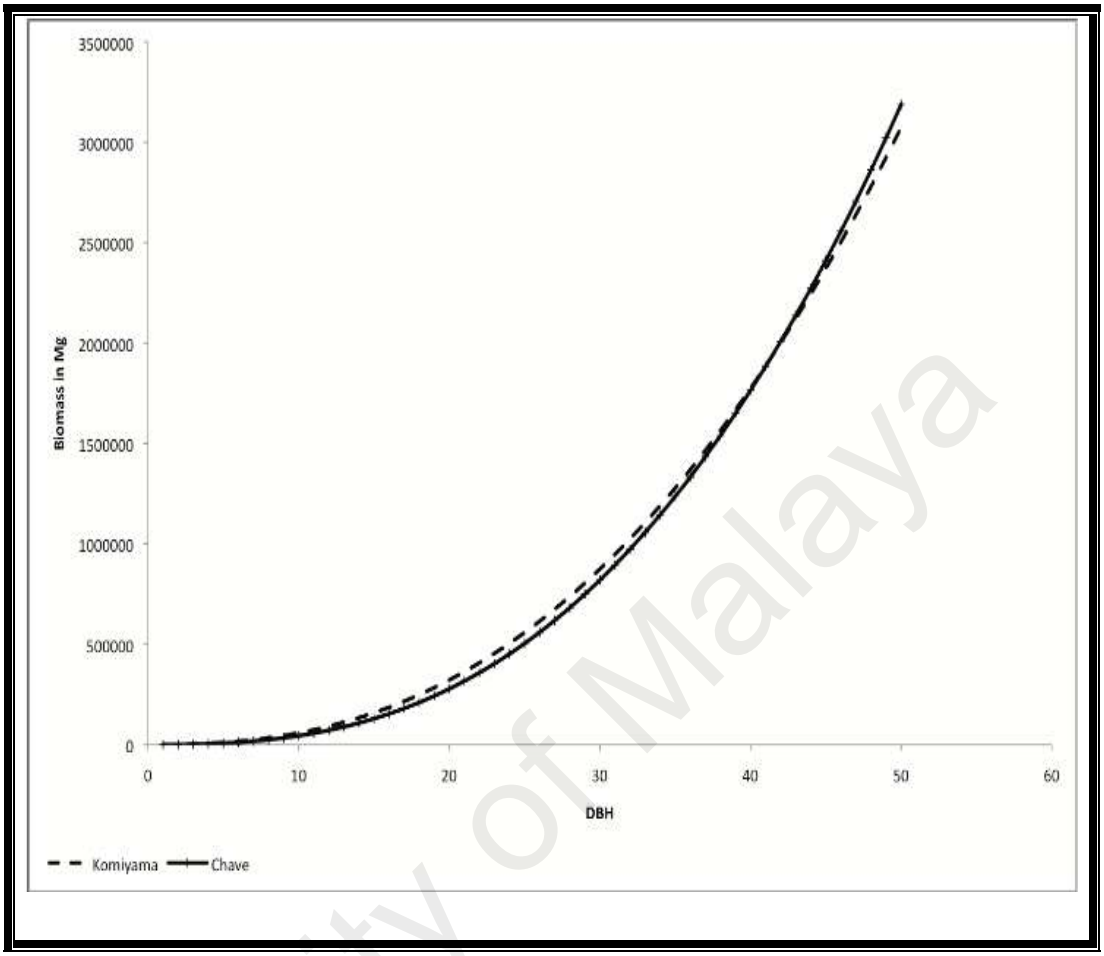


Figure 2.18: Allometric Equations for *Avicennia marina* Developed by Chave *et al.*, (2005) and Komiyama *et al.*, (2008)

2.10.2.3 Review of Biomass Equations

Many studies were conducted to develop biomass equation that relates dry biomass of forest trees to its biophysical variables (e.g. diameter at breast height, tree height) (Aboal *et al.*, 2005; Brown, 1977; Araujo *et al.*, 1999; Arevalo *et al.*, 2007; Cole & Ewel, 2006; de Gier, 1989,1999,2003; Losi *et al.*, 2003; Laclau, 2003; Ketterings *et al.*, 2001; Zianis & Mencuccini, 2004; Overman *et al.*, 1994). The parameters of the biomass equation are typically estimated using linear least squares regression. There are some assumptions that should be met when

performing this estimation procedure. The residuals must be distributed normally, independently and with constant variance (Furnival, 1961). The assumption of constant variance is crucial in liner regression as it affects the validity of hypothesis testing. Typically, biomass data exhibits heteroscedasticity, that is, the error variance is not constant across all observations. This problem can be dealt with either by (1) transformation, such as taking the logarithm of the variables, or (2) by using weights to stabilize the variance. However, the use of transformation leads to another problem discussed below.

The most common biomass equation is a power function with multiplicative error term

(1) $$\boldsymbol{B = a \times (DBH)^{b}\ e.}$$

Where:

B is dry weight of tree components, DBH is diameter at breast height, a is B intercept, and b is regression coefficient, e is (crown area × number of prop root)

For example, Ter-mikaelian and Korzukhin (1997) reviewed biomass equations for 65 tree species of North America, all of the form in equation 1. The popularity of this power function stems from the good fit exhibited by the model using single and easily measurable variable (DBH). Power function in (1) is actually not a linear model. It is linearized by taking the logarithm of both the left and right hand side of the equation, giving the linear function:

(2)

$$\text{In } B = \text{In } a + b \times \text{In (DBH)} + \text{In}_e.$$

Where:

B is dry weight of tree components, DBH is diameter at breast height, a is B intercept, and b is regression coefficient, e is (crown area × number of prop roots), In is logarithm.

Log-transformation is often used to resolve the issue of heteroscedasticity, hence linear least- squares regression is carried out on transformed variables. There are two reasons for the adoption of such common approach; first by, there is easy assessment of linear function while the next is about its established statistical theory (Smith, 1993). However, the problem associated to this transformation is that there is a bias from the de-transformed predicted values (Miller, 1984; Smith 1993; Sprugel, 1983; Wiant and Harner, 1979). De-transformed estimate of the afore-mentioned model leads to generation of the geometric average of the actual values that is often below the average arithmetically (Miller, 1984; Smith 1993; Parresol, 1999).

2.11 Primary Production

The main primary producers in the mangrove are vascular plants- the trees and shrubs. Gross primary production is the total energy fixed by plants during the process of photosynthesis. The plant itself uses part of this energy for metabolic processes; what remains is converted to plant biomass, which then becomes potentially available to other organisms (herbivores and decomposer). This constitutes the net primary production and essentially consists of the growth in biomass as well as losses (from the plant) in terms of litter production (both

above- and below- ground) and root exudates. The summary of the different components of primary production are stated as follows;

Gross primary production (GPP) = all the carbon fixed during photosynthesis

(Net primary production = photosynthesis and respiration during photosynthesis)

Net primary production (NPP) is the sum of every energy (or nutrients) generated by any studied ecological unit which can be at either overall community level, discrete population or even at the level of an individual organism. The difference between respiration and the gross primary production is equivalent to the net primary production which is demonstrated in the following equation:

Net primary production (NPP) = GPP – respiration

NPP = Biomass increment + litter fall

2.11.1 Net Primary Production

The standing plant biomass is the biomass present in an ecosystem at any one time. Above – ground biomass in mangroves can be as high as 460 t ha $^{-1}$, found in the forest of Malaysia that is dominated by old *R. apiculata* (Putz and Chan , 1986) or as low as 7.9 t ha $^{-1}$, found in a *R. mangle stand* in Florida(Lugo and Snedaker, 1974). Putz and Chan (1986) while reporting about the diameter growth rates in the Malaysia's Matang mangrove forest reserve, indicated that for *R.*

apiculata trees within diameter class sizes of 10- 60 cm, 0.24–0.29 cm was the range.

2.11.2 Litter Production

Small litter (flowers, leaves, twigs and small branches) production in the mangroves ranges from 4–13 t ha^{-1} yr^{-1} (Bouillon *et al.,* 2008). These rates vary with latitude, with the highest values (average of 10.4 t ha-1 yr-1) between 0 and 10º latitude and the lowest values (average of 4.7 t ha^{-1} yr^{-1}) at latitudes >30º. Fine roots are also lost as litter underground. It is difficult to estimate fine root litter production in the mangrove vegetation but the amount can be considerable. The other component lost from roots is soluble root exudates. This is soluble organic matter that leaches out of living roots into the soil. Again, this is difficult to measure accurately and may also be a significant production. As can be seen from the above discussion, we lack information on the below-ground component of productivity and more studies are needed to address this.

The decomposition dynamics in mangrove ecosystems are primarily controlled by the nature of litter, temperature, humidity, soil pH, aeration, microbial populations and soil fauna. The ecological significance of the observed differences in decomposition rates is that the most litters can be removed by ocean currents to distant places before decomposition fully sets in, thus may be partly responsible for supply of nutrients to ecosystems away from the litter source. The forest of *Rhizophora* are known to produce much litter, and is characterized of tallest trees

with much developed canopy cover and ground structures that covers large surface area. It serves as a potential refugee for juvenile finfish and crustaceans and ultimately as a nursery ground. The *Ceriops* and *Avicennia* forests do not produce much litter and are may be due to the conditions of water and salinity stresses that take place in the dry season. The litter would accumulate on the forest floor for much of the year, but during wet seasons, it is drifted away by the rainfalls and high tides. The litter thus is sent to the estuary, hence non-permanent/ short-time habitats are developed within the estuary which can carter for Juvenile crustaceans and finfish.

2.11.3 Forest Floor – Litter (Standing Crop)

Composition of freshly fallen non-woody and dead organic matter on the topsoil is referred to as litter layer. This is to imply that dead flowers, leaves, fruits, bark fragments and seeds constitute the litter layer. Within a number of mangrove forests, the carbon level of such organic matter is often insignificant as a result of the activities of the detritus-consuming crabs, and dispersion by waves and floods. A destructive sampling via use of micro-plots is adopted in most litter biomass studies. The size of most micro-plot can be from 30×30 cm to 1 m^2, yet the common plot size used is 50×50 cm. during such sampling, woody particles and every other organic matter found on the surface is picked into the sampling bag (Cummings *et al*., 2002).

2.12 Carbon and Global Climate Change

Terrestrial carbon can be found in diverse pools like detritus, vegetation, soil, harvested products and black carbon residues from fires etc. (Schulze *et al.*, 2000). Within the temperate lands and boreal regions, about 1–2 giga tons (Gt) (10^9) of carbon is believed to be sequestered yearly (Rayner *et al.*, 1999; Bousquet *et al.*, 2000). These sinks represent 15–30% of yearly global carbon emissions emanating from fossil fuels and industrial activities. Some of the missing carbon is absorbed back into the vegetation biomass and, under the Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC), industrialized nations are permitted to utilize certain forest biomass sinks in order to achieve their agreed targets on GHG emissions. There is often much debate over the use of carbon sinks in policies pertaining to GHG emission and intended reduction (IPCC, 2000). Hence, much importance, both politically and scientifically, is attached to characterization and mechanism of carbon sinks.

The live tree biomass includes branches, stumps, bark, wood, twigs, and roots. Productivity investment in the mentioned components helps to gain carbon from the vegetation pool, while death, harvesting, aging, disease, wind throw, fire and even insect attacks can initiate loss of carbon.

Therefore, it is evident that mangrove forests have high effectiveness in carbon storage, and serve as sinks. Its importance is not limited to possession of significant biomass, rather its carbon-rich soil help to sequestering carbon over

millennial timescales. The carbon storage role of mangroves required stringent awareness both at national and international levels of strategies that are being put in place to harness climate change. This should include work on establishing methods and approach for payment via carbon markets, and should include credits, offsets and potential payments under the UNFCCC and even the Voluntary Carbon Markets (VCM) with national or regional trading schemes.

About 150,000 hectares of mangrove is lost yearly (1% per annum) according to the United Nations Food and Agriculture Organization– FAO (FAO, 2007), and loss in mangrove is equal to loss of carbon sequestration potential. Therefore, about 225,000 metric tons of carbon sequestration potential is equally lost on yearly basis as mangrove forests are being destroyed.

Mangroves take up (sequester) approximately:

- 1.5 metric tons/hectare/yr of carbon
- 3.7 lbs/acre/day of carbon (1336 lbs/acre/yr)

Similarly, about 11 million metric tons of carbon is released annually from mangrove soils.

2.12.1 Carbon Sequestration

Carbon sequestration is all about removal of CO_2 from the atmosphere by some predominant agricultural and forestry activities. Hence, lands, be it agricultural or forest are deemed to be carbon sinks once they absorb CO_2 which is a significant gas that encourages global warming due to anthropogenic activities. Global climate change can be mitigated by sequestration when carbon storage in soils and

trees is enhanced. Carbon can still be sequestered by protection of existing trees and soil carbon while reducing greenhouse gas emissions especially carbon dioxide, methane and nitrous oxide.

The value of carbon sequestration by forests has continued to increase as a result of climate change, and mangrove's high biomass density and productivity project it as a key player in carbon sequestration. About 22.8 million metric tons of carbon can be sequestered by mangroves and its associated soil, every year (Giri *et al.*, 2011). Similarly, Walters *et al.*, (2008) found that a 22-year old *R. apiculata* forest in Malaysia have a photosynthetic rate value of 155 kg C ha^{-1} day^{-1}. However, when we consider the influence of a number of factors to the intensity of sequestration, then it becomes a complex scenario (Figure 2.19).

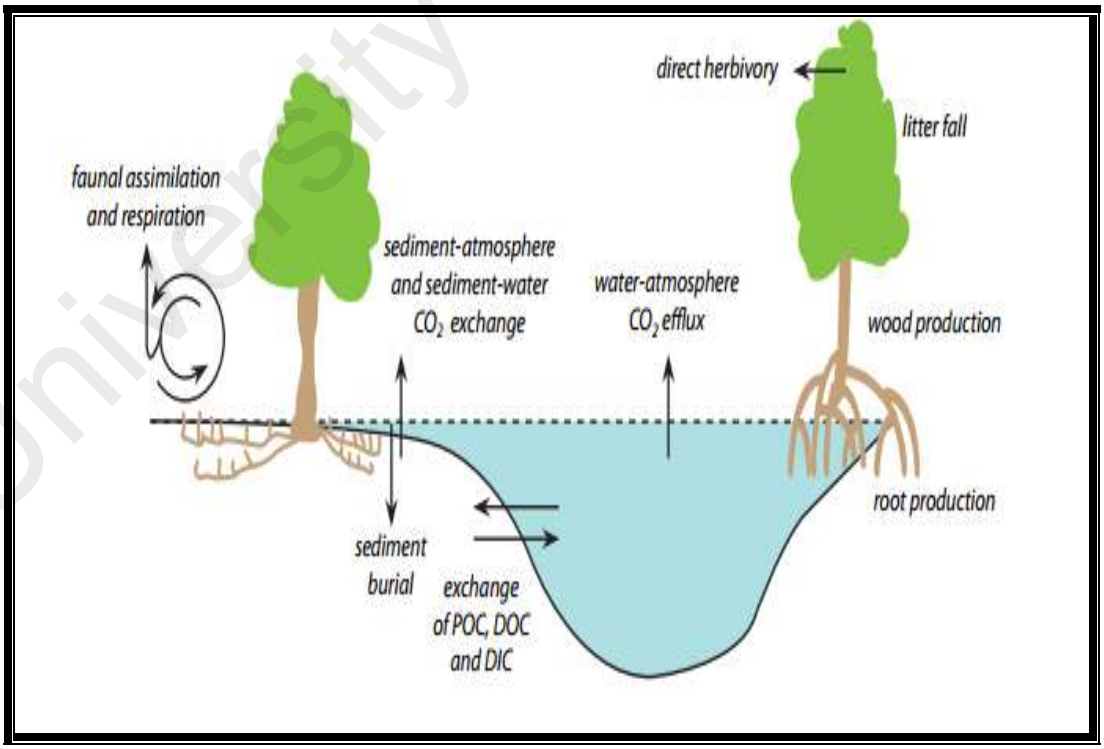


Figure 2.19: Process of Carbon Sequestration in Mangroves (Bouillon *et al.*, 2008)

Sequestration of carbon or carbon storage takes place in soils and forest via photosynthesis. The tiny openings in leaves (stomata) take up the atmospheric carbon dioxide (CO_2) and absorb it into the woody biomass of agricultural crops and trees in form carbon. About 50% of the biomass is carbon, and some eventually re-enter soil during the decay process of litter, vegetation and plant roots. In similar way some agricultural activities such as tillage and burning, can initiate return of carbon from forests and soil back to the atmosphere. Hence, it is easy to regard agricultural soils and forests as net source of carbon or carbon sink. Therefore, carbon movement in and out of forest trees and soils is viewed as an integral part of the world's carbon cycle.

In fact, proper recording of carbon stock is very important. The United Nations Framework Convention on Climate Change (UNFCCC) did urge member nations to ensure precise and accurate assessment of their forest's carbon stocks which are reported as forest resources (Basuki *et al.,* 2009; Kim *et al.,* 2011).

Such data entry has reported that about 80% and 40% of every above and below-ground carbon, respectively, are stored in the forest biomass (Dixon *et al.,* 1994). Lim *et al.* (2003), further explained the relevance of forest carbon budgets, stating that forest ecosystem is a major carbon sink and that in situations of deforestation and degradation, the system can release carbon. Other studies (Watson *et al.,* 2000; Lehtonen *et al.,* 2004; Tobin and Nieuwenhuis 2007; Bollandsas *et al.,* 2009; Teobaldelli *et al.,* 2010; Li *et al.,* 2010) had demonstrated that forest carbon stock estimations is a significant area of research interest due to the impact

forests have towards global climate change and estimation of precise carbon amount in a given forest enhances accurate biomass evaluation (Xiao & Ceulemans, 2004; Fehrmann *et al.,* 2008; Chung *et al.,* 2009; Hosoda & Iehara, 2010).

2.12.2 Carbon Storage and Sequestration in Mangroves

Healthy mangrove forests have potential economic value both as carbon stores and as important locations for carbon sequestration. When mangrove forests are cleared and the land drained for other uses there is substantial release of carbon from the rich organic sediments and decaying roots. Crooks *et al.,* (2011) estimated that the 35,631 km^2 of mangroves reported by FAO (2007) which were cleared and drained worldwide between 1980 and 2005 would have released emissions totaling 0.02-0.12 $PgCyr^{-1}$ during that time, or between 2% and 10% of all emissions from deforestation. It follows that a nation that protects or expands its mangrove forests can both reduce emissions, and indeed facilitate carbon sequestration and such measures should be of considerable interest in growing carbon markets. The IPCC (2007) reported that reducing and/or preventing deforestation is the mitigation option with the largest and most immediate carbon stock impact in the short term. Furthermore, a report released by UNEP, IOC-UNESCO, IUCN and FAO (Nellemann *et al.,* 2009) has shown that as much as 7% of the CO_2 reductions required to keep atmospheric concentrations below 450 ppm could be achieved simply by protecting and restoring mangroves, salt marshes and seagrass communities. The value of this approach is now being

realised and a small number of restoration efforts are now being funded by the private sector for the value of their carbon credits alone. It is important to note that the rate at which carbon is lost from disturbed mangrove areas is typically much greater than the rate at which it can be restored; there is a considerable time lag following the initiation of restoration and the time at which carbon sequestration in the mangrove forest matches natural reference sites (Lovelock *et al.*, 2011).

Mangrove forests are also among the major carbon sinks of the tropics (Cahoon *et al*., 2003; Bouillon *et al*., 2008; Nellemann *et al*., 2009). Perhaps the least investigated, yet critically important, ecosystem service of mangroves is that of carbon storage. Mangrove carbon pools are among the highest of any forest type (IPCC, 2001; Laffoley & Grimsditch 2009; Donato *et al*., 2011; Kauffman *et al*., 2011). For example, ecosystem carbon pools of mangroves in the Indo Pacific region are more than twice those of most upland tropical and temperate forests. A great proportion of this pool is belowground in organic-rich soils which are highly susceptible to releasing significant volumes of greenhouse gases if disturbed by land-use or climate change (Page *et al*., 2010; Hooijer *et al*., 2006). Because of the values of, and threats to, mangroves, surveys to describe forest composition, structure and ecosystem carbon pools are needed to monitor status and trends.

Mangroves are quite different from upland forests in both composition and structure. The presence of stilt roots or pneumatophores is an obvious difference.

In addition, understory vegetation and a well-developed floor litter are usually absent. Because of numerous differences in the structure and environment of mangroves compared to upland forests, approaches to quantifying their composition, structure, carbon stocks and status are different (Donato *et al*., 2011; Kauffman *et al*., 2011).

However, carbon emissions resulting from mangrove loss especially biomass are uncertain. The information on mangrove's biomass toward carbon stock is needed because when the changes occur much of carbon stock in the ecosystem is released to the atmosphere (Khairunnisa & Mohd Hasmadi, 2012). Information on the spatial variation of carbon sequestration in different types of forest cover in the land can enhance further improvements on the accuracy of global sinks. According to Fuchs *et al.* (2009), forest ecosystems are an important part of the global carbon cycle because they store a large part of the total terrestrial organic carbon and exchange CO_2 with atmosphere. Trees act as a sink for CO_2 by fixing carbon during photosynthesis and storing excess carbon as biomass. As the tree biomass experience growth, the carbon held by the plant also increases carbon stock (Bipal *et al.,* 2009). Mangroves forests have long been known as a harsh environments and extremely productive ecosystems in cycling carbon.

Mangrove forest accounts for about 2.4% of tropical forest and to improve accuracy of global carbon sink, the quantification of carbon dynamics is essential in the mangrove swamps (Chmura *et al.,* 2003). Coastal mangrove forests store

more carbon than almost any other forest on Earth (Daniel *et al.*, 2011). The carbon content of 25 mangrove areas per hectare across the Indo-Pacific region was found to store up to four times more carbon than most other tropical forests around the world. For existing forests, inventory data are the most practical means for estimating above-ground biomass carbon as the data are generally collected at the required scales and from the population of interest in a statistically well-designed manner. The ability to accurately and precisely measure the carbon stored and sequestered in forests is increasingly gaining global attention in recognition of the role forests have in the global carbon cycle, particularly with respect to mitigating carbon dioxide emissions (Kauppi & Sedjo, 2001).

2.12.3 The Importance of Biomass and Carbon in Terrestrial Ecosystem

Quantification of terrestrial carbon and monitoring of these stocks over time are important for reasons of climate change mitigation. Improved management of the carbon stored in the world's terrestrial vegetation and soil in existing and new terrestrial carbon pools, above and below ground, is significant environmental assets, and necessary part of the global effort to avoid dangerous climate change. Terrestrial carbon stocks are also important indicators for other development and environmental goals where changes in stocks may have direct implications on the socio-economic health of local communities as well as on biodiversity.

Carbon stocks are the combined storage of carbon in terrestrial ecosystems (Achard *et al.*, 2011). In simplified terms, forest carbon accounting tracks changes

in carbon stocks due to land-use and land cover change: deforestation, degradation, conversion, afforestation etc. In order to quantify carbon stocks of mangroves, the ecosystems are conceptually subdivided into components that can be accurately measured using specific techniques for each pool. One important division is above-ground and below-ground components. Some pools are more critical than others to obtaining accurate estimates of forest biomass and ecosystem carbon stocks. Carbon stocks can also be subdivided on the basis of susceptibility to loss by land-use or land-cover change. Generally, carbon pools vulnerable to these changes are above-ground biomass and below-ground pools to 30 cm. However, in wetland organic soils, the entire below-ground pool may be susceptible to loss via tidal and storm surges as well as decomposition following land-cover change.

Similar to most forest types, mangroves can be roughly divided into five carbon pools: 1) above-ground biomass of live vegetation; 2) below-ground biomass of live vegetation; 3) dead wood; 4) forest floor (litter); and 5) soil. A pool should be measured if it is: (1) large; (2) if it is likely to be affected by land use; (3) if the future land-uses are uncertain; and (4) if the pool size is uncertain. Small pools or those unlikely to be affected by land use change may be excluded or sampled less frequently. In mangroves, non-tree vegetation and litter are usually minor ecosystem components and can often be excluded from measurements without compromising the accuracy of the sample. Trees are always included since they are relatively easy to measure, good scaling equations exist, and they are heavily

affected by land use. Dead wood is often an important pool in mangroves, especially following disturbances such as land-use change or tropical storms (Kauffman & Cole, 2010). Many mangroves have deep organic-rich soils (peat) resulting in large carbon pools. The large size of these belowground pools and their poorly understood vulnerability to land-use change makes their measurement relatively important.

Methods to measure and monitor changes in terrestrial carbon stocks from emissions and removals are also increasingly used to inform national land-use policy and in attracting new investment in sustainable land use projects and payments for environmental goods and services, including carbon credits (Havemann, 2009). About 62% to 78% of the global terrestrial carbon is sequestered in the forests, and about 70% of this carbon is stored in the soil (Dixon *et al.,* 1994; Schimel, 1995). Changes in carbon dynamics in tropical forest with 50% contribution to global terrestrial gross primary production (GPP) (Grace *et al.,* 2001) could alter the pace of climate change (Adams & Piovesan, 2005). Regional studies of carbon exchange vary in showing disequilibrium state of tropical forest and in increasing stocks of tree carbon (Phillips *et al.,* 1998; Lewis *et al.,* 2009). Apart from resource availability and pollution stress, succession and global change could have varying importance at different region to produce different spatial and temporal pattern of carbon uptake by trees (Muller-Landau, 2009).

CHAPTER THREE

MANGROVE FOREST STRUCTURE AND BIOMASS

3.1 Introduction

The unique and dynamic nature of mangrove forest ecosystem is characterized by community of plants that can survive both in seawater and land. Considering that plant diversity that characterizes such environment, the forest is found to be structured in pattern, species and distribution. Understanding mangrove forest structure is important as it allows one to identify the common mangrove forests and the potential environmental interactions. Hence, a key component of forest structure is the biomass. Biomass assessment is totality of the available organic material of both above- and below- ground, and even both living and dead components of the forest (FAO, 2004). The relevance of biomass assessment with mangrove forest structure is to give an insight into the carbon cycle or carbon stock of such designated environment. Therefore, the methods and associated material adopted in executing this research are explained in this chapter. The core components of the research involve site investigation, species identification, measurement of diameter at breast height (DBH) and biomass estimation. Hence, the results were discussed subsequently.

3.2 Objective of the Study

This research was conducted at Kuala Selangor and Sungai Haji Dorani sites that are natural and degraded mangrove forest types, respectively in Peninsular Malaysia. The overall objective of the study was to have a better understanding of mangrove functioning on carbon sequestration. However, the specific objectives of the study were as follows:

- To describe the structure of forest among the selected natural and degraded mangrove forests of Malaysia.
- To estimate above-ground and below-ground biomass of common/ dominant mangrove species that exist in the selected mangrove forests using published allometric equations.
- To estimate biomass increment within mangrove forests of Malaysia.
- To estimate the net primary productivity

3.3 Materials and Methods

The study was conducted in accordance to standard procedures typical of each stage of the research as mentioned subsequently. Figure 3.1 gives a general overview of the methodological flow of the study.

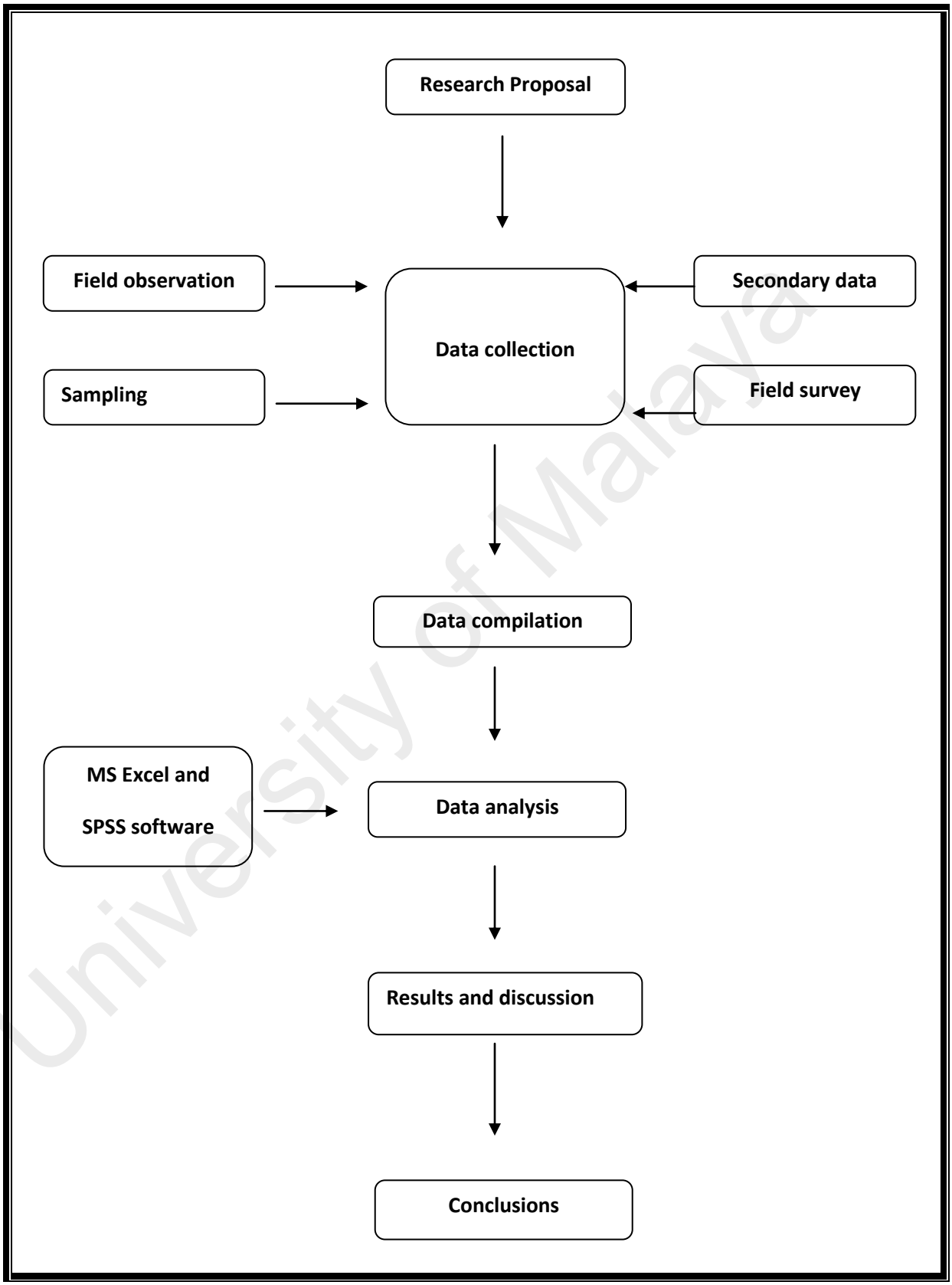


Figure 3.1: Process Flowcharts for the Research Approach

3.3.1 Research Basis

In this study, information on mangrove diversity in two study areas was collected to determine biomass and carbon pool. The important parameters considered in the study were DBH and height of trees in mangroves forest. This is based on the fact that the application of DBH and height has direct relationship to the rates of biomass generation. It depends on different species in the distinguished mangrove areas. The diversity of species in both areas leads into investigation on the different rates of biomass availability. In this study, Kuala Selangor was selected based on its natural states and Sungai Haji Dorani due the anthropogenic influence. The mangrove trees with DBH less than 4 cm were not recorded in this study because such were considered to be sapling.

3.3.2 Field Observation (Visual Imaging)

Direct observation was essential during the survey. Photographs from the study areas were taken to have visual observations of the sites and activities. Relevant photographs are included in the chapters where appropriate.

3.3.3 Study Area

The study was carried out in two mangrove forests of Selangor state (about 26,283.56 ha of mangroves) namely, Kuala Selangor and Sungai Haji Dorani (Sg. Hj Dorani) which were located along the straits of Malacca at the west of Peninsular Malaysia (Figure 3.2). The mangroves in this area extend from the mouth of Selangor River to areas along the Straits of Malacca.

Kuala Selangor as a natural mangrove forest includes 95 hectares of mangrove forest between 03° 20′ N and 101°14′ E which is a broad part of Selangor state and is totally protected since 1984. This mangrove forest is inundated only by the spring high tides and classified as Watson inundation class 4. The second study area was located in Sungi Haji Dorani (03° 38′ N and 101° 00′ E) on the west coast on Peninsular Malaysia, some 90 km to the north of Kuala Lumpur which is located near Sungai Besar, along the coastline. The mangrove trees in this area have been degraded and most of them have disappeared. This was due to the beach's exposure to direct wave action, as well as the conversion of mangrove area to agricultural land for oil palm, which then resulted in coastal erosion and degradation (Kathiresan and Rajendran, 2005). Sungi Haji Dorani is a macro-tidal beach with a semi-diurnal tidal regime and a maximum tidal range of 3.2 m. According to the Metrological Department of Malaysia, the significant wave height is lower than 1 m which is about 89% of the time; the significant offshore wave height with a return period of 10 years is about 1.50 m (Kamali *et al*., 2010).

Based on climatic consideration, three seasons were identified in both study areas: the wet season (October to December), dry season (April to September), and intermediate season (January to March**).** The mean annual rainfall of the areas was about 1701- 1710 mm, with 27.3 °C - 27.7 °C annual temperature.

Figure 3.2: Study Areas

3.3.4 Sampling

Data acquisition was made using Quarter Method (QM) for sampling at the study areas. The methodology and measurement accuracy were in accordance with Cintron and Novelli (1984). Such technique did not allow for only the measurement of mean diameter, basal area, density, but also allowed for assessment of the relative composition of mangrove stand. For each mangrove area, three transects line of minimum 100 m^2 (10m×10m) (depending on accessibility) were set up by using a compass prismatic. However, in Sungai Haji Dorani, its degraded nature influenced the size of plot 5, hence 20 m× 5 m was adopted. At every 10 m along transects, six quarters plot were established by drawing a line perpendicular to the transect line (Figure 3.3).

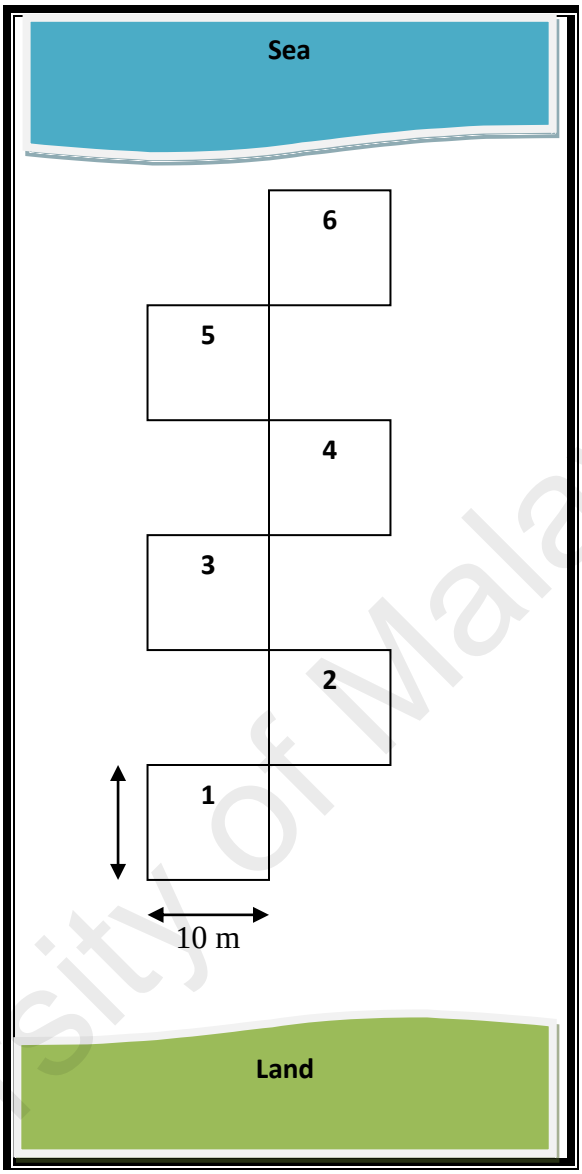


Figure 3.3: Model of Strip Transect Used In the Inventory of the Mangroves

All the quarters plots were numbered from 1-6 (herewith known as Site A), followed by 7-12 (Site B), and from 13-18 (Site C). GPS reading was taken only for the origin point in all the plots at both study areas (Table 3.1). The total sample area was 0.18 ha in each study field (Plate 3.1).

Table 3.1: Specific Spots for all Sampled Sites

Sampling Areas	Sampling Point	Location			
		KSNP		SHD	
		Latitude N	Latitude E	Latitude N	Latitude E
	1	03° 20′ 31.7″	101° 14′ 16.3″	03° 38′ 22.9″	101° 00′ 54.2″
	2	03° 20′ 32.0″	101° 14′ 14.7″	03° 38′ 21.9″	101° 00′ 54.8″
	3	03° 20′ 30.8″	101° 14′ 14.5″	03° 38′ 23.9″	101° 00′ 53.4″
	4	03° 20′ 31.2″	101° 14′ 13.7″	03° 38′ 24.2″	101° 00′ 52.8″
	5	03° 20′ 31.8″	101° 14′ 14.2″	03° 38′ 25.2″	101° 00′ 51.2″
SA	6	03° 20′ 31.8″	101° 14′ 13.4″	03° 38′ 24.3″	101° 00′ 52.4″
	1	03° 20′ 23.9″	101° 14′ 14.1″	03° 37′ 48.4″	101° 01′ 38.4″
	2	03° 20′ 08.9″	101° 14′ 10.0″	03° 37′ 48.4″	101° 01′ 38.4″
	3	03° 20′ 09.2″	101° 14′ 09.3″	03° 38′ 19.6″	101° 01′ 08.9″
	4	03° 20′ 10.0″	101° 14′ 09.9″	03° 37′ 44.9″	101° 01′ 41.1″
	5	03° 20′ 09.5″	101° 14′ 08.3″	03° 37′ 44.5″	101° 01′ 41.0″
SB	6	03° 20′ 10.8″	101° 14′ 08.4″	03° 37′ 44.5″	101° 01′ 41.0″
	1	03° 20′ 04.4″	101° 14′ 00.8″	03° 39′ 15.5″	100° 59′ 50.2″
	2	03° 20′ 03.9″	101° 14′ 00.8″	03° 39′ 15.4″	100° 59′ 50.1″
	3	03° 20′ 03.4″	101° 13′ 59.6″	03° 39′ 15.8″	100° 59′ 48.9″
	4	03° 20′ 02.9″	101° 13′ 59.9″	03° 39′ 16.3″	100° 59′ 48.5″
	5	03° 20′ 02.7″	101° 14′ 01.1″	03° 39′ 16.7″	100° 59′ 47.9″
SC	6	03° 20′ 02.3″	101° 13′ 59.6″	03° 39′ 17.5″	100° 59′ 47.3″

Plate 3.1: Plot establishment

All trees within the plots were tagged and identified up to species level based on an updated list of mangrove plants taken from a global database (Appendix A) (Nibedita *et al.*, 2014; Alem *et al.*, 2010; Saenger *et al.*, 1983; Ashton & Macintosh, 2002; MOSTI, 2003). A unique numbered tag was nailed to the stem 20 cm above the DBH measuring point. The tags for this study were numbered from 1 to 150 for each sites of the study area (Plate 3.2).

Plate 3.2: Label on the Trees

Then in each quarter plot, following the scheme given by Cintron and Novelli (1984), DBH was obtained by measuring girth at 1.3 m from the ground in the case of tall trees. An important exception, concerns the mangroves with stilts-roots, such as *Rhizophora* spp., where the diameter measurement should be taken at 30 cm above the root (FAO, 2003). Trees with DBH of ≥4 cm were measured using diameter tape according to Lugo and Snedaker (1974) standard procedures. All the measurements were made using simple equipment. For measuring the tree diameter at breast height, a measuring tape was used, whereas pole height was used to measure the tree height (H) (Plate 3.3).

Plate 3.3: Measuring the Height of Trees

3.3.5 Class Stage

Considering the fact that the exact age for each species or individual tree may have been underestimated, classification was based on height instead of age. Regardless of species, the height reading was taken for all individual tree, whereas the diameter of seedlings was not considered. Therefore, the class stage of each individual tree as identified in this study is shown as below;

1m ≤ Height ≤ 5 meters = Pre- Juvenile

5 m≤ Height ≤ 10meters = Juvenile

Height ≥ 10 meters = Adults

3.4 Forest Structure

The study of tree structure was done by quadrate sampling method with 10× 10 m plots that was be described in section 3.2.3 of this report. The forest structural characteristics of trees which included density, relative density, frequency and relative frequency, mean DBH, mean height, basal area, relative dominance and importance value index of trees were calculated from the relationship given by Cintron and Novelli (1984). For the calculation of the vegetation structured attributes the following methodology and formula were used.

The density is the total number of trees that could be calculated in the stand of 1 hectare where the minimum distance between the trees is given by the mean distance.

$$\text{Density (stem/ha)} = \frac{\text{Total number of individual stem}}{\text{Plot area (ha)} \times \text{Number of sample plots}}$$

The frequency of a species is the percentage of sample points at which a species occurs and is determined based on the formula:

$$\text{Frequency (\%)} = \frac{\text{Number of plots where individual species are present}}{\text{Total number of plots}} \times 100$$

The relative attributes such as relative density, relative frequency and relative dominance of a species is simply the proportion of observations of that species multiplied by 100 to present it as percentage. To obtain this it was computed as follows:

$$\text{Relative density}\,(\%) = \frac{\text{Number of individuals of a species}}{\text{Total number of individuals}} \times 100$$

$$\text{Relative frequency}\ \ (\%) = \frac{\text{Frequency of a species}}{\text{Total frequency of all species}} \times 100$$

$$\text{Relative dominance}\ (\%) = \frac{\text{Total basal area of a species}\,(\text{cm}^2)}{\text{Basal area of all species}(\text{cm}^2)} \times 100$$

The space covered by the tree stem is described as basal area. The basal area is the same as the cross section of a stem at the point of DBH. By adding the cross sections of trees, a basal area for a group of trees can be determined. Basal area (BA) is an important parameter to illustrate the development of a stand, and it can easily be linked to biomass and wood volume (Cintrón and Schaeffer-Novelli, 1984b). The basal area for each tree is obtained using the formula,

$$\text{BA}\,(\text{cm}^2)\ = \frac{\pi\, \text{d}^2}{4}$$

where, d is the diameter of the tree trunk at breast height

If a tree has multiple trunks, the basal area for each trunk is computed separately and the results are averaged. Then, the total basal area of all trees present in the plot is calculated according to species, and the mean basal area for each species present in the sample can be determined.

$$\text{Basal area per hectare } (m^2) = \frac{\text{Total basal area of individual species } (m^2)}{\text{Sample plot area (ha)} \times \text{Number of sample plots}}$$

The definition of the mean stand diameter is "the diameter of the stem of mean basal area". The calculation for the diameter of the stem of mean basal area is determined by:

$$\text{Mean DBH (cm)} = \frac{\text{Mean basal area per stem of individual species } (cm^2) \times 4}{\pi}$$

$$\text{Mean Height} = \frac{\text{Total height (m) of all stems in the sample plot}}{\text{Number of stems in the sample plots area}}$$

Importance value index (IVI): It indicates the structural importance of a species within a stand of mixed species. It is calculated by summing up the relative percentages of basal area, density and frequency, each weighed equally for each species, relative to the same dimensions for the entire stand.

$$\text{Importance Value (\%)} = \frac{\text{Relative density + Relative frequency + Relative dominance}}{3}$$

3.5 Species diversity

A number of different measures of species diversity have been proposed in this study. This exercise explores three methods for measuring species diversity of communities; Shannon-Weiner Index, the Simpson's Index and Sorenson's Similarity Index.

3.5.1 Species Diversity Indices

3.5.1.1 Shannon-Wiener Index

Species diversity is described according to the value of Shannon- Weniner index (H') based on the relative abundance (proportion) of the i^{th} species in the community, and natural log (ln). H' is calculated using the following formula by Mac Arthur (1969):

$$H' = -\sum p_i \ln p_i$$

The Shannon Index is used to measure habitat quality. Its range is from 0.0 to approximately 4.6. A value of 0.0 means that every organism in the sample is of the same species and 4.6 means the number of individuals are evenly distributed among numerous species.

3.5.2 Species Richness Indices

3.5.2.1 Simpson's Index (D_s)

A measure that accounts for both richness and proportion (%) of each species is the Simpson's diversity index. It has been a useful tool for understanding the

profile of biodiversity across the zones. If a community with high diversity was randomly-sampled twice, there is a good chance that the two samples will contain different species. However, if a low-diversity community were sampled twice, it is likely that both of the samples will contain many of the same species (Simpson, 1949). The study derived a formula based on the expected outcome of two random samples and had been adopted in the present study;

$$Ds = \frac{N(N-1)}{\sum ni(ni-1)}$$

where N the total number of individuals of all species, n_i the number of individuals of species i.

3.5.2.2 Sorenson's Similarity Index (S)

The Sorenson's similarity index is used to indicate that vegetation species found in the plot's analysis are similar to those vegetation species found in other plots. The range of Sorenson's similarity index is from 0 to 1. A value of 0 indicates complete dissimilarity while a value of 1 indicates complete similarity (Goldsmith *et al.*, 1986). The similarity index is calculated by following formula:

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

where J total species which is similar in both samples, A shows total species in sample A, and B indicates total species in sample B.

3.6 Above-ground Biomass

According to sampling which was described in section 3.2.3, the biomass estimation of mangrove trees inside the plots were carried out from January 2012 until April 2012. By using DBH and height, the biomass of different components of the individual tree (leaves, branches, stem, flowers and buds) were estimated by allometric equation formula (Komiyama *et al.*, 2005; Clough and Scott, 1989; Ong *et al.*, 1984; Putz and Chan, 1986). Allometric equation describes relationship for estimating leaf, branch, stem, and total above-ground biomass of species. The formula for the estimation of biomass is as follows, where A and B are constants in the equation log Biomass:

$$\text{Log Biomass} = A + B \log_{10} \text{DBH}$$

Furthermore, above-ground of the sampling tree were divided into trunk, branch, bark, leave, flower and fruit components. An excavation method (Bledsoe *et al.*, 1999) was used to estimate root biomass of the three individual trees that were selected for above-ground biomass (AGB).

3.6.1 Biomass Increment

For assessment of the biomass increment in both study sites, individual ranges of every species were identified based on the measurement of the DBH and height of each species. This procedure was carried out yearly for period of two years as a way of estimating the increment on the biomass.

3.7 Below- ground Biomass

To estimate root biomass, three pits (1 x 1 x 1 m) were dug at each study site, and were placed at distances of 1 m away from mangrove trees in each study area. All the soil samples and roots were collected together from the pits. The collected root samples were sorted and washed. For the root diameter, the higher diameter of fine roots was sorted in to 2 groups, namely fine and coarse. The total fresh weight of each component of root was measured in the field, and representative subsamples were taken to the laboratory, where they were oven-dried to constant weight at 65°C. The total harvested dry-weight of each component was calculated from the ratio of dry weight to fresh weight of the corresponding subsamples (Plate 3.4).

Plate 3.4: Pits for Root Sample 1m×1m

After collection of root samples from the pits, each of the pitch was refilled with sand and marked properly (Plate 3.5 and 3.6). The spots served as the points for yearly collection of root samples for estimation of the root biomass increment (Plate 3.7).

Plate 3.5: Refilled of Pits for Root Biomass Increment

Therefore, for belowground biomass (BGB, referring to root biomass in this study), all roots in 1 m depth within the radius of 1 m from the tree center were excavated, and then the roots were washed with a fine sieve to collect all roots. The roots were sorted into two size classes: fine roots (diameter 0.2–0.5 cm) and coarse roots (diameter >1 cm) (Plate 3.8). There was no separation of live and

dead roots. Then, the total fresh weight of each root component was measured in the field. Each tree organ was dried to a constant mass at 65°C using oven.

Plate 3.6: Sampling Spot with Visible Landmarks (Circled) to Show the Earlier Excavated Area

Plate 3.7: Yearly Re-Excavation of the Pitch for Collection of Root Samples

Plate 3.8: Separation and Measurement of Root Samples

3.8 Net Primary Productivity

Net primary productivity (NPP) of the natural and degraded mangrove was evaluated to give idea of their respective ecosystem maturity. This was done via the summation of the biomass increment in each study area with its corresponding litter production (Mahmood *et al.,* 2008). Therefore, it was generated as;

$$NPP = BI + LP$$

Where: NPP = Net Primary Productivity

BI = Biomass Increment

LP = Litter Production

3.9 Result and Discussion

3.9.1 Forest Structure

A total of 302 individual trees were recorded from the sample plots of Kuala Selangor and 401 individuals at Sungai Haji Dorani. A total of 8 species from four families has been reported from the two study sites (Table 3.2). The plant species richness of SHD is higher when compared to KSNP. While both study areas showed similarity in terms of the present mangrove trees families namely, Avicenniaceae, Rhizophoraceae and Sonneratiaceae, but the absence of Euphorbiaceae and Meliaceae gave species diversity edge to SHD. This development might depict the original degree of mangrove forest richness of SHD before socio-economic developments initiated its degradation. The species diversity as identified in this study is typical of similar mangrove forests studies in Peninsular Malaysia, especially in Pulau Kukup and Tanjung Piai (Tan *et al.,*

2012). However, it is a far cry from the dense species diversity found in Semporna mangrove forest (Lo *et al.,* 2011) and the reason may be due to natural and degree of strict eco-conservation being practiced in Sabah, the Eastern part of Malaysia. Hence, this might imply the degree of species loss with the peninsular Malaysia, though prior baseline date on species diversity was not available for comparison.

Table 3.2: Mangrove Tree Species Recorded in Both Study Areas

Family	Species		Local name (Malay)
	SHD	KSNP	
Avicenniaceae	*Avicennia marina*		Api-api Jambu
		Avicennia officinalis	Api-api Iudat
Rhizophoraceae	*Bruguiera cylindrica*		Berus
		Bruguiera parviflora	Lenggadai
		Rhizophora mucronata	Bakau Kurap
Sonneratiaceae	*Sonneratia alba*	*Sonneratia alba*	Perepat
Euphorbiaceae	*Excoecaria agallocha*		Buta-buta
Meliaceae	*Xylocarpus mekongensis*		Nyireh batu

Sonneratia alba possessed the highest DBH value in the Kuala Selangor; however, *Excoecaria agallocha* was only found in Sungai Haji Dorani and appears as biggest tree with average DBH value of 11.90±1.58 cm. However, the sparse distribution of *S. alba* (6 tree/ha) shifts importance towards *Bruguiera*

parviflora which has about 84 % (1,406 tree/ha) of the total trees density in Kuala Selangor. Both *Bruguiera* species found on both study sites were taller than others in their discrete localities; with mean height value of *B. parviflora* at 12.56±0.47 m in Kuala Selangor while *B. cylindrica* recorded 6.89 ± 0.12 m in Sungai Haji Dorani. *B. parviflora* possessed the highest IVI (70.96 %) as against 0.85 % shown by *S. alba.* However, the only similarity between both study areas in terms of tree diversity is the presence of *S. alba* (Table 3.3).

Table 3.3: Stand Structure of the Study Sites

Species	Mean DBH(cm)± SE		Mean Height (m)± SE		Density (trees/ha)		IVI (%)	
	KSNP	SHD	KSNP	SHD	KSNP	SHD	KSNP	SHD
A. officinalis (n=36)	13.58± 1.25	-	10.45± 1.11	-	200	-	23.20	-
A. marina (n=207)	-	7.90± 0.25	-	5.64± 0.25	-	1150	-	46.16
B. parviflora (n=253)	10.25± 0.27	-	12.56± 0.47	-	1406	-	70.96	-
B. cylindrical (n=172)	-	7.67± 0.24	-	6.89± 0.12	-	955.5	-	40.59
R. mucronata (n=12)	7.31± 1.36	-	8.07± 1.07	-	67	-	4.99	-
S. alba (n=1)	22± 0	6.50± 0	4.21± 0	4.21± 0	6	5.5	0.85	1.03
E. agallocha (n=13)	-	11.90±1.58	-	6.01± 0.58	-	72.2	-	3.60
X. mekongensis (n=8)	-	6.68± 0.3	-	6.52± 0.39	-	44.4	-	5.62

Kuala Selangor Nature Park (KSNP), Sungai Haji Dorani (SHD) - Species not present in the study areas

Result of the class stage from both study areas showed high proximity in distribution across the three classes; pre-juvenile (123 tree/ha), juvenile (221 tree/ha) and adult (247 tree/ha). Therefore, the adult class was dominant in both study areas; KSNP (124 tree/ha) and SHD (123 tree/ha) but the difference was not pronounced (Figure 3.4). As anticipated the adult class in SHD should have been very much less than the total obtained in KSNP, since it is a degraded mangrove, however, the ability to maintain such close value with KSNP may imply that the anthropogenic activities or other related interferences on SHD may not have been target- oriented (not specific on class of wood to cut down). It might be indiscriminate interferences. Yet, another significant aspect of the both study areas is compared. The population in SHD was double (155 tree/ha) of the number found in KSNP. This may imply the potentials of SHD to regenerate its forest, hence the reason for it to still labour more adult class despite the level of degradation. However, the order of class stage variation was pre-juvenile < juvenile < adult for KSNP while SHD revealed that juvenile < pre- juvenile < adult. Such variation may be attributed to nature of tree species in the study areas.

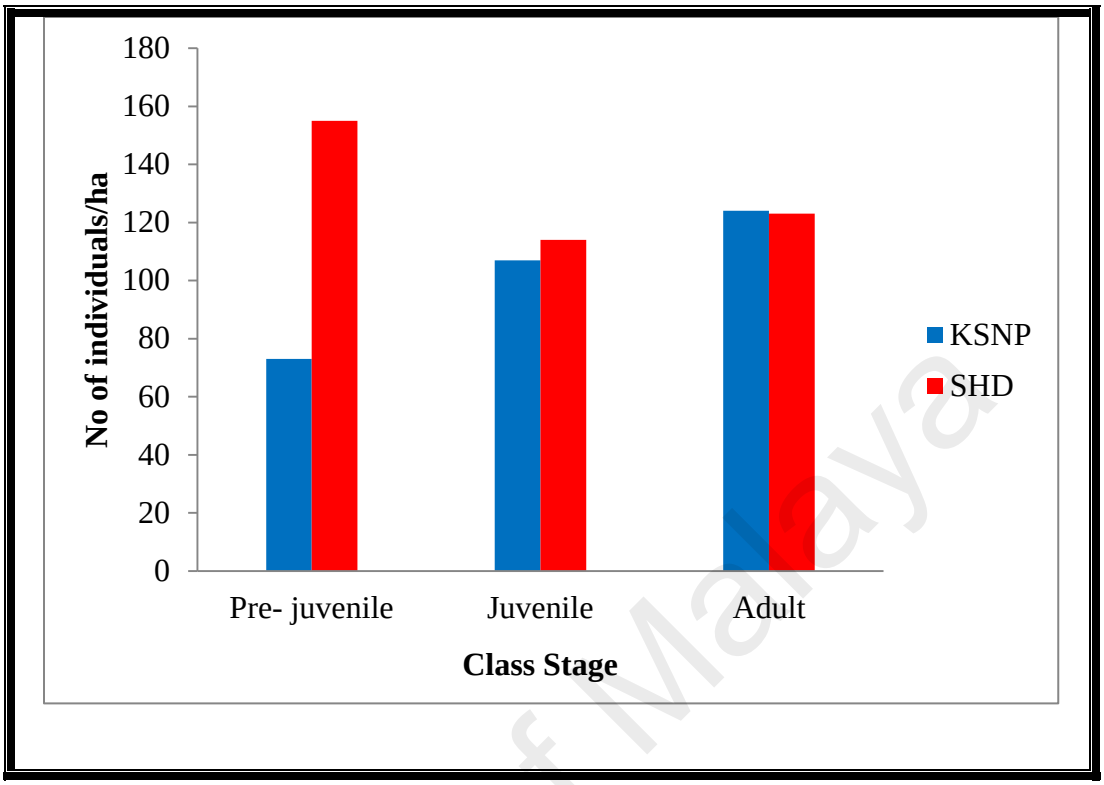


Figure 3.4: Class Stage at KSNP and SHD

3.9.2 Species Diversity

From the comparison of diversity between the two study areas, the Shannon–Weiner index result showed that the diversity index was higher at Sungai Haji Dorani with value of 0.91 (H') than at Kuala Selangor with the value of 0.55 (H') (Table 3.4 and Table 3.5). The Shannon–Weiner index was 1.65 times greater (0.91/0.55 = 1.65) at the Sungai Haji Dorani compared to Kuala Selangor. The Shannon–Weiner index was high in SHD because this area supported 5 common species namely *A. marina*, *B. cylindrica*, *E. agallocha*, *X. mekongensis*, *S. alba.*

Table 3.4: Shannon-Weiner Index for KSNP

Species	No. of Individuals	p_i	ln p_i	p_i ln p_i	H'
A. officinalis	36	0.12	-2.13	-0.254	0.55
B. parviflora	253	0.84	-0.18	-0.148	
R. mucronata	12	0.04	-3.23	-0.128	
S. alba	1	0.003	-5.71	-0.019	
Total	302			-0.549	

Table 3.5: Shannon-Weiner Index for SHD

Species	No. of Individuals	p_i	ln p_i	p_i ln p_i	H'
A. marina	207	0.52	-0.66	-0.341	0.91
B. cylindrica	172	0.43	-0.85	-0.363	
E. agallocha	13	0.032	-3.43	-0.111	
S. alba	1	0.002	-5.99	-0.015	
X. mekongensis	8	0.020	-3.91	-0.078	
Total	401			-0.909	

By right, the maximum diversity that can be obtained from KSNP is 75.5 (since the diversity number of species was 4) while 80.2 was found in SHD (since the number of species was 5). This development implies a low degree of species diversity in both study areas. While *B. parviflora* (253 individuals) as the most abundant species of KSNP must have triggered such diversity range, *A. marina*

and *B. cylindrica* were implicated for this in SHD. Hence if the Shannon-Weiner index range (0.0 to 4.6) is put into account, the SHD which recorded a value of 0.91 as against 0.55 found in KSNP, is considered to tend towards being described as an environment with a better even distribution of species. Therefore a more complex ecological community and associated complex food web can be found in SHD than in KSNP (Mac Arthur 1969). It may be caused by human activity which disturb zonation of mangrove species and lead various species grow same zonation.

According to Simpson index in both study areas result indicated that the diversity index was higher at Sungai Haji Dorani with value of 2.22 (D_S) than at Kuala Selangor with the value of 1.40 (D_S) (Table 3.6 and 3.7). This analysis justified the fact that higher species diversity abound in SHD than with KSNP. It implied that at random assessment that chances of obtains more than one species of the trees in a particular area is more pronounced in SHD despite the degradation that had taken place within the mangrove forest. This may imply the potentials of SHD to recover with time.

Table 3.6: Simpson Index for KSNP

Species	No. of Individuals(n_i)	N-1	n_i-1	N(N-1)	$\sum n_i (n_i-1)$	D_S
A. officinalis	36	301	35	90902	1260	1.40
B. parviflora	253		252		63756	
R. mucronata	12		11		132	
S. alba	1		0		0	
N(total)	302				65148	

Table 3.7: Simpson Index for SHD

Species	No. of Individuals(n_i)	N-1	n_i-1	N(N-1)	$\sum n_i(n_i-1)$	Ds
A.marina	207	400	206	160400	42642	2.22
B. cylindrica	172		171		29412	
E. agallocha	13		12		156	
S. alba	1		0		0	
X. mekongensis	8		7		56	
N(total)	401				72266	

In order to identify the similarity between the two study areas, all the relevant data were gathered and analyzed on Sorenson's similarity. Based on comparison result show that the similarity of species in both areas was very low with a value of 0.22 (value from 0 to 1). This is because only one species, *S. alba*, was found at both study areas out of the total eight species (Table 3.8). Reason for disparity may be attributed to geographical location and some other environmental and climatic factors.

Table 3.8: Sorenson's Similarity Index in Both Study Areas

No. species in KSNP (A)	No. species in SHD (B)	Similar species in both areas (J)	S
4	5	2	0.22

The degraded study site of Sungai Haji Dorani is higher in species diversity compared to Kuala Selangor. This may be due to the degradation of the mangrove forest through agricultural land clearing or tidal movement of water into the hinter parts of the mangrove, which allows for the mixing or inter-woven nature of the trees breeding, hence increasing the density. These are the major differences across the sites over the monitored parameters which might be due to the environmental conditions and even standing age (Ong 1982).

A. marina is the most important and dominant species with the highest Important Value Index (IVI) value in Sungai Haji Dorani. This agrees with Clough *et al.,* (1997) that opined that, unlike other species, *A. marina* can still thrive in windy situations and some other environmental conditions like high salinity and high temperature areas. On the other hand, Rhizophoraceae was the largest family in the Kuala Selangor, which is consistent with its widespread distribution worldwide, and this family is also very adaptable in extreme mangrove environments (Tomlinson 1986). *B. parviflora* with high IVI is dominant in the area of Kuala Selangor. This finding agrees with Mahmood *et al.,* (2003). The dominance exhibited by *B. parviflora* in Kuala Selangor is based on the fact that it thrives more within mangrove areas located by river banks (Tomlinson, 1986; Giesen *et al.,* 2006). A high salinity level may not be easily tolerated by *B. parviflora,* unlike *A. marina* which is well known to grow and survive in extreme saline condition (Bagust *et al.,* 2005).

The results have shown that Kuala Selangor, being a natural mangrove, possesses not only larger but also taller mangrove trees when compared to Sungai Haji Dorani. Therefore, while the population density of trees is higher in Sungai Haji Dorani, individual tree size measured in terms of height and DBH is higher in Kuala Selangor mangrove area.

3.9.3 Biomass

Above-ground biomass of *A. officinalis* and *B. parviflora* were 37.22 and 266.74 t/ha, respectively, and 305.46 t/ha of total above-ground biomass was recorded for Kuala Selangor. On the other hand, the total above ground biomass was 122.78 t/ha for Sungai Haji Dorani. *A. marina* and *B. cylindrica* contributed the major portion of this biomass (Table 3.9).

Table 3.9: Above-ground Biomass of Mangroves Tree in Both Study Areas (2012)

Species	Above-ground biomass(t/ha)	
	KSNP	SHD
A. officinalis	37.22	-
B. parviflora	266.74	-
R. mucronata	1.07	-
S. alba	0.43	0.02
A. marina	-	108.63
B. cylindrica	-	12.95
E. agallocha	-	0.92
X. mekongensis	-	0.25
Total	305.46	122.78

- Species not present in the study areas

The above-ground biomass of *B. parviflora* was found to be 61.62%,30.01% and 8.37% for the stem, branch and leaf, respectively, in the Kuala Selangor mangrove forest, while the percentage of above-ground biomass of *A. marina* in Sungai Haji Dorani was found to be 49.66%,43.79% and 6.55% for stem, branch and leaf, respectively (Table 3.10).

Table 3.10: Percentage of above-ground Biomass in Component of Tree

Component	Above- ground biomass (%)	
	Bruguiera parviflora	*Avicennia marina*
Leaf	8.37	6.55
Branch	30.01	43.79
Stem	61.62	49.66

Although the density in Sungai Haji Dorani is higher, the value of the estimated above-ground biomass was lower in comparison to the natural mangrove in Kuala Selangor. The variation in above-ground biomass may be related to different local climatic conditions such as temperature, solar radiation, rain, and frequency of storms. Environmental factors such as soil properties and nutrient status may also affect the growth rate in mangrove biomass (Komiyama *et al.*, 2008). Specifically, it is expected that species from degraded mangrove (Sungai Haji Dorani) show less above-ground biomass because of environmental interference that leads to much smaller size of trees. This is typical of mangrove forests where immature mangrove vegetation is exploited or experiences over-logging (Tomlinson, 1986) which is the case at Sungai Haji Dorani. Publications on *A. marina* are very limited when compared to other mangrove tree species, as regards biomass estimation. Reasons for this, point towards the fact that *A. marina* shows lower biomass than other tree species within the mangrove ecosystem. Similarly, its irregular features and the multi-stemmed nature give less

recognition (Ong *et al.,* 2004; Sherman *et al.,* 2003). With the comparison of the biomass production in different parts of trees from both study areas, the result suggests that production of stem was higher than branch and leaf production. This agrees with Chandra *et al.,* (2011) on higher biomass production of stems.

Below-ground biomass showed a variation between the two study areas. A comparatively higher amount of root biomass (12.12 t/ha) was observed for Sungai Haji Dorani, while 4.60 t/ha of root biomass was estimated for Kuala Selangor (Table 3.11).

Table 3.11: Below-Ground Biomass of Mangrove Trees in Both Study Areas

Component	Below- ground biomass(t/ha)	
	Mean ± SE	
	KSNP	SHD
Coarse root	3.44 ± 0.34	7.61± 1.80
Fine root	1.26± 0.14	4.51± 1.36

Surprisingly, the estimated value of below-ground biomass in Sungai Haji Dorani was higher compared to Kuala Selangor. Surveys of the mangroves in both study sites reveals that the density of root biomass at the top 10 cm is high, because some factors such as resilience, salinity, and softness might have played

significant role in enhancing the degree of fine root biomass available within the top 10 cm profile (Briggs, 1977; Komiyama *et al.,* 2008). These findings concur with Mayo *et al.,* (2011), Tamooh *et al.,* (2008) and Lauff (1967) that affirmed the concentration of *A. marina* roots at the top 30 cm below the ground level. According to Stafford-Deitsch (1996), anoxic environment might be responsible for the high root biomass in the upper profile because it halts root growth into deeper soil profiles. With many roots in the top profile, active transport of water and minerals are enhanced by the quality of roots in the top profile, and are characterized of accumulated organic matter and terrestrial forests nutrients (Claus & George, 2005).

3.9.4 Biomass Increment

Result of the biomass assessment within the first year of the study gave rise to assessment of biomass in subsequent years with view to evaluating the degree of biomass increment across significant tree species of both mangrove forests. The measured DBH values (both lowest and highest) for *A. officinalis*, *B. parviflora, R. mucronata* in KSNP were classified into ranges to obtain discrete selections as found in Table 3.12-3.14. Similar classification was adopted in SHD (Table 3.15-3.18).

Table 3.12: DBH Class for *A. officinalis* in KSNP Mangroves Forest

DBH class for *A. officinalis*			
5 to 23			
class	range	mean	number
1	5 to8	6.5	10
2	8 to 11	9.5	7
3	11 to 14	12.5	6
4	14 to 17	15.5	1
5	17 to 20	18.5	3
6	20 to 23	21.5	7

Table 3.13: DBH Class for *B. parviflora* in KSNP Mangroves Forest

DBH class for *B. parviflora*			
4 to 19			
class	range	mean	number
1	4 to 7	5.5	91
2	7 to 10	8.5	39
3	10 to 13	11.5	53
4	13 to 16	14.5	45
5	16 t0 19	17.5	22

Table 3.14: DBH Class for *R. mucronata* in KSNP Mangroves Forest

DBH class for *R. mucronata*			
5 to 8			
class	range	mean	number
1	5 to 8	6.5	11

Table 3.15: DBH Class for *A. marina* in SHD Mangroves Forest

DBH class for *A. marina*			
4 to16			
class	range	mean	number
1	4 to 7	5.5	102
2	7 to 10	8.5	58
3	10 to 13	11.5	20
4	13 to 16	14.5	11

Table 3.16: DBH Class for *B. cylindrica* in SHD Mangroves Forest

DBH class for *B. cylindrica*			
4 to 16			
class	range	mean	number
1	4 to 7	5.5	94
2	7 to 10	8.5	50
3	10 to 13	10.5	16
4	13 to 16	12.5	7

Table 3.17: DBH Class for *E. agallocha* in SHD Mangroves Forest

DBH class for *E. agallocha*			
5 to 22.70			
class	range	mean	Number
1	5 to8	6.5	5
2	8 to 11	9.5	3
3	11 to 14	12.5	0
4	14 to 17	15.5	2
5	17 to 20	18.5	2
6	20 to 23	21.5	1

Table 3.18: DBH Class for *X. mekongensis* in SHD Mangroves Forest

DBH class for *X. mekongensis*			
5to 8			
class	range	mean	Number
1	5 to8	6.5	8

Therefore, it was observed that biomass increment was recorded in both study areas and across the selected tree species. The overview assessment of the estimated biomass that spanned across three years (2012-2014) indicated a maximum increment on *R. mucronata* (44.4 %) in 2014 for KSNP as against maximum 42% on *B. cylindrica* in 2014 at SHD. In as much as a direct comparison on the degree of increment may not be made between both study areas since they have high species variation, yet they varied markedly within the study areas (Table 3.19 - 3.20)

Table 3.19: Above-ground Biomass Increment in Selected Species of KSNP (2012-2014)

Species	2012 (t/ha/yr)	2013 (t/ha/yr)	2014 (t/ha/yr)
A. officinalis	16.53	18.41	19.13
B. parviflora	21.35	21.96	22.71
R. mucronata	0.09	0.12	0.13

Table 3.20: Above-ground Biomass Increment in Selected Species of SHD (2012-2014)

Species	2012 (t/ha/yr)	2013 (t/ha/yr)	2014 (t/ha/yr)
A. marina	13.12	15.15	16.73
B. cylindrica	1.89	2.03	2.68
X. mekongensis	0.09	0.11	0.12
E. agallocha	0.30	0.35	0.37

in KSNP, the degree of biomass increment was most pronounced on *R. mucronata* as it recorded 33.3% and 44.4% in 2013 and 2014, respectively based on recorded increase from its 0.09 t/ha of the trees coverage in 2012. While *A. officinalis* recorded its maximum increment at 19.13 t/ha (15.7%) and *B. parviflora* showed 6.4% increment by 2014. Species type may be the core reason for variation.

The biomass increment in SHD was highest with *B. cylindrica* (41.7%) but shared proximity with *X. mekongensis* (33.3%). This may be associate to species nature on some other associated environmental factor such salinity and tidal movements. Hence, the overall order of biomass increment in SHD was *E. agallocha* < *A. marina* < *X. mekongensis* < *B. cylindrica.* Both study areas showed potentials of biomass increment regardless of the natural or degraded condition of the mangrove forests.

Unlike the above- ground biomass increment, Table 3.21 shows a reduced trend in the below-ground biomass. While only 0.13 t/ha of the coarse root biomass was found in KSNP, approximately 1 ta/ha was recorded in SHD. Similar occurrence was found in the fine root biomass as well. Therefore, both study areas showed drastic reduction of the root biomass which expectedly might be due to the fact that growth rate of such plant part is very slow at least when the excavation activity and replacement with sandy soil is considered. However, the variation between the two might be associated to nearness to sea. SHD in near to sea than KSNP, and this might influence its root biomass potential. Also the abundance of *A. marina* in SHD might have influence the root biomass potential because the species is more tolerant to sandy environment.

Table 3.21: Below-Ground Biomass Increment in Both Study Areas

	SHD		KSNP	
	2012	2013	2012	2013
Coarse root	7.61±1.81	0.99±0.51	3.44±0.34	0.13±0.04
Fine root	4.51±1.36	0.40±0.16	1.26±0.14	0.03±0.03

3.9.5 Net Primary Productivity

Evaluation of the net primary productivity of both study areas was obtained as estimation of the biomass increment of the mangrove trees species. Table 3.22 and 3.23 showed that biomass incremental differences across each species of

KSNP and SHD, respectively. *Avicennia* species demonstrated the highest biomass increment in both mangrove forests as already mentioned in the previous chapter. However, the overall increment in KSNP (taken from all three species) for 2013 was 2.52 t ha^{-1} yr^{-1}. Similar increment was recorded in 2014 (1.48 t ha^{-1} yr^{-1}), yet it was slightly less than the degree of increment in 2013. Meanwhile, in SHD while 2.24 t ha^{-1} yr^{-1} was the overall increment (taken from the four species) in biomass for 2013, it increased further to 2.26 t ha^{-1} yr^{-1} in 2014. Reason may be associated to prevalent species types in the study areas wherein some species may have the tendency to initiate pronounced increase on yearly basis, especially as seen with *B. cylindrica* which showed an approximate of five (5) times increment between 2013 and 2014 from 0.14 t ha^{-1} yr^{-1} to 0.65 t ha^{-1} yr^{-1}. However, biomass increment is highly variable both locally and regionally (Clough, 1992; Mahmood *et al.*, 2008).

Table 3.22: Biomass Increment in Selected Species of KSNP (t/ha/yr)

Species	2012	2013		2014	
		Value	Increment	Value	Increment
A. officinalis	16.53	18.41	1.88	19.13	0.72
B. parviflora	21.35	21.96	0.61	22.71	0.75
R. mucronata	0.09	0.12	0.03	0.13	0.01
Total			2.52		1.48

Table 3.23: Biomass Increment in Selected Species of SHD (t/ha/yr)

Species	2012	2013		2014	
		Value	Increment	Value	Increment
A. marina	13.12	15.15	2.03	16.73	1.58
B. cylindrica	1.89	2.03	0.14	2.68	0.65
X. mekongensis	0.09	0.11	0.02	0.12	0.01
E. agallocha	0.30	0.35	0.05	0.37	0.02
Total			2.24		2.26

Therefore, calculating the net primary productivity which is the summation of the biomass increment (BI) and litter production (LP), 15.01 ha^{-1} yr^{-1} and 13.87 ha^{-1} yr^{-1} was recorded for KSNP and SHD, respectively (Table 3.24). Despite higher species diversity in SHD, KSNP was high in net primary productivity and this may be due to species types and the prevalent abiotic factors such as degree of salinity and organic carbon content in each mangrove forest. Also the undisturbed nature of KSNP might accord the mangrove forest optimal growth edge than SHD which is degraded and might need longer time for possible recovery. Geographical location, stand age and stand density may have influenced the difference in net primary productivity of both forests (Aksornkoae, 1993; Ong *et al.*, 1985; Mahmood *et al.*, 2008).

Table 3.24: Net Primary Productivity in Both Study Areas

	BI (t/ ha/yr)	LP(t/ ha/yr)	NPP (t/ ha/yr)
KSNP	2.00	12.92	14.92
SHD	2.25	11.61	13.86

Note:

- Biomass Increment (BI)
-Litter Production (LP)
-Net Primary Productivity (NPP)

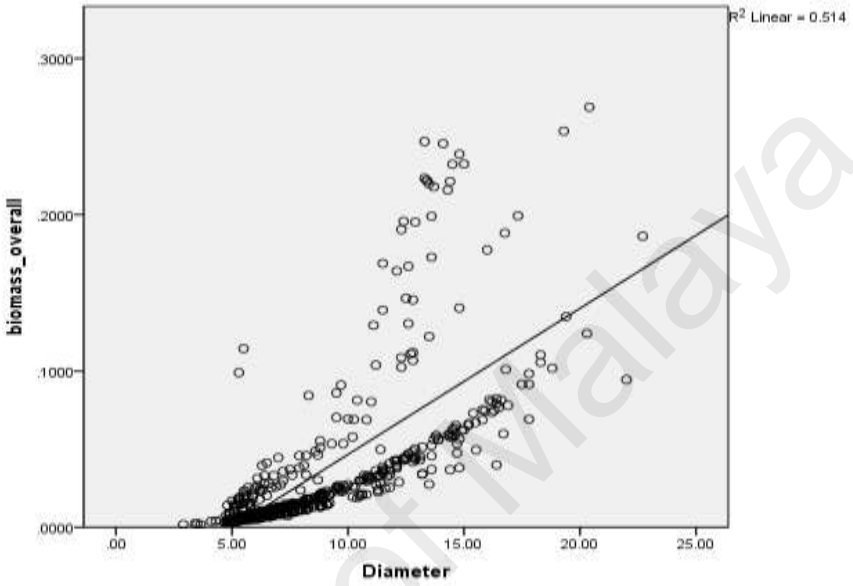
A linear regression method was used to determine the contribution of predictors on the dependent variable. The analysis assessed the effects of DBH and Height as independent variable or predictor on the overall Biomass as dependent variable or criterion.

The prevalence approach conducted in this study to test the linearity was the scatter-plot. A scatterplot diagram helps to determine if the relationship between the independent variable and the dependent variable is linear or non-linear, which is a key assumption of regression analysis. Figure 3.5 shows the scatterplots between the predictors (DBH & Height) and dependent variable biomass.

Dependent Variables Predictors

DBH

Biomass



Height

Biomass

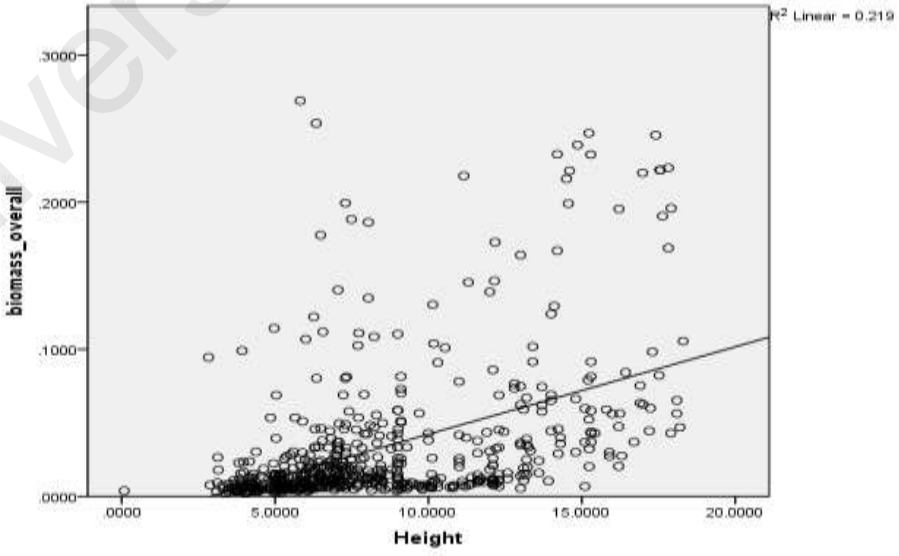


Figure 3.5: Results of Scatterplot for Testing Linearity

As can be seen in Figure 3.5, by following the darker dots in each of the scatterplots, there appears to be a dark line run from the bottom left to the upper right, suggesting a positive relationship between the independent and dependent variables. The relationships thus appear to be linear, which are good for regression analysis.

The results for multiple linear regression indicated that the effects of DBH and Height on the Biomass were statistically significant (Table 3.25). The sign of the regression standardized coefficient (Beta) represents the positive or negative effects of the predictors on the dependent variables. Therefore, it could be stated that the effects of DBH and Height on the Biomass were positive. It means that with an increasing in DBH or Height, the dependent biomass variable will rise too.

Table 3.25: Results of Multiple Linear Regressions in DBH and H

Dependent Variables	Predictors	Unstandardized Coefficients		Standardized Coefficients	t	p-value	Significant Effect
		B	Std. Error	Beta			
Biomass	(Constant)	-.051	.004		-13.534	.000	
	Diameter	.009	.000	.667***	19.203	.000	Yes
	Height	.001	.000	.087*	2.508	.012	Yes

* Contribution is significant at the 0.01 level (2-tailed); ***. Contribution is significant at the 0.001 level (2-tailed)

The abso lute value of beta indicates the magnitude of predictors' influences on the dependent variable. Hence, the results indicated that the DBH had higher significant effect on the Biomass in comparison with the effect of Height on biomass. The result of the multiple linear regression in living part is shown in Figure 3.6.

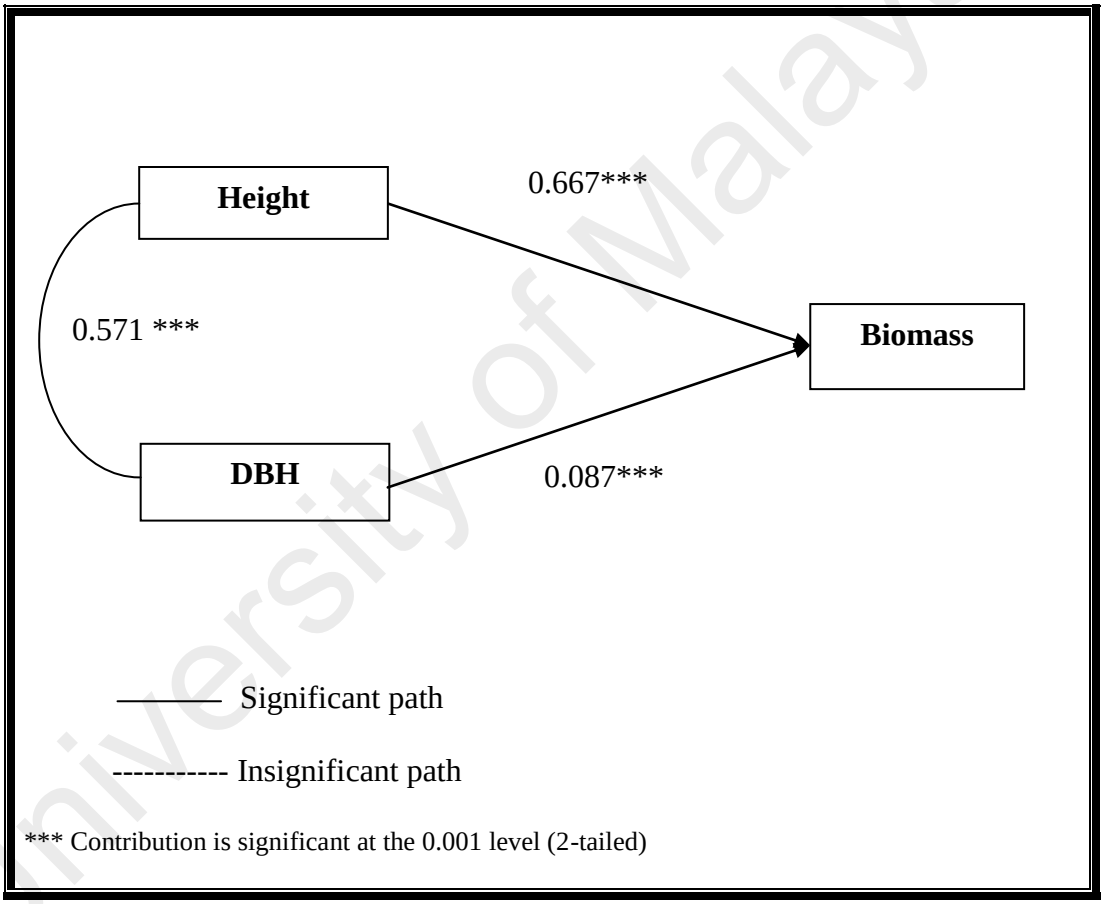


Figure 3.6: Results of Multiple Linear Regression in Biomass

Therefore, this section of the study described the structural distribution of mangrove forest of both natural and degraded conditions in Peninsular Malaysia. The distribution of trees in terms of population and species diversity was pronounced in SHD which was characterized of 401 individual trees and 5 species

as against 302 individual trees and 4 species found in KSNP. The estimated above-ground biomass in SHD (122.78 t/ha) was less than half of the sum total found in KSNP (305.46 t/ha). However, the reverse was noted when below-ground was assessed; SHD (12.12 t/ha) recorded almost thrice the estimation from KSNP (4.60 t/ha). Hence, SHD demonstrated edge over KSNP in below-ground biomass whereas higher value was associated to KSNP in respect to the above-ground biomass. Furthermore, the assessment of the degree of biomass increment indicated a slight difference between two study areas; KSNP recorded 2 t/ha/yr while SHD was increasing at 2.25 t/ha/yr. However, the net primary productivity of KSNP (14.92 t/ha/yr) was 0.06 t/ha/yr more than SHD's productivity (13.86 t/ha/yr).

CHAPTER FOUR

CARBON POOL

4.1 Introduction

Soil still remain an integral component of ecosystem, and plays a key role in the carbon cycle. It has the potential of serving as carbon sink depending on soil type, vegetative composition, and climate situations. Therefore, mangrove forest is one of such ecosystems that play a significant role in carbon distribution and sequestration in the environment. Yet considering the fact that mangrove soil differ across geographical locations and forest species, assessing its carbon pool potential involves assessment of the discrete components of the forest especially, soil nature, living part of tree species, degree of litter production, quantification of standing crop and calculation of the net primary productivity. Considering the fact that economic advancements are inevitable in as much as it is even encouraging environmental degradation, mangrove forests have gotten a share as tampered habitat; hence degraded and natural mangrove classifications. This makes it imperative to investigate and understand the carbon storage and sequestration of mangrove forest as such knowledge will help to identify areas and changes in land use that are of particular importance to the profit or loss of carbon from the soil (Cerón-Bretón *et al.,* 2011). Assessment of the net primary productivity will give an idea of the extent of mangrove ecosystem maturity while providing a baseline data for sustainable management (Mahmood *et al.,* 2008; Kimmins, 2004).

4.2 Objectives

The objectives of this study were

- To estimate the litter standing crop and litter production in the selected natural and degraded mangrove forests of Malaysia.
- To estimate carbon pool in both vegetation and soil of the selected natural and degraded mangrove forests of Malaysia.
- To measure the soil physical and chemical properties in the selected mangrove forests of Malaysia.
- To estimate carbon sequestration by mangrove plants in the selected natural and degraded mangrove forests of Malaysia.

4.3 Materials and Methods

4.3.1 Litter Production

For the collection of litter products from each site in both areas of study, 1 m quadrant traps were established and suspended by rope between trees, at a height of 2 m above the ground so as to keep them beyond the reach of high tides in each plot. Initially, a total of fifteen traps were taken randomly by quadrate sampling method (Plate 4.1). Litter traps were frequently damaged by monkeys; hence damaged traps were replaced every month. This study was conducted for 24 months from June 2012 to June 2014. All litter products (leaves, branches, flower and propagules) inside the individual trap were collected. They were placed inside labeled plastic bags and carried to laboratory for analyses. The samples were oven dried at 65°C until net weight was achieved. Oven-dried litter products were then

separated into different parts (leaves, small branches, flower, seeds, and propagules) and their corresponding weights were taken by using electric balance. Some sub-samples were taken from all the components of produced litter**.** These sub-samples were crushed and pulverized, before being sieved through 2 mm mesh (Allen *et al.,* 1974) for the determination of carbon level present in the samples. The total means of litter production were achieved for individual site by the end of June 2014.

Plate 4.1: Collection of Litter Production

4.3.2 Litter Standing Crop

For the collection of litter standing crop at individual site, a total of fifteen plots, each 1m × 1m were taken randomly by quadrate sampling method on the forest floor during the dry (August 2012 & 2013), wet (November 2012 & 2013), intermediate (April 2013 & 2014) seasons. From each individual sample plot, all litter standing crop compositions (leaves, small branches, flower, seeds, and propagule) were collected (Plate 4.2). All collected samples were transferred to the laboratory (in labeled plastic bags) for further processing. Collected litter standing crop samples were washed to remove dirt and sediment parts. Samples were oven dried at 65 ˚C for four days to get the oven-dry weight. The oven-dried litter standing crops were then separated into different parts (leaves, small branches, flower, seeds, and propagule) and the corresponding weights were recorded. After measuring such weights, the means of sample plots were calculated for individual sites at each season. Some sub-samples (500g or 200g) were taken from all the components of litter standing crop**.** These sub-samples were crushed and pulverized, before being sieved through 2 mm mesh (Allen *et al*, 1974) for the determination of carbon in the samples.

Plate 4.2: Collection of Standing Crop Production

4.3.3 Living Part of Tree

Three trees from each species were selected (avoiding insect damaged ones) while collecting samples from different components of the plant (leaves, branches, stem, bark and roots) during different seasons. The barks of the selected trees were removed using a keen knife (Plate 4.3).

Plate 4.3: Collecting Bark Sample

Desired samples were taken from the stem by drilling until the center of stem (Plate 4.4). For the collection of leaves samples, both old and young leaves were collected using tree cutter (Corona TP 32-6) (Plate 4.5). Similarly, root samples were also obtained from living trees (Plate 4.6). All samples from all parts of tree were placed in a plastic bag and duly labeled before being transferred to the laboratory. Samples were oven-dried at 65 ˚C for two days. For estimation of organic carbon, the samples were crushed by using mechanical grinder (A10

manufactured by 1 KA-Labortechnik) and sieved through 2 mm mesh (Allen *et al.*, 1974).

Plate 4.4: Collecting Stem Sample

Plate 4.5: Collection of Leaf Sample from Living Tree

Plate 4.6: Collection of Root Sample from Living Tree

4.3.4 Soil

Soil characteristic is one of the most important environmental factors directly affecting mangrove productivity and structure. The sampling was carried out by seasonal sequence as stated in previous section (4.3.2). Fifteen samples were selected randomly at each study area for the estimation of soil organic carbon. Samples were drained of excess water while the found biomass and solid materials like roots, leaves etc. were removed. Soil cores were extracted with a sampler constructed of 5cm diameter PVC pipe, minimizing soil disturbance during the extraction process (Plate 4.7). The samples were collected for determination of organic carbon at the following depths: 0–10 cm, 10–20 cm, and 20–30 cm (Plate 4.8). Soil samples were transported from the field and immediately placed at room temperature for air drying. The amount of organic carbon was obtained from analyzed soil samples via the Walkley-Black method (1934). The following equation was used for the estimation of the carbon storage rate (Gonzalez *et al.,* 2008):

$$C= CO\% \ D_a \ P_r$$

Where, C= carbon storage rate

CO% = percentage of organic carbon content

D_a= bulk density

P_r= soil depth

Plate 4.7: Collection of Soil Sample with PVC Pipe

Plate 4.8: Collection and Sample Labeling

4.3.4.1 Soil analysis

4.3.4.1.1 Salinity

Soil salinity was determined with a refractometer at the beginning and at the end of each transect. This parameter was excluded in transects where no interstitial water could be found at the depth of 30 cm.

4.3.4.1.2 *In situ* pH and Redox Potential

For the determination of soil pH in this study, one gram soil was added to 10 ml deionised water, and allowed to stand for a while and pH of the mixture was measured by using pH meter (± 0.05 accuracy YSI Multi – probe meter). Redox value indicates the extent of oxidation state of ionic species in the solution. Redox values of soil samples were determined in conjunction with *in situ* pH result by using the same pH meter (Allen *et al.*, 1974).

4.3.4.4.1.3 Soil Texture

Soil texture which is defined as the relative proportions of each class was determined by using test sieve (500 µm–200 mm) (Table 4.1). The coarse sand particles were separated by sieving (Gee & Bauder 1986). Fine sand, silt and clay were separated by using different sizes of sieve, and their textural classification was obtained using soil texture triangle.

Colour of the soil was also analyzed using Munsell Soil Color Charts (1994). The soil particles taken from both study areas were compared against the standard soil colour chart.

Table 4.1: Soil Texture Classification

Soil separate fraction name	Size range
Very coarse sand	1.00-2.00 mm
Coarse sand	0.5-1.0 mm
Medium sand	0.25-0.50 mm
Fine sand	0.10-0.25 mm
Very fine sand	0.05-0.10 mm
Silt	0.002-0.05 mm
Clay	< 0.002 mm

Source: Salako *et al.,* 2006

4.3.4.1.4 Soil Bulk Density and Porosity

Bulk density is a measure of a soil mass per unit volume of soil. For calculating bulk density of the soil sample, the core method (Blake, 1965) was used. 30cm long core was divided into 6 small cores each of 5 cm (Figure 4.1).

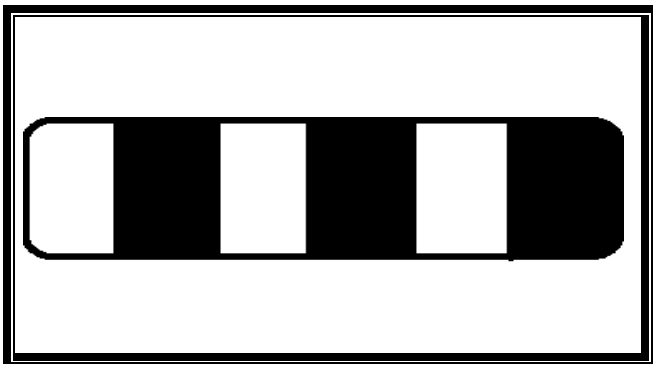


Figure 4.1: Core Method

All the cores were inserted symmetrically into the soil and these cores were taken as intact. From all cores, only one of the soil cores was selected randomly, and then it was placed in a plastic bag after cleaning all the dirt particles attached with the core to be ready for laboratory analysis. The collected core was dried at 65° C for three to four days. After oven-drying, the weight of the soil core was measured, and also the volume of the core was measured. For the estimation of bulk density, the following equation was used:

$$\text{Bulk Density (g/cm}^3\text{)} = \text{soil dry weight (g)} / \text{volume of soil core (cm}^3\text{)}$$

Similarly, given that the particle density was 2.65 g cm^{-3} (average mineral specific gravity for the sand fraction), the percentage of soil porosity was also calculated as follows:

$$\text{Porosity (\%)} = \left(1 - \frac{\text{Bulk Density}}{\text{Particle Density}}\right) \times 100$$

4.3.4.1.5 Moisture content

The moisture content of soil was measured with weight loss procedure (Allen *et al.*, 1974). A fresh air-dried soil sample was dried in an oven at 105 ºC for two days to achieve the constant weight. Percentage of moisture content was measured by the following formula.

$$\text{Moisture (\%)} = \frac{\text{Dry weight of sample (g)}}{\text{Wet sample weight (g)}} \times 100$$

4.3.4.1.6 Organic Carbon

For the calculation of organic carbon, between 10 mg and 20 mg of the sample was weighted accurately and placed in a dry 250 mL conical flask. Then 10 mL of 1 N, $K_2Cr_2O_7$ was added and the flask was swirled gently to disperse the sample in the solution. Finally 20 ml of concentrated H_2SO_4 was added to direct the stream into the suspension. Immediately the flask was swirled until the sample and the reagent were mixed. The solution was heated on a hot plate until the temperature reaches 135 °C (approximately ½ minute). After this process, sample was set aside to cool slowly. The blank (without soil) was run in the same way to standardise the ferrous sulphate ($FeSO_4$) solution. When it was cooled (20–30 minutes), the solution was diluted to 200 mL with deionised water and preceded with addition of 3 or 4 drops of ferroin indicator before being titrated with 0.4 N $FeSO_4$.

Addition, drop-by-drop of the ferrous sulphate continued until the solution turned greenish colour and then changed to blue-green (Plate 4.9).

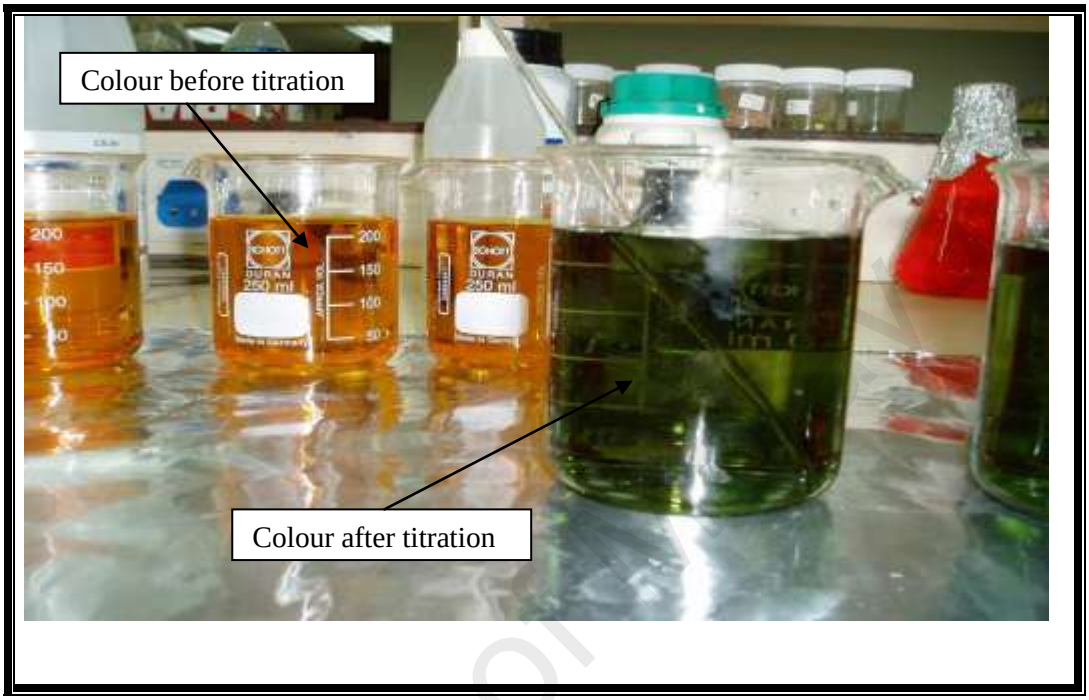


Plate 4.9: Titration Process

At this point, the amount of organic carbon was recorded by using the following formula:

$$2Cr_2O_7^{2-} + 3C + 16H+ \rightarrow 4Cr^{3+} + 8H_2O + 3CO_2\uparrow$$

1 mL of 1 N Dichromate solution is equivalent to 3 mg of carbon.

Where the quality and normality of the acid/dichromate mixture used are as stated in the method, the percentage carbon is determined from the following:

$$\text{Organic Carbon (\%)} = \frac{0.003\text{g} \times N \times 10ml \times (1\frac{T}{S}) \times 100}{\text{ODW}}$$

$$= \frac{3(1 - \frac{\text{T}}{\text{S}})}{ODW}$$

Where:

N = Normality of $K_2Cr_2O_7$ solution

T = Volume of $FeSO_4$ used in sample titration (mL)

S = Volume of $FeSO_4$ used in blank titration (mL)

ODW = Oven-dry sample weight (g)

4.4 Carbon Concentration and Carbon Sequestration

The amount of carbon stored in trees depends on tree species, growth conditions in the environment, age of tree and density of surrounding trees. Carbon concentration is obtained via multiplication of the tree biomass (according to different tree parts) with the quantified organic carbon. For the estimation of carbon sequestration, the biomass of the each species in different part of tree is multiplied by a factor of 1.83(constant standard for converting carbon to CO_2) (Ximenes *et al.*, 2008).

4.5 Data analysis

Data for biomass and carbon sequestration was manually compiled while the graphical and statistical representations were generated using Microsoft Excel. The Statistical Package for Social Sciences (SPSS version 20) software was used to analyze the comparison of the result in both study areas. After data entry, a thorough check was carried out and any discrepancy was rectified by revisiting the tree in the field, re-sampling the individual, and changing the entry in the computer if necessary.

4.6 Result and Discussion

4.6.1 Litter Production

Production of litter at both mangrove forests was observed throughout the year (Table 4.2). Though there was high proximity in pattern of distribution across the months, yet distinct seasonal variation was observed. Leaves and branches accounted for the largest part of the litter produced throughout the year which is typical of previous studies (Woodroffe, 1992; Sasekumar & Loi, 1983). Similarly with more than 70 % of the total litter being leaf, it can be attributed to the type of tree distribution in the mangrove area which includes leafy trees like distribution as observed during the dry season (averaged 61.39%). High proximity in distribution was found between wet season and intermediate season as their average values were 78.53% and 72.97%, respectively in KSNP. However evaluating the leaf litter distribution across individual months of the year, December was found to be the peak period for both mangrove forests; 81.63% and 85.29%, for SHD and KSNP, respectively. However, when the natural and degraded mangrove were compared in term of leaf litter production, least value 34.76% was collected in the natural mangrove (KSNP) while about 35.9% was found in the same month (July) at SHD which is a degraded mangrove forest. In SHD, the trend of leaf litter fall showed a continuous increase from September until December before decelerating, with the exception of switch between February to May.

Flower litter was not a significant part of the total litter production for both mangroves from June to December and this is attributed to the non- flowering period of the mangrove trees. However, they became part of the total litter from January and increased until April and May. Therefore, the presence of flower litter is highly limited to intermediate season in mangrove forests of Peninsular Malaysia regardless of natural or degraded status of the mangrove. Sequel to flowering period is seed production in trees; hence the absence of propagule in the litter from October until March is accounted for by the plant cycle.

Therefore dry season is the peak of propagule litter production in both mangrove forest; 55.13% and 56.04 % for SHD and KSNP respectively, in the July. Bracts which were the very small leaves attached to the trees, were also parts of the litter production through the year. Peaks for bracts litter were found at the early wet season and mid intermediate season but the least distribution was found in dry season especially in July wherein 4.22 % and 4.31 % were obtained in SHD and KSNP, respectively.

Table 4.2: Litter Production in Both Study Areas

Month	Leaves (%)		Branches (%)		Flowers (%)		Bracts (%)		Propagule (%)	
	SHD	KSNP	SHD	KSNP	SHD	KSNP	SHD	KSNP	SHD	KSNP
Aug	50.25	55.02	13.15	8.13	0.0	0.0	4.90	3.91	31.70	32.94
Sep	63.03	66.18	18.73	19.33	0.0	0.0	14.82	8.97	3.42	5.51
Oct	72.49	72.77	14.85	12.51	0.0	0.0	12.66	14.72	0.00	0.00
Nov	78.53	77.54	12.43	11.33	0.0	0.0	9.03	11.13	0.00	0.00
Dec	**81.63**	**85.29**	12.40	5.24	0.0	0.0	5.97	9.47	0.00	0.00
Jan	79.18	79.23	11.07	2.21	1.59	7.98	8.16	10.58	0.00	0.00
Feb	74.82	69.12	11.47	12.09	3.17	3.84	10.54	14.95	0.00	0.00
Mar	70.79	70.57	13.08	13.36	5.03	5.41	11.10	10.66	0.00	0.00
Apr	70.86	72.56	13.20	11.40	6.06	5.37	7.70	8.86	2.18	1.81
May	67.39	72.32	9.93	9.16	5.86	5.26	7.95	8.20	8.87	5.06
Jun	64.64	67.55	10.50	10.32	0.00	0.00	10.20	10.62	14.66	11.51
Jul	35.90	34.76	4.74	4.89	0.00	0.00	**4.22**	**4.31**	**55.13**	**56.04**

Furthermore, the results of the litter production rate showed that the individual litter rate ranged from 0.08 to 6.59 g m^2 day and 0.09 to 8.82 g m^2 day for SHD and KSNP, respectively. Discrete analysis revealed that the leaf production rate for the degraded mangrove was 6.59 g m^2 day in March (Figure 4.2) as against 5.29 g m^2 day recorded in November for the natural mangrove (Figure 4.3). The result from natural mangrove is similar to Sasekumar and Lio (1983) which found Malay mangrove to be

comparable to those of Queensland where 5.36 g m^2 day can be obtained (Duke *et al.*, 1981). However, the higher value found in SHD may be attributed to the interferences in its existence brought about by the anthropogenic activities (resort, fishing etc.) around it. From the foregoing, it also showed that the rate of daily leaf litter production varied between the wet and intermediate seasons for both mangrove forests. Therefore it is worthy to note that mangrove productivity may vary considerably due to nutrient conditions of the soil (Cerón-Bretón *et al*., 2011).

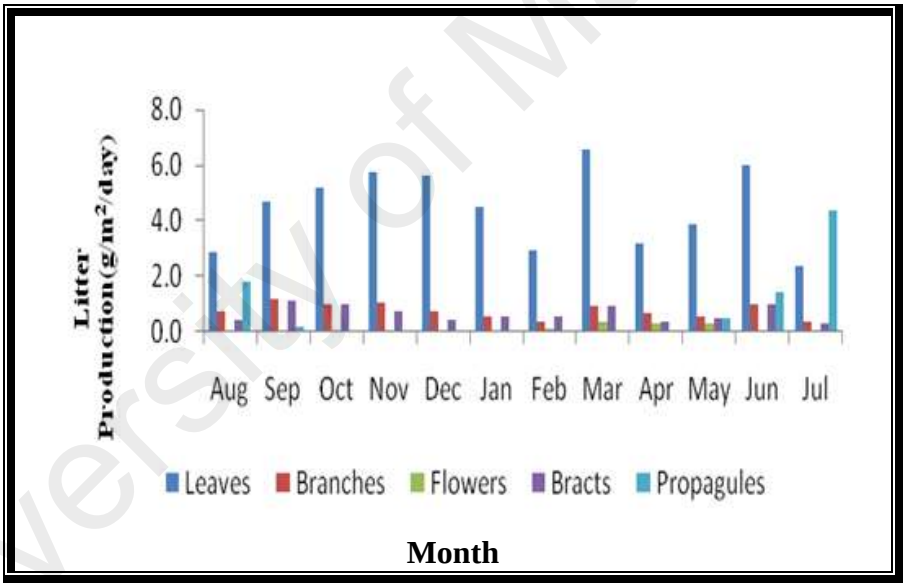


Figure 4.2: Litter Production in SHD Mangrove Forest

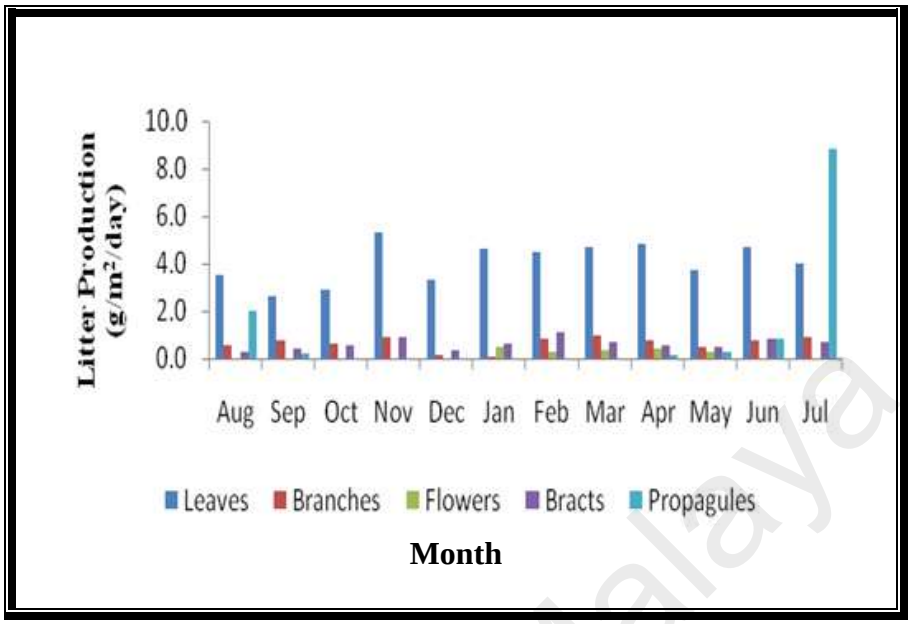


Figure 4.3: Litter Production in KSNP Mangrove Forest

Similarly, the higher rate of propagules litter (8.82 g m^2 day) found in KSNP than in SHD (4.36 g m^2 day) might be an evidence of an enriched nature of natural mangrove, hence seed production become associated to degree of mangrove productivity. In overall, the non- leaf litter accounted for less than 30% of total litter production in both mangrove forest.

Also the carbon concentrations (CC) in the produced litter were evaluated and represented in Figure 4.4. About 0.42 t ha^{-1} yr^{-1} of carbon was found in the leaf litter of KSNP in wet season to mark the highest concentration of carbon within the studied areas and seasons as against approximately 0.37 t ha^{-1} yr^{-1} and 0.29 t ha^{-1} yr^{-1} obtained in intermediate and dry seasons. However the trend in branch and propagules were slightly different. Highest carbon concentration was found in the intermediate season, followed by wet season before the dry season. Expectedly dry season often show that soil contains more carbon concentration

than in the wet season because dry season is characterized of evapotranspiration that allows for vertical transport of organic carbon (Cerón-Bretón *et al.*, 2011). However, the high degree of carbon concentration in the branch and propagules for the intermediate and wet seasons may be as a result of the ability of such plant parts to retain and store nutrients than in leaf where exposure to sunlight and increased surface area may be limiting factors. Carbon concentration in all the tree parts (leaf, branch and propagules) revealed that KSNP showed higher concentrations that what was found in SHD. This might be a reflection of the degraded nature of SHD unlike KSNP that is natural and have almost undisturbed vegetation; hence nutrient conservation is expectedly higher. The human activities that included cutting down of trees and other related process could have aided in reduction of the total carbon concentration of SHD.

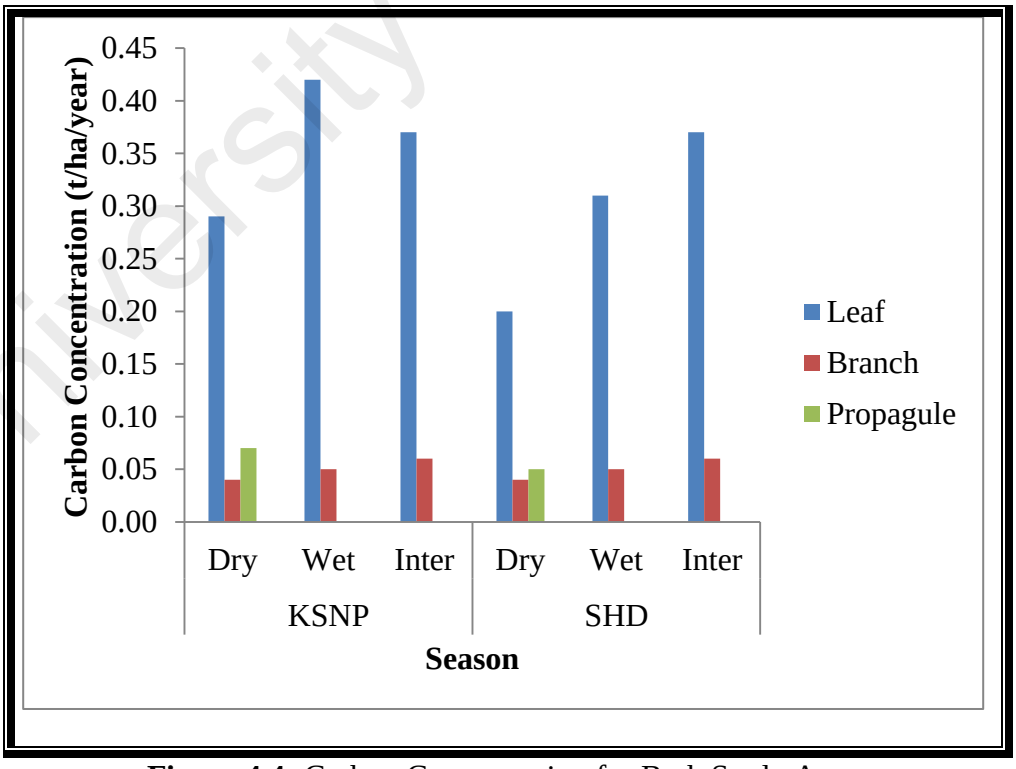


Figure 4.4: Carbon Concentration for Both Study Areas

The potentials of the mangrove forests to sequester carbon were assessed (Figures 4.5 & 4.6). Hence, it was found that KSNP demonstrated a higher carbon sequestration rate (41.63 t C ha^{-1} yr^{-1}) than the mangrove forest of SHD (37.94 t C ha^{-1} yr^{-1}) as shown in Tables 4.3 and 4.4. This variation may be expected due to difference in mangrove forest nature of both areas. The rate of carbon sequestration mostly depends on the growth characteristics of the tree species, the conditions for growth where the tree is planted, and the density of the tree's wood (Jana *et al.,* 2009). Therefore, the aforementioned factors might have accorded KSNP the edge over SHD since the trees population is higher in KSNP. Similarly, species zonation was prevalent in KSNP unlike the arrangement in SHD; hence such condition could have influenced the carbon sequestration.

Comparison of the carbon sequestration rate across the tree parts, the rate was increasing in the order of propagule < branches < leaves in both study areas. Leaves contributed more than 75% of the total carbon sequestration rate in each study area. Reason for such may be associated to metabolic activities of leaves especially the photosynthetic role wherein oxygen is given off while carbon dioxide is trapped, hence the increased carbon content. Also, the comparison across seasons shows that the highest carbon sequestration rate can be obtained within the wet and intermediate seasons; average of 3.69 t C ha^{-1} yr^{-1} in wet season for KSNP, and 3.57 t C ha^{-1} yr^{-1} in intermediate season for SHD.

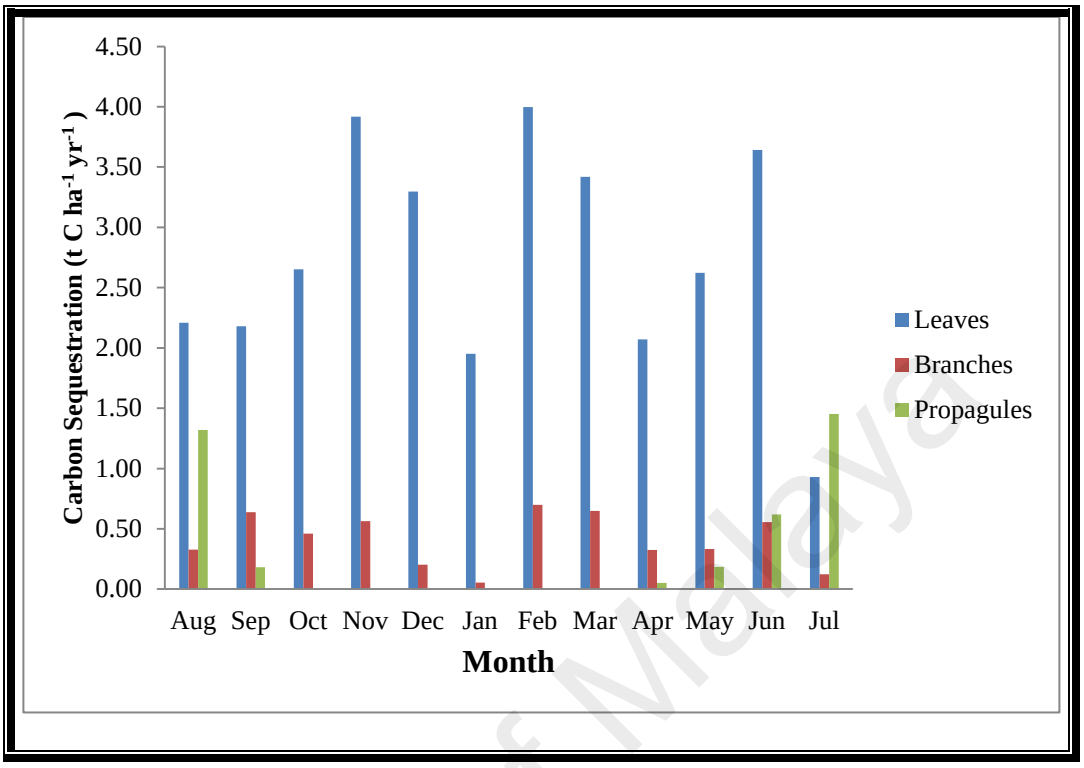


Figure 4.5: Carbon Sequestration in KSNP

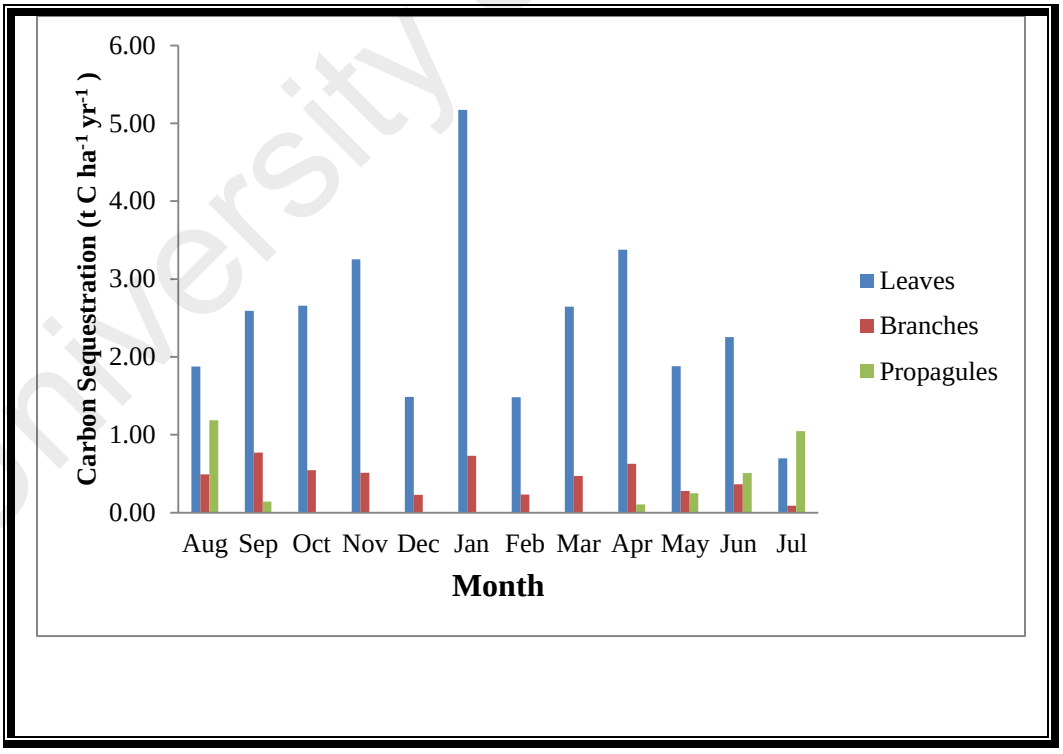


Figure 4.6: Carbon Sequestration in SHD

Table 4.3: Carbon Sequestration in Litter Production of KSNP (t C ha^{-1} yr^{-1})

	Leaves	Branches	Propagules	Total
Aug	2.21	0.33	1.32	3.86
Sep	2.18	0.64	0.18	3.00
Oct	2.65	0.46	0.00	3.11
Now	3.92	0.56	0.00	4.48
Dec	3.30	0.20	0.00	3.50
Jan	1.95	0.05	0.00	2.01
Feb	4.00	0.70	0.00	4.70
May	3.42	0.65	0.00	4.07
April	2.07	0.32	0.05	2.45
May	2.62	0.33	0.18	3.14
June	3.64	0.56	0.62	4.82
July	0.93	0.12	1.45	2.50
Total	32.89	4.93	3.81	41.63

Table 4.4: Carbon Sequestration in Litter Production of SHD (t C ha^{-1} yr^{-1})

	Leaves	Branches	Propagules	Total
Aug	1.88	0.49	1.19	3.55
Sep	2.59	0.77	0.14	3.50
Oct	2.66	0.54	0.00	3.20
Now	3.25	0.51	0.00	3.77
Dec	1.49	0.23	0.00	1.71
Jan	5.17	0.73	0.00	5.90
Feb	1.48	0.23	0.00	1.71
May	2.64	0.47	0.00	3.12
April	3.38	0.63	0.10	4.11
May	1.88	0.28	0.25	2.40
June	2.25	0.37	0.51	3.13
July	0.70	0.09	1.04	1.83
Total	29.71	5.34	3.23	37.94

The statistical evaluation of the results indicated that there were significant relationships between some variables and not others. Upon the Pearson correlation results, Biomass was in significant positive relationships with carbon concentration (CC) and carbon sequestration (CS) in relation to leaf, branch, propagule and also in overall. However the existing of a significant relationship between Biomass and organic carbon (OC) could not be supported. The results also showed a significant positive relationships between organic carbon (OC) and carbon concentration (CC) in leaf, branch and overall. The exception was the relationship between organic carbon (OC) and carbon concentration (CC) in propagule which was not statistically significant; r= -0.043. The other reminder relationships were statistically significant and positive (Table 4.5).

Table 4.5: Correlation Coefficients between All Variables in Litter

	Variable	Biomass	OC	CC	CS
Leaf	Biomass	1			
	OC	.293	1		
	CC	.914***	.644**	1	
	CS	1.000***	.296	.915***	1
Branch	Biomass	1			
	OC	.228	1		
	CC	.528*	.600**	1	
	CS	.600**	.260	.910**	1
Propagule	Biomass	1			
	OC	-.129	1		
	CC	.979***	-.043	1	
	CS	1.000***	-.131	.978***	1
Overall	Biomass	1			
	OC	.267	1		
	CC	.852***	.631**	1	
	CS	.978***	.261	.865***	1

*. Correlation is significant at the 0.05 level (2-tailed); **. Correlation is significant at the 0.01 level (2-tailed); ***. Correlation is significant at the 0.001 level (2-tailed)

As shown in Table 4.6, the results of the One-Way ANOVA test indicated that there were significant differences between the groups of month toward the overall Organic Carbon (OC); Statistic = 10.791, p-value = 0.000. However, the presence of significant differences between the month's groups could not be supported for biomass, carbon concentration (CC) and carbon sequestration (CS) as their p-values were above the 0.05 level.

Table 4.6: Results of One-Way ANOVA test for Species Groups in Litter

	Biomass	OC	CC	CS
One Way ANOVA Statistic	0.237	10.791***	0.737	0.358
Sig (p-value)	0.987	0.000	0.689	0.946
Significant Difference	No	Yes	No	No

***. Difference is significant at the 0.001 level (2-tailed)

The results for single linear regression indicated that the effects of Month on the Biomass, organic carbon (OC), carbon concentration (CC) and carbon sequestration (CS) were negative but were not statistically significant as their p-values were above the 0.05 level. The result of the single linear regression in litter is shown in Figure 4.7.

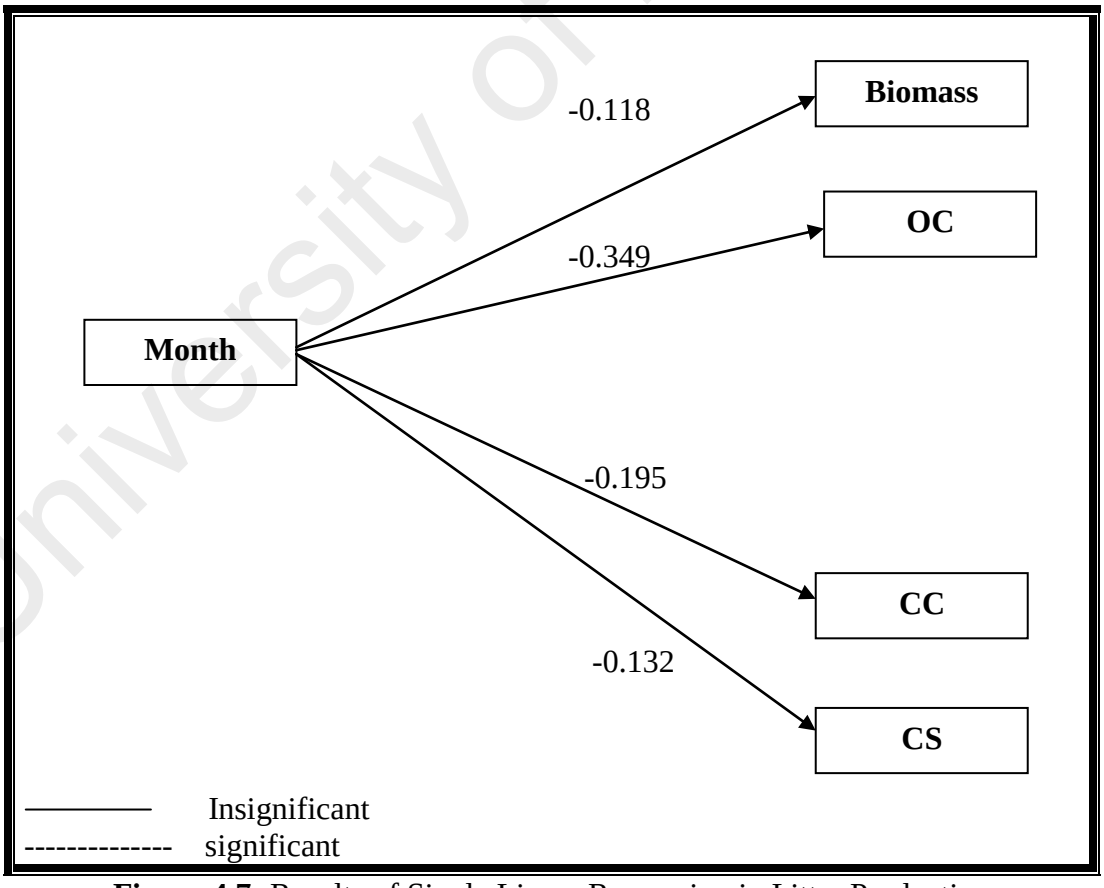


Figure 4.7: Results of Single Linear Regression in Litter Production

4.6.2 Standing Crop

Similarly, organic carbon content of standing crop was observed across the three seasons and the plant parts (leaf, branch and propagules) as shown in Figure 4.8. Carbon storage was more prevalent in the propagules part within both study areas; 44.93% and 45.38% for KSNP and SHD, respectively. In fact both sites showed slight similarity in order of carbon increase in the plant parts; leaf< branch< propagules (SHD); branch < leaf < propagules (KSNP). The reason might hinge on the biochemical activities that take place on the identified plant parts. Considering the potential degree of carbon loss brought about by photosynthesis and exposure on the leaf and branch, respectively, it is possible to find higher carbon content in the propagules part.

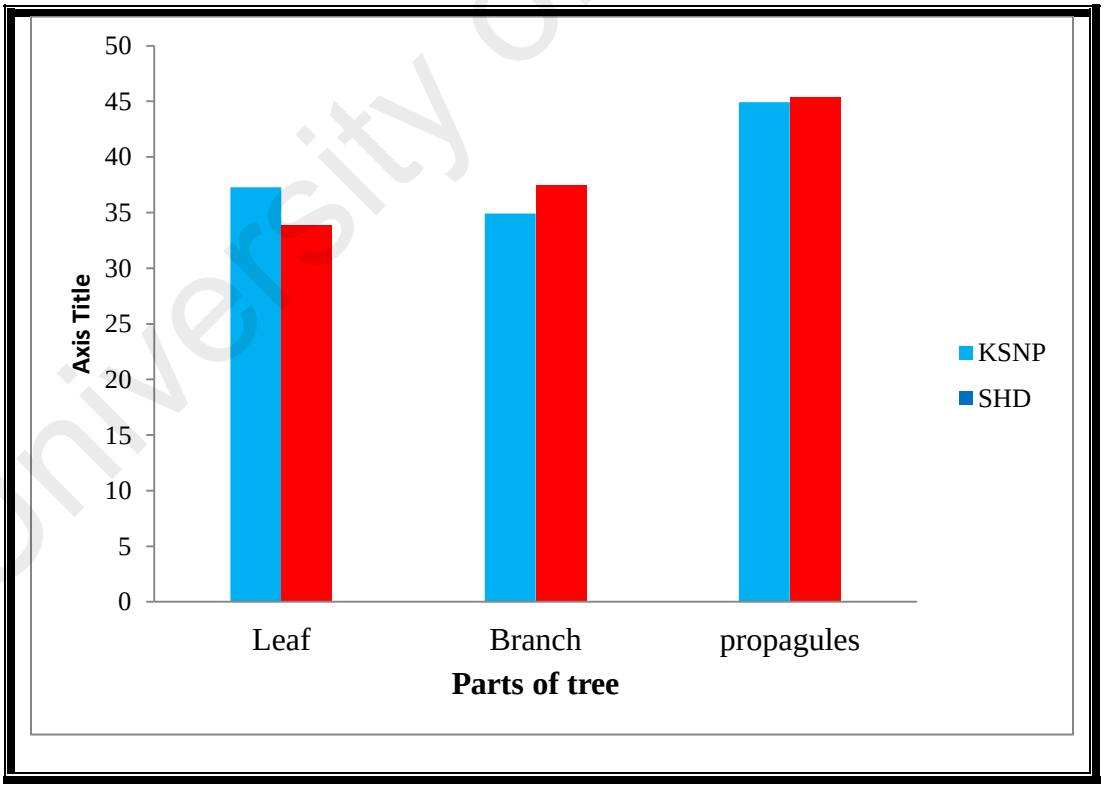


Figure 4.8: Organic Carbon in Litter Standing Crop at Plant Part for Both Study Areas

Seasonal assessment of the carbon concentration on the litter standing crop revealed that the lowest concentration (0.34 t C ha^{-1} yr^{-1}) was recorded in wet season for both study areas, yet the highest yield for SHD (0.46 t C ha^{-1} yr^{-1}) was also obtained in the dry season and KSNP (0.43 t C ha^{-1} yr^{-1}) was recorded in intermediate season. The reason may be attributed to the degree of variation in plant species within each study area; some trees respond differently to seasons, and the most abundant species can influence the litter generated in the season. However, both study areas showed high similarity in C during the wet season (Table 4.7 - 4.8).

Table 4.7: Carbon Concentration (t C ha^{-1} yr^{-1}) KSNP

	Dry	Wet	Inter	Mean
Leaf	0.45	0.28	0.36	0.37±0.09
Branch	0.31	0.40	0.50	0.40±0.1
Propagules	0.44	0.00	0.00	0.43±0.25
Mean	0.40±0.07	0.34±0.21	0.43±0.26	

Table 4.8: Carbon Concentration (t C ha^{-1} yr^{-1}) SHD

	Dry	Wet	Inter	Mean
Leaf	0.40	0.37	0.23	0.33±0.09
Branch	0.50	0.31	0.37	0.40±0.1
Propagules	0.47	0.00	0.00	0.47±0.27
Mean	0.46±0.05	0.34±0.2	0.30±0.19	

Also the carbon sequestration potential of the standing crop from both mangrove forests is shown in Table 4.9 across the three seasons. Propagules potential was only measured in the dry season because it cannot be found during the wet and intermediate seasons. The result showed that leaf part demonstrated higher sequestration ability over the other two parts. Reason for the foregoing may be liked to diverse meth activities that take place on different parts of the tree.

Table 4.9: Carbon Sequestration in Both Study Areas (t C ha^{-1} yr^{-1})

	KSNP	SHD	KSNP	SHD	KSNP	SHD
	Dry		Wet		Inter	
Leaf	0.0073	0.0104	0.0079	0.0079	0.0063	0.0072
Branch	0.0053	0.0048	0.0049	0.0049	0.006	0.005
Propagules	0.0095	0.0059	0.00	0.00	0.00	0.00

In general a statistical assessment of the standing crop components (leaf, branch, propagules) in relation to the normality of data set of described parameters namely biomass, organic carbon(OC), carbon concentration (CC) and carbon sequestration (CS) in given in Table 4.10.

The normality test according to Kolmorove-Smirnov (K.S) test, was used to determine whether the data set of biomass, organic carbon (OC), carbon concentration (CC) and carbon sequestration (CS) in each standing crop as well as overall were well-modelled by the normal distribution or not. Normality is the

main assumption of the parametric test. Table 4.10 demonstrates the results of normality test for all variables in standing crop.

Table 4.10: Results of Normality Test for All Variables in Standing Crop

	Variable	Kolmogorov-Smirnova			Skewness	Kurtosis	Distribution
		Statistic	df	Sig.			
Leaf	Biomass	.217	12	.123	-1.368	2.204	Normal
	OC	.203	12	.185	-0.1	-1.941	Normal
	CC	.180	12	.200	-0.188	-1.321	Normal
	CS	.221	12	.110	-1.396	2.237	Normal
Branch	Biomass	.247	12	.042	-0.342	1.141	Normal
	OC	.212	12	.143	-0.667	2.429	Normal
	CC	.117	12	.200	-0.236	-0.189	Normal
	CS	.244	12	.047	-0.394	1.129	Normal
Propagule	Biomass	.408	12	.000	1.06	-0.813	Normal
	OC	.178	12	.200	0.939	2.301	Normal
	CC	.378	12	.000	1.889	2.896	Normal
	CS	.408	12	.000	1.06	-0.814	Normal
Overall	Biomass	.260	12	.024	0.457	-1.201	Normal
	OC	.242	12	.051	-0.061	0.687	Normal
	CC	.316	12	.002	1.645	2.077	Normal
	CS	.260	12	.025	0.451	-1.201	Normal

From the Table 4.10, the Kolmogrov-Smirnov p-values of some_variables in standing crop were lower than 0.05 levels which could not support the null hypothesis that the data set of variables was well-modelled by a normal distribution at the initial step.

However, according to Schumacker & Lomax (2010) the general rule is that the data may be assumed to be normally distributed if skew and kurtosis is within the range of -1 to +1, or -1.5 to +1.5 or even 2.0. They suggested using a cut-off point of less than 7 as an acceptable value for the kurtosis. They added that the data which is skewed within the range of +2 to -2 could be considered as being normally distributed. Therefore, since the Skewness of these variable were located between -2 and +2 and also their kurtosis laid between -7 and +7, it can be concluded that the data set of all variables in standing crop were well-modelled by a normal distribution.

Similarly Table 4.11 was used to the independent sample t-test on the standing crop while comparing the differences between both study areas.

Table 4.11: Results Independent Sample T-test for Area Groups in Standing Crop

		Biomass	OC	CC	CS
Area					
KSNP		0.914	39.208	0.363	3.357
SHD		0.774	38.963	0.298	2.841
Mean Difference		0.140	0.246	0.066	0.516
T-test	t	0.998	0.056	0.733	1.006
	df	10	10	10	10
	Sig (p-value)	0.342	0.956	0.48	0.338
	Significant Difference	No	No	No	No

The analysis indicated that there was no any significant difference between the groups of area in relation to the overall biomass, organic carbon (OC), carbon concentration (CC) and carbon sequestration (CS). Although the mean values of these variables in KSNP were slightly higher than what achieved in SHD these differences were not significant. For example, organic carbon in KSNP were slightly and insignificantly higher than what achieved in SHD; mean difference = 0.246, t (10) = 0.056, p-value = 0.956.

Also statistical evaluation of the described parameters (variables) across seasons using one-way AVOVA test is described in Table 4.12. Conversely, the assumption of equality of variance could not be supported for organic carbon (OC) and carbon concentration (CC) as their p-values were below the 0.05 level. Hence, the Welch ANOVA was conducted for this variable.

Table 4.12: Results of One Way and Welch ANOVA test for Season Groups in Standing Crop

	Biomass	**OC**	**CC**	**CS**
One-Way/Welch ANOVA Statistic	31.928***	1.457	2.851	31.532***
Sig (p-value)	.000	.331W	.142W	.000
Significant Difference	Yes	No	No	Yes

***. Difference is significant at the 0.001 level (2-tailed); W: Welch ANOVA test

As shown in the Table 4.12, the results of the One-Way ANOVA test indicated that there were significant differences between the groups of season in relation to

the biomass, carbon sequestration (CS) at 0.001 statistical level. However, the results of Welch ANOVA test indicated that the differences between the groups of season were not statistically significant in relation to organic carbon (OC) and carbon concentration (CC) as their p-values were above the 0.05 level.

4.6.3 Living Part

Analysis of the degree of organic carbon content in the mangrove tree species showed the parts, namely, root, stem, branch, leaf and bark contained high amount of organic carbon. In KSNP, collective evaluation of the tree plants showed that the stem, contained more organic carbon (47.63% of its root composition) (Table 4.13). It decreased from stem to roots in the order, stem > bark < branch < leaf < root. Among the tree species, *R. mucronata* recorded the highest average organic carbon concentration (44.57% of selected parts composition), as against average of 32.18% and 42.07% obtained in *B. parviflora* and *A. officinalis*, respectively.

Table 4.13: Organic Carbon (%) in Different Part of Tree Species in KSNP

	Root	Stem	Branch	Leaf	Bark
B. parviflora	30.89	46.27	42.19	41.57	45.83
A. officinalis	36.78	48.04	40.24	41.43	43.84
R. mucronata	36.68	48.58	47.79	42.84	44.97

Seasonal assessment of the organic carbon content across the species of KSNP as shown in Figure 4.9 indicated that highest record was found in the wet season of 2012 and 2013 for *B. parviflora* and *A. officinalis* as against *R. mucronata* which recorded highest (49.26%) in intermediate season. This trend is expected as wet season encourage the retention of organic matter due to high moisture level where the slight deviation as relates *A. officinalis* might be associated with some plant's peculiarity.

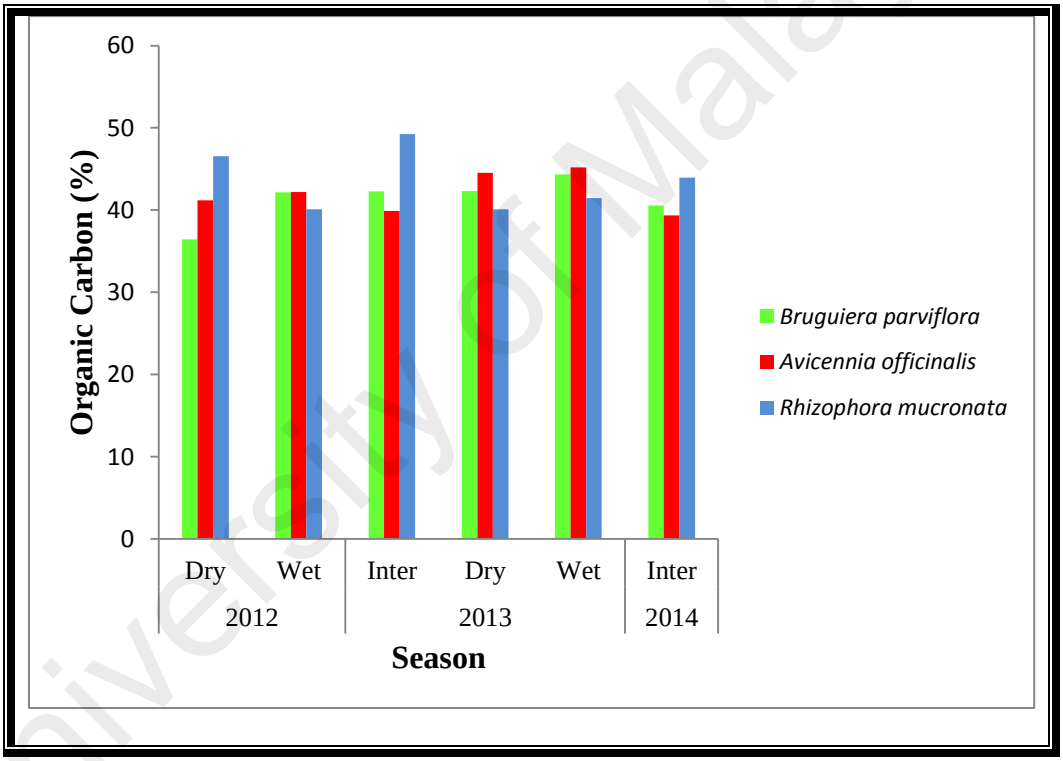


Figure 4.9: Seasonal Assessment of the Organic Carbon Content in KSNP

Also, the carbon concentration in the different living parts of the tree species of KSNP showed that the stem contained the highest; 31.87 t C ha^{-1} and 14.31 t C ha^{-1} yr^{-1} for *B. parviflora* and *A. officinalis* respectively (Table 4.14).

Table 4.14: Carbon Concentration in Different Part of Species in KSNP (t C ha^{-1} yr^{-1})

	Root	Stem	Branch	Leaf
B. parviflora	5.25	31.87	13.94	4.29
A. officinalis	0.76	14.31	2.04	0.12
R. mucronata	0.08	0.14	0.25	0.02

Correspondingly, the carbon sequestration potential of the aforementioned parts was also more pronounced in the stem; 126.37 t C ha^{-1} yr^{-1} and 54.68 t C ha^{-1} yr^{-1} for *B. parviflora* and *A. officinalis* whereas the maximum obtained from *R. mucronata* was in the branch at 0.95 t C ha^{-1} yr^{-1} (Table 4.15). The total carbon sequestration potential of the plant parts was 125.83 t C ha^{-1} yr^{-1}.

Table 4.15: Carbon Sequestration in Different Part of Tree Species in KSNP (t C ha^{-1} yr^{-1})

	Root	Stem	Branch	Leaf
B. parviflora	31.20	126.37	61.56	17.16
A. officinalis	3.77	54.68	9.32	0.54
R. mucronata	0.41	0.53	0.95	0.07

When similar analysis were carried out on the mangrove tree species of SHD namely *X. mekongensis, B. cylindrica, A. marina* and *E. agallocha,* the degree of organic carbon was most prevalent in the stem at an average of 43.42% as against 43.31%, 42.47%, 38.76% and 34.41% recorded in the branch, bark, leaf and root, respectively, in a descending order (Table 4.16) and is almost similar to what was

found in KSNP except for the switch in position between bark and branch. The maximum degree of organic carbon presence was found in *A. marina* (50.58%) which even reflected in it average percentage for all the tree parts (43.52%) whereas the least was found in *X. mekongensis*; 29.76% in its root and average of 29.2% for all selected plant parts.

Table 4.16: Percentage of Organic Carbon in Different Part of Tree Species in SHD

	Branch	Stem	Root	Leaf	Bark
X. mekongensis	40.65	38.47	29.76	37.11	44.7
B. cylindrica	42.75	45.18	42.42	38.65	47.23
A. marina	48.00	50.58	31.25	42.1	45.65
E. agallocha	41.84	39.44	34.21	37.18	32.3

The seasonal assessment for the organic carbon content in SHD across the species also showed proximity across the seasons, yet the wet and intermediate seasons appear to have slight edge (Figure 4.10). In wet seasons for 2012 and 2013, 40.11% found in *X. mekongensis* was the maximum recorded when compared to other seasons.

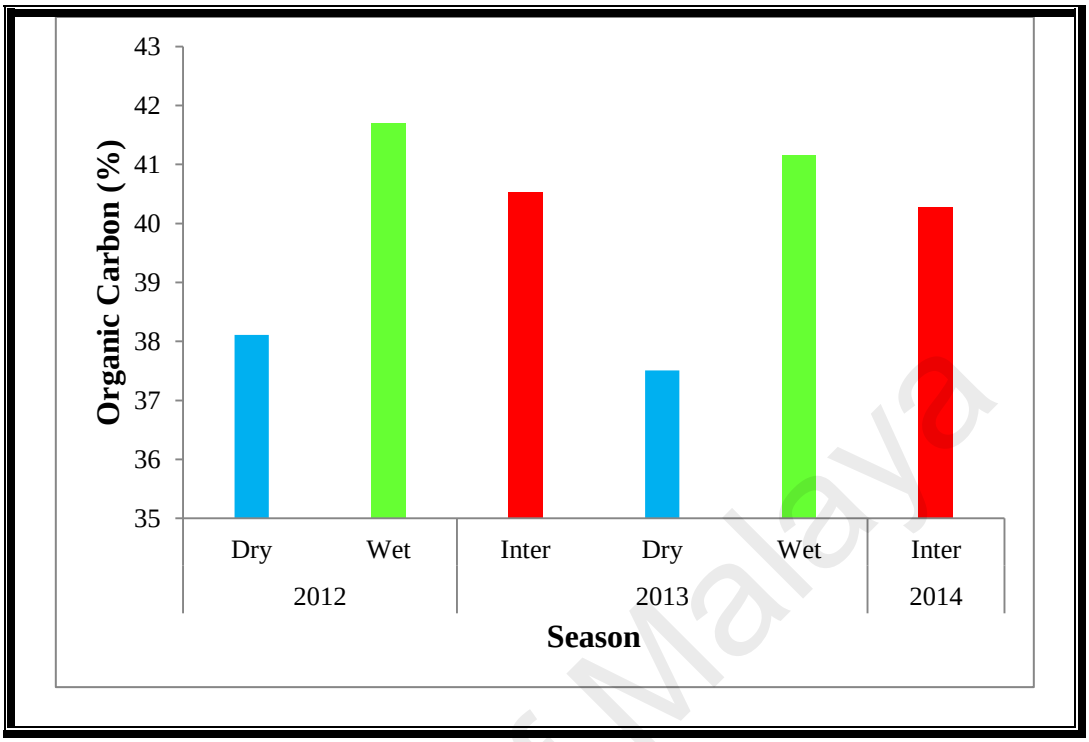


Figure 4.10: Percentage of Organic Carbon According Season in SHD

Also evaluating the carbon concentration in the difference parts of the mangrove tree species of SHD, the also contained the highest; 6.17 t C ha^{-1} yr^{-1}, 0.02 t C ha^{-1} yr^{-1} and 0.14 t C ha^{-1} yr^{-1} for *A. marina*, *X. mekongensis* and *E. agallocha*, respectively, while the maximum obtained in *B. cylindrica* was at branch (2.75 t C ha^{-1} yr^{-1}) (Table 4.17). The trend did not directly influence the corresponding carbon sequestration potentials of the plant parts. For *A. marina* and *X. mekongensi*, the shift of highest carbon sequestration stem to root (26.84 t C ha^{-1} yr^{-1}) and branch (0.21 t C ha^{-1} yr^{-1}), respectively was influenced by the biomass rather than just the carbon concentration (Table 4.18). The total carbon sequestration potential of the plant parts was 97.15 t C ha^{-1} yr^{-1}.

Table 4.17: Carbon Concentration in Different Part of Tree Species in SHD (t C ha^{-1} yr^{-1})

	Root	Stem	Branch	Leaf
A. marina	4.57	6.19	5.18	0.68
B. cylindrica	1.24	0.27	2.75	1.16
X .mekongensis	0.02	0.02	0.05	0.01
E. agallocha	0.001	0.14	0.03	0.01

Table 4.18: Carbon Sequestration in Different Part of Tree Species in SHD (t C ha^{-1} yr^{-1})

	Root	Stem	Branch	Leaf
A. marina	26.84	22.46	19.81	2.96
B. cylindrica	5.38	1.10	11.80	5.49
X. mekongensis	0.11	0.11	0.21	0.03
E. agallocha	0.01	0.67	0.13	0.04

Therefore, it is basic to associate the varying organic carbon content, carbon concentrations and sequestration potentials in different parts of the mangrove species to the biological activities of the plants parts(Santa Regina, 2000) and the related structural components of plant cell (Mahmood, 2014; Kaakinen *et al.*, 2004). When comparing the plant parts, the higher carbon concentrations on the stem, branch and bark (considered woody parts) rather than on the leaves comparable to study by Hart *et al.,* (2003) and this is due to the higher concentrations of cellulose, hemicellulose and lignin on such woody parts

(Schadel *et al.,* 2009; Korner, 2003). The differences in the carbon concentrations between the study areas may be attributed to the plant species and physiological age of the tissue (Salazar *et al.,* 2010). In terms of influence of seasonal variation, wet season appeared more influential on the tree species, but is in contrast to reports by Mitra *et al.,* (2011) and Mahmood (2004) wherein dry seasons were found to show higher carbon concentration of the plant parts. In general, the total carbon sequestration potential of the plant parts was higher in KSNP (125.83 t C ha^{-1} yr^{-1}) than in SHD (97.15 t C ha^{-1} yr^{-1}). This may be influenced by plant biomass and species diversity.

The Pearson correlation test indicated that all relationships were statistically significant at 0.001 level, indicating that biomass, carbon concentration (CC) and carbon sequestration (CS) were in significant positive relationship with each other in overall as well as each dimension of living part. The positive direction means that with an increase in one variable, for example Biomass, the other variables will raise too and vice versa.

The value of the correlation coefficient represents the strength of linear dependence between the correlated variables. The higher value of (r) refers to higher correlation, with a range from 0 to 1. Based on the correlation results, the relationships between biomass, carbon concentration (CC) and carbon sequestration (CS) in all living part dimensions as well as overall were strong or very strong.

Table 4.19: Correlation Coefficients between all Variables in Living Part

Living Part	Variable	Biomass	CC	CS
Stem	Biomass	1		
	CC	.698***	1	
	CS	1.000***	.698***	1
Leaf	Biomass	1		
	CC	.994***	1	
	CS	1.000***	.994***	1
Branch	Biomass	1		
	CC	1.000***	1	
	CS	1.000***	1.000***	1
Root	Biomass	1		
	CC	.980***	1	
	CS	1.000***	.980***	1
Overall	Biomass	1		
	CC	.794***	1	
	CS	1.000***	.794***	1

***. Correlation is significant at the 0.001 level (2-tailed).

The results of the independent sample T-test (Table 4.20) indicated that there were significant differences between the groups of area in relation to the overall biomass, carbon concentration (CC) and carbon sequestration (CS). In other word the mean values of these variables in in KSNP were significantly higher than what achieved in SHD. For example, biomass in KSNP were significantly higher than what achieved in SHD; mean difference = 0.0323, t (331.27) = 8.19, p-value = 0.000.

Table 4.20: Results Independent Sample T-test for Area Groups in Living Part

		Biomass	CC	CS
Area				
KSNP		0.0508	0.0210	0.1864
SHD		0.0185	0.0081	0.0678
Mean Difference		0.0323***	0.0129***	0.1186***
T-test	t	8.19	8.078	8.191
	df	331.27	350.564	331.263
	Sig (p-value)	.000	.000	.000
	Significant Difference	Yes	Yes	Yes

***. Difference is significant at the 0.001 level (2-tailed)

Therefore, the one-way ANOVA test was run to compare the mean differences of overall biomass, carbon concentration (CC) and carbon sequestration (CS) between the seven groups of species: *A. officinalis*, *B. parviflora*, *R. mucronata*, *A. marina*, *B. cylindrica*, *X. mekongensis* and *E. agallocha*.

As shown in Table 4.21, the results of the Welch ANOVA test indicated that there were significant differences between the groups of species toward the overall biomass, carbon concentration (CC) and carbon sequestration (CS) at 0.001 statistical level.

Table 4.21: Results of Welch ANOVA test for Species Groups in Living Part

	Biomass	CC	CS
Welch ANOVA Statistic	14.925***	15.413***	14.923***
Sig (p-value)	.000	.000	.000
Significant Difference	Yes	Yes	Yes

***. Difference is significant at the 0.001 level (2-tailed)

4.6.4 Soil Analysis

Results from the soil sampling areas shows that the bulk density were 0.65 g/cm3 and 0.57 g/cm3 for KSNP and SHD, respectively. It also revealed that soil in both study areas have high organic matter and with soil porosity of 75% and 79% for KSNP and SHD respectively (Table 4.22).

Table 4.22: Bulk Density and Soil Property in Study Areas

Study area	soil dry weight (g)	volume of soil core(cm^3)	Bulk Density(g/cm^3)	particle density (g/cm^{-3})	BD/PD	soil Porosity	Soil Porosity (%)
KSNP	310	475	0.65	2.65	0.25	0.75	75
SHD	270	475	0.57	2.65	0.21	0.79	79

Note:

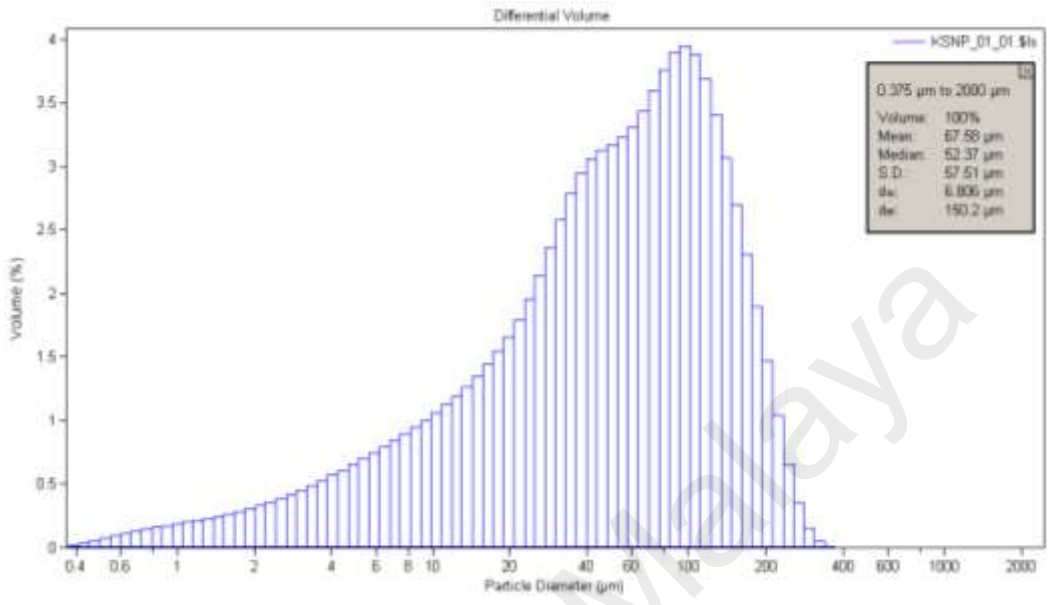
< 0.8 g/cm^3 = soil high in organic matter

0.8 -1.2 g/cm^3 = well aggregated loamy soils

1.2- 2.0 g/cm^3 = sand and compacted horizons in clay soils

Furthermore on the soil analysis of both study areas showed variations with the soil particle size when profiled at depths of 10 cm, 20 cm and 30 cm (Figures 4.11 to 4.13). Generally, the particle size of the study areas ranged from 0.375µm - 200 µm in diameter. Though at the 10 cm depth, the mean particle size of both areas were close; 60.58 µm for SHD and 67.58 µm for KSNP, yet the mean particle size varied significantly at 20 cm and 30 cm depths. It revealed that particle size in KSNP was much smaller than that of SHD. This may be associated to the anthropogenic activities that did take place in SHD which enhanced its degraded nature and possibly affected some depths of soil compartments. Such might have been the reason for the slightly higher porosity level of SHD (79%) over KSNP (75%); hence slight variation in their organic matter content.

KSNP



SHD

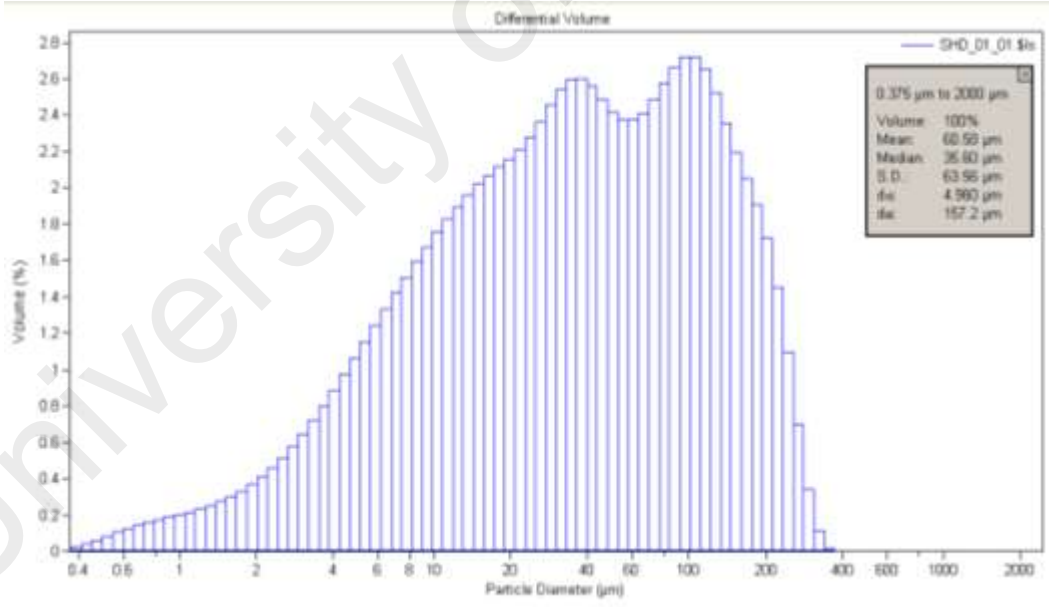
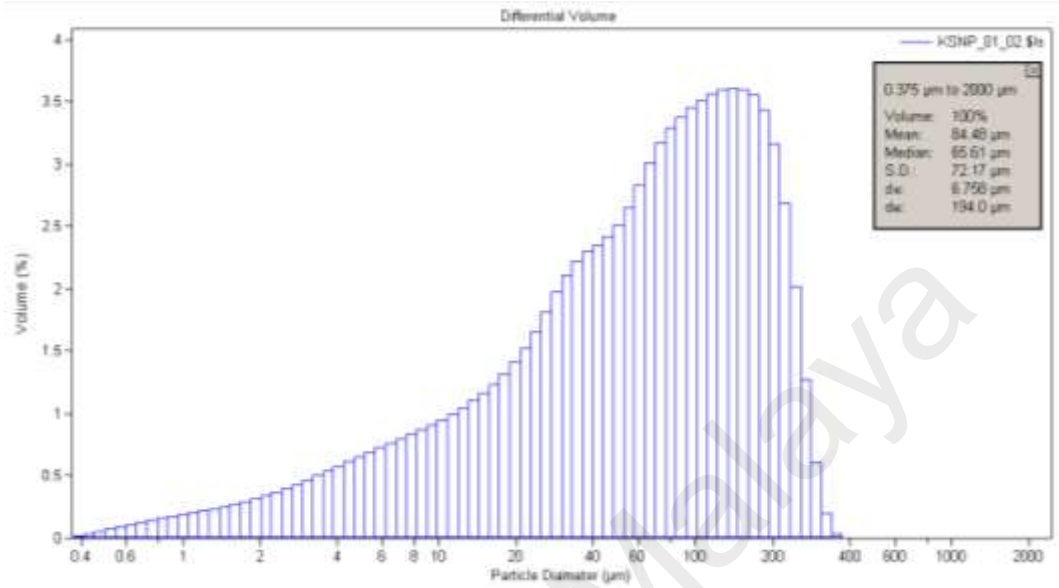


Figure 4.11: Particle Size in 10 cm Depth of Soil in Both Study Areas

KSNP



SHD

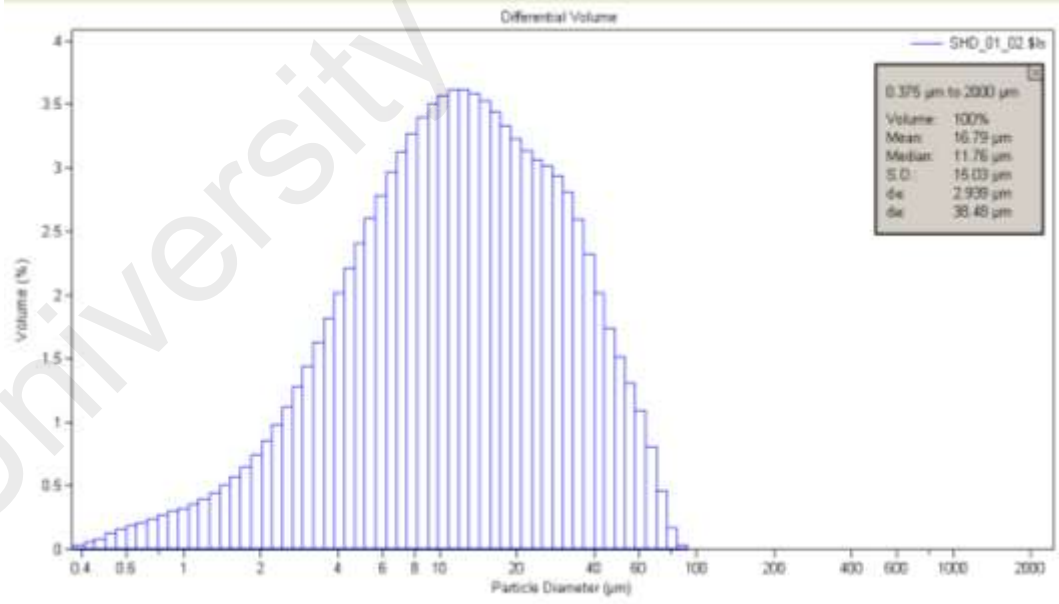
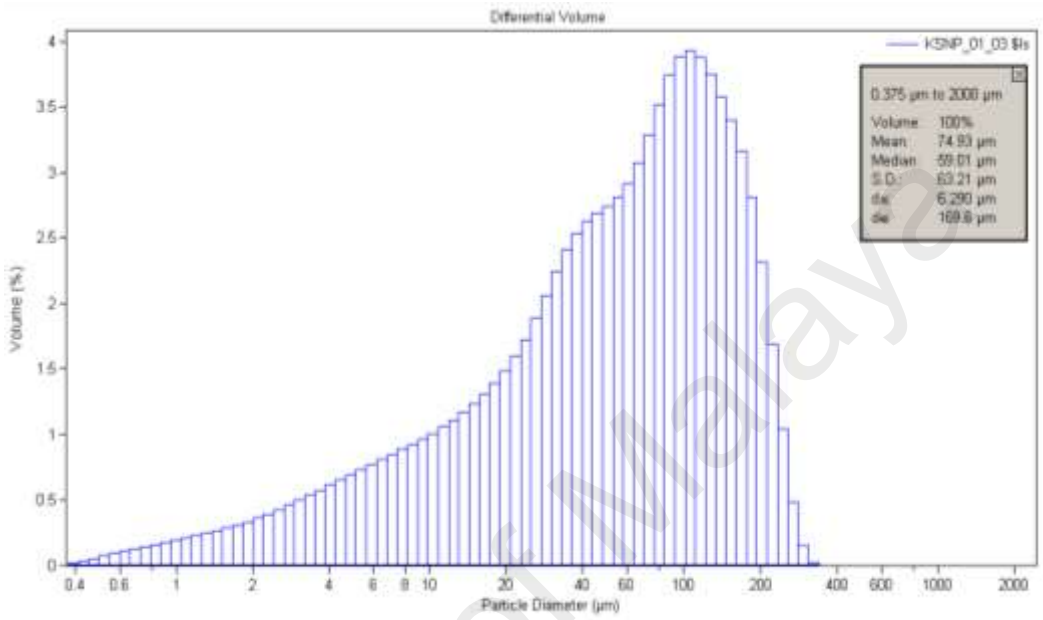


Figure 4.12: Particle Size in 20 cm Depth of Soil in Both Study Areas

KSNP



SHD

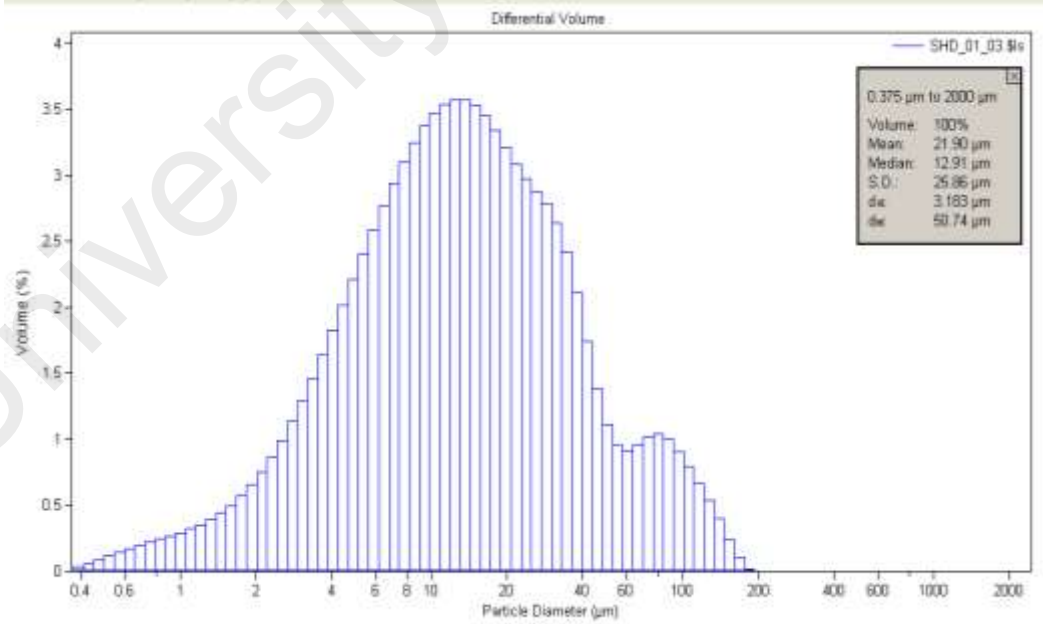


Figure 4.13: Particle Size in 30 cm Depth of Soil in Both Study Areas

Soil identification based on texture showed that both study areas are clayey (Table 4.23), and colour chart classified the colouration to be dark grayish yellow for KSNP and grayish yellow for SHD (Table 4.24).

Table 4.23: Soil Texture in study areas

Study area	Sand(g)	Silt (g)	Clay(g)	Total weight(g)	Sand (%)	Silt (%)	Clay (%)	Texture
KSNP(10cm)	43	31	119	193	22.3	16	61.7	Clay
KSNP(20cm)	67	27	128	222	30	12	58	Clay
SHD(10 cm)	49	6	100	155	31.6	3.9	64.5	Clay
SHD(20 cm)	55	9	114	178	31	5	64	Clay

Gee & Bauder 1986

Table 4.24: Soil Color

Study area	Value	Chroma	Hue	Result
KSNP	5	2	2.5 Y	5/2/2.5 Y Hue
SHD	6	2	2.5 Y	6/2/2.5 Y Hue

Munsell Soil Color Charts. 1994

However, the observed pH values slightly varied across the seasons and between the study areas. The highest pH values were obtained in the rainy season for both mangrove forests; pH 7.36 for KSNP and 7.64 for SHD. Such result agreed with the dominant vegetation in both mangrove forest but with SHD showing a slight edge because the species are typical of high tolerance to salinity and high pH values (Figure 4.14). The high salinity values found in SHD (Figure 4.15), also

affirms why the species distribution there was higher than obtained in KSNP. It was observed that pH of the soils slightly decreased with increased depth.

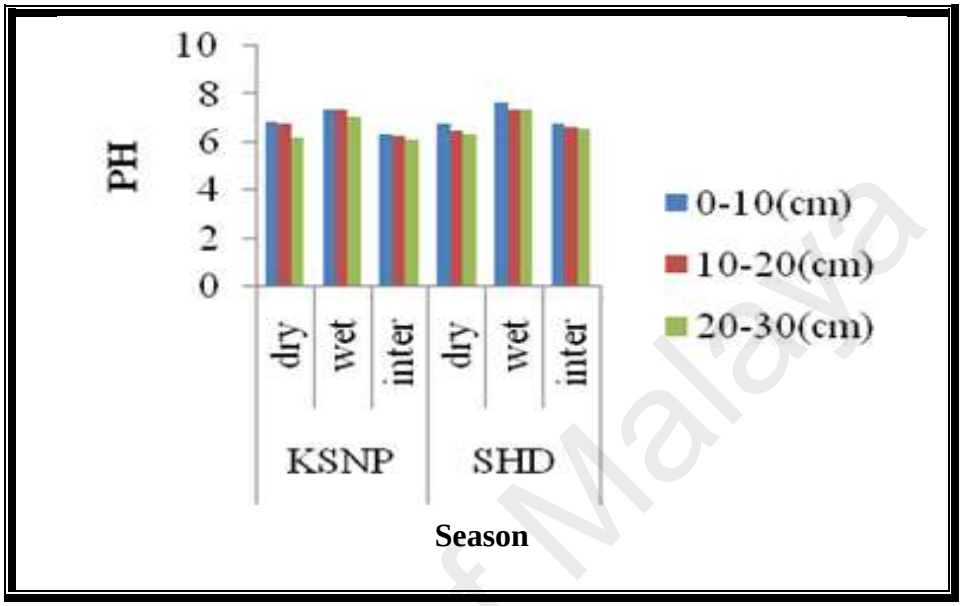


Figure 4.14: Main value for pH for each Climate Season at both Sampling Areas

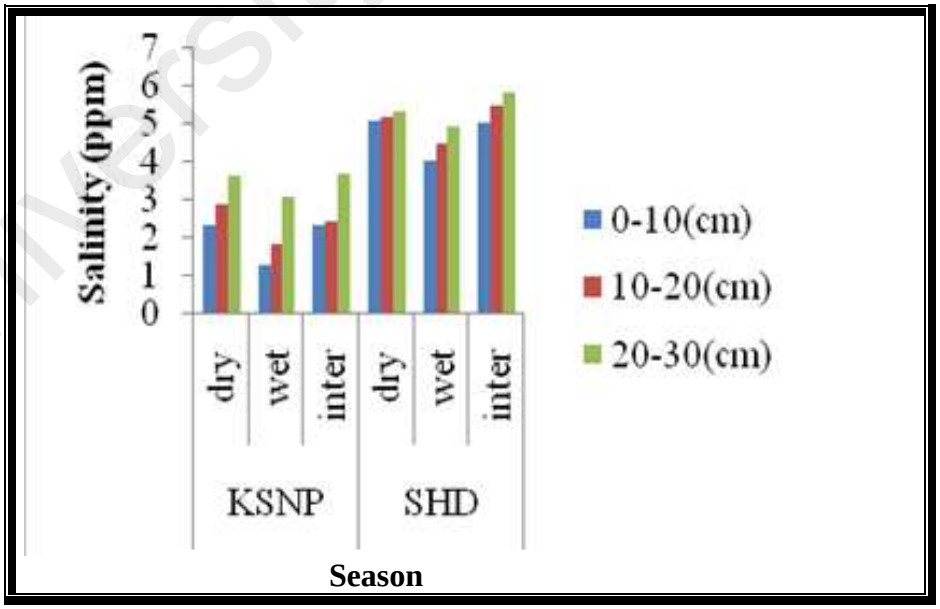


Figure 4.15: Main value for Salinity for each Climate Season at both Sampling Areas

Both study areas were wet during the raining season with SHD still showing higher distribution (Figure 4.16). The similarity in degree of wetness may not only be attributed to the season but the soil texture as well which is clay because it can retain water more than some other forms of soil. Since SHD is closer to sea and experiences high tide flooding, the degree of wetness is expected to be higher than obtained from KSNP.

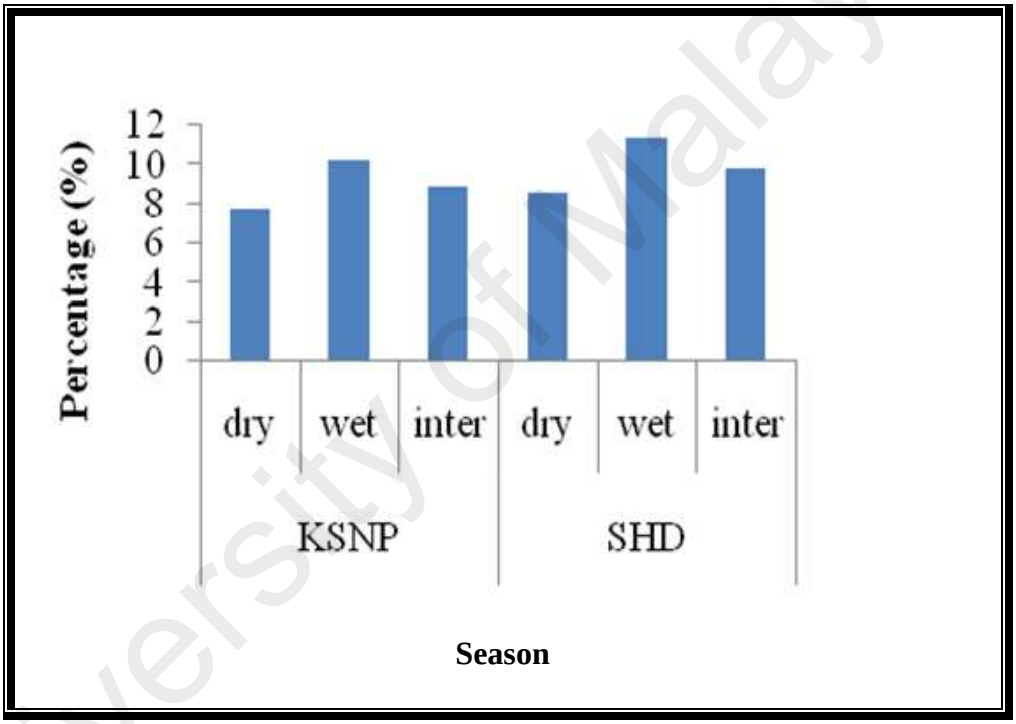


Figure 4.16: Moisture Content in both Mangrove Forests

Figure 4.17 and Figure 4.18 showed the carbon concentration for the different climatic seasons across the two mangrove areas. The organic carbon content for KSNP was 101.41 t C ha^{-1} yr^{-1} while about 116.72 t C ha^{-1} yr^{-1} was obtained in SHD. Peculiar to both study areas is the fact that the highest values of organic carbon content were found at of 20-30 cm depth. Generally it can be deduced that increased depth of soil showed gradual increase in organic carbon content and this

partly disagrees with the reverse obtained by Cerón-Bretón *et al.*, (2011) in Mexico. However, the distribution pattern of organic carbon in this study fits into the trend commonly found in tropical forest (Cerón-Bretón *et al.*, 2011). The greater carbon content was found in SHD and this point to its greater concentration of species associated to black mangrove (Guerra *et al.*, 2011). Since the soils are often flooded, its poor drainage invariably improves the accumulation and decomposition of organic matter (Mayo *et al.*, 2011).

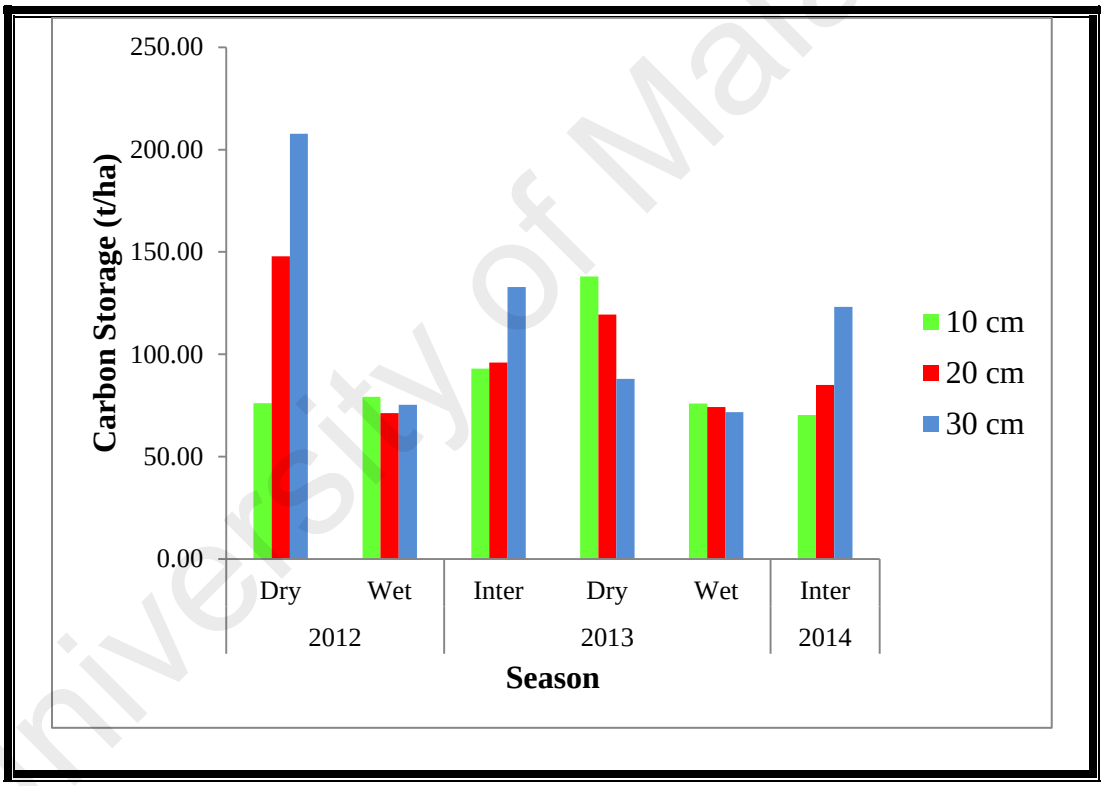


Figure 4.17: Carbon Storage according depth of soil in KSNP

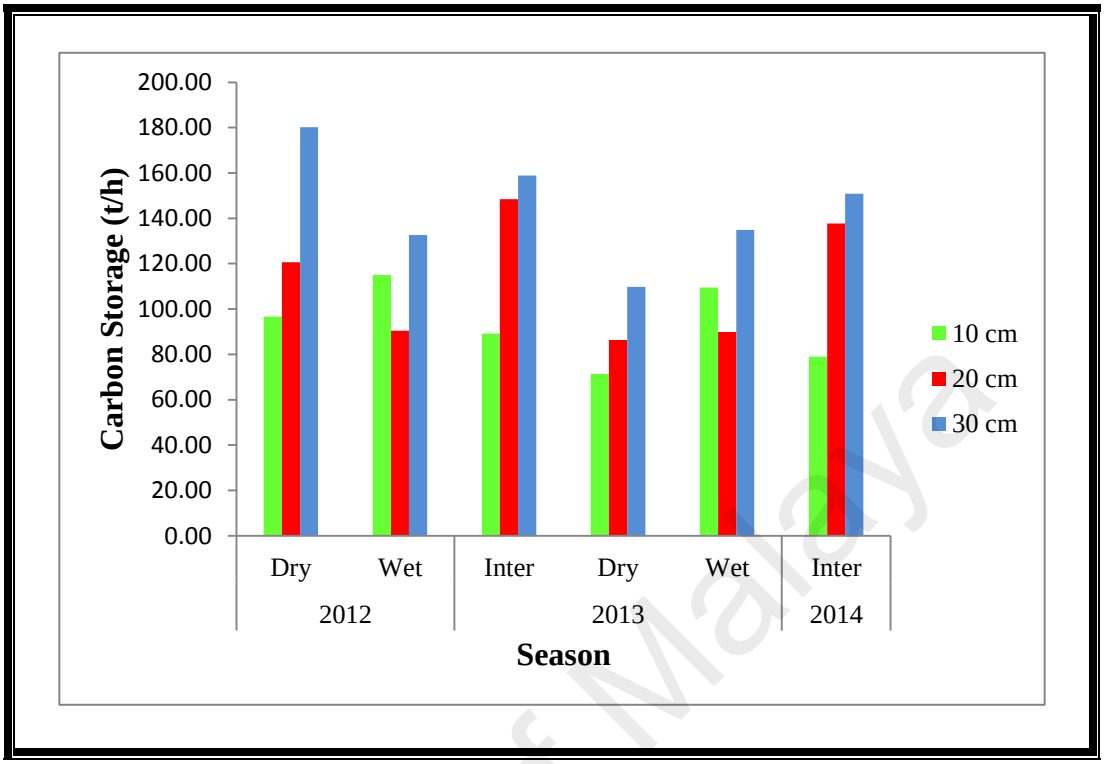


Figure 4.18: Carbon Storage according depth of soil in SHD

Similarly, the prevalence of high pH value and anoxic conditions may have contributed significantly to the high concentrations of organic carbon. This is based on the fact that rainy season (wet) avails the mixing of the water seasons (tides, run off and rainfall) which in turn give rise to low organic carbon concentrations, but evapotranspiration that characterize dry seasons eventually concentrate the salts and dissolved organic carbon which becomes vertically transported (Cerón-Bretón *et al.*, 2011). However, the variation in mangrove soil organic carbon can be also attributed to forest age, pattern of tidal exchange and sedimentation of suspended matter.

Increased biomass and associated rise in organic carbon often stem from development of mangrove trees. Therefore carbon storage rate becomes a significant component for assessing carbon distribution in mangrove forest, and even carbon pool. The dry season in KSNP and intermediate seasons in the SHD mangrove forest of Malaysia showed greater carbon storage (Figure 4.19- 4.20). It can be observed that the carbon storage rate values found in the both mangrove forests have good potential as carbon pool.

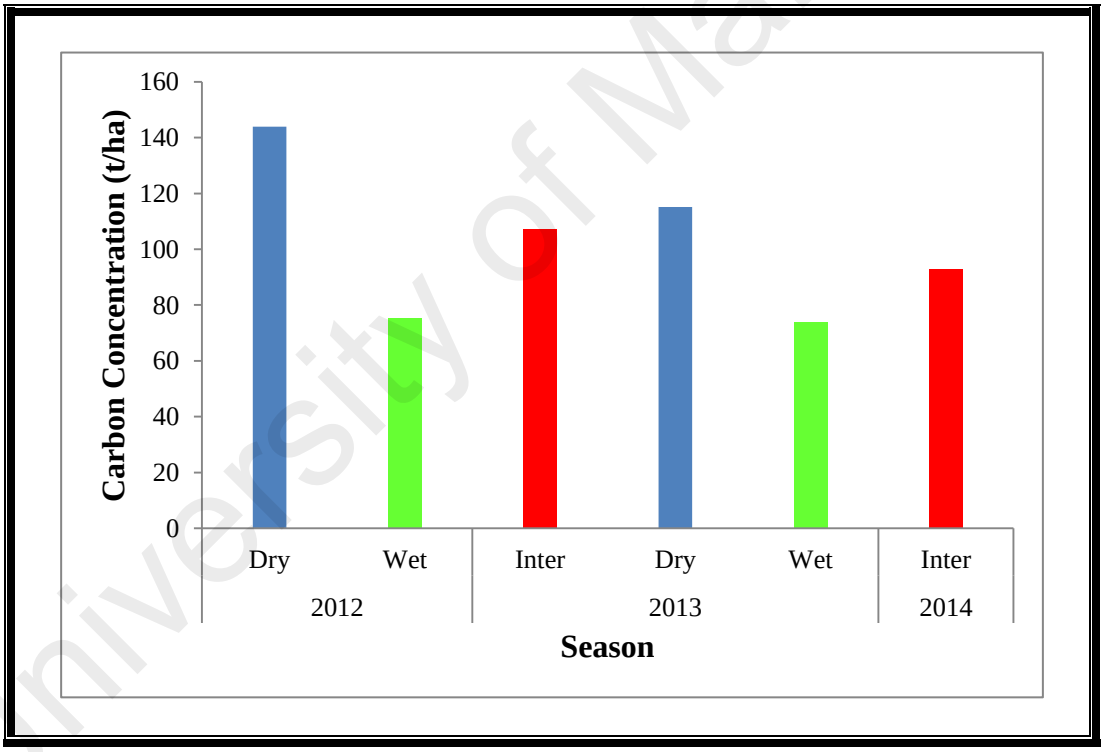


Figure 4.19: Carbon Storage according Season in KSNP

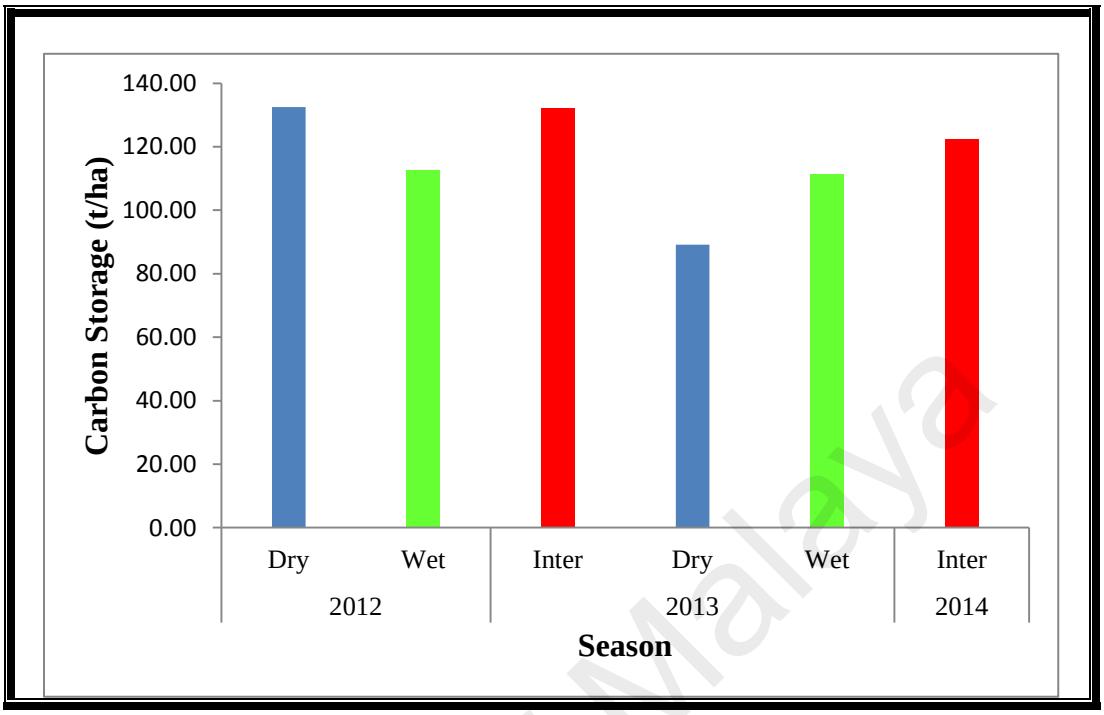


Figure 4.20: Carbon Storage According to Season in SHD

The Pearson correlation was deployed to examine the importance, strength and direction of the inter-relationships between the organic carbon (OC) and carbon concentration (CC) in overall as well as in each soil deep (i.e., 10 cm, 20 cm and 30 cm). Table 4.25 shows the correlations between the variables.

Table 4.25: Correlation Coefficients between all Variables in Soil

Soil Depth	Variable	OC	CC
10cm	$OC_{(10cm)}$	1	
	$CC_{(10cm)}$	0.962^{***}	1
20cm	$OC_{(20cm)}$	1	
	$CC_{(20cm)}$	0.931^{***}	1
30cm	$OC_{(30cm)}$	1	
	$CC_{(30cm)}$	0.989^{***}	1
Overall	$OC_{(Overall)}$	1	
	$CC_{(Overall)}$	0.957^{***}	1

***. Correlation is significant at the 0.001 level (2-tailed).

The results indicated that all relationships were statistically significant at 0.001 level, indicating that organic carbon (OC) and carbon concentration (CC) were in significant positive relationship with each other in overall as well as each deep of soil. The positive direction means that with an increase in organic carbon, the carbon concentration will raise too and vice versa. The value of the correlation coefficient represents the strength of linear dependence between the correlated variables. The higher value of (r) refers to higher correlation, with a range from 0 to 1.

As recommended by Salkind (2003), the relationship between variables can be described as weak if the correlation coefficient (r) ranges from 0.20 to 0.39, moderate if ranges from 0.40 to 0.59, strong if ranges from 0.60 to 0.79, and very

strong if the correlation coefficient ranges from 0.80 to 1.0. Based on the correlation results, the relationships between organic carbon (OC) and carbon concentration (CC) in all soil deep as well as overall were very strong. The most powerful relationship between organic carbon (OC) and carbon concentration (CC) occurred in the soil deep of 30cm with the Pearson correlation coefficient of 0.989.

Also from Table 4.26, the results of the independent sample T-test indicated that there were significant differences between the groups of area toward the overall organic carbon (OC) and carbon concentration (CC). In other word the mean values of organic carbon (OC) in SHD were significantly higher than what achieved in KSNP; mean difference = -5.15983, t (108.610) = -7.174, p-value = 0.000. Similarly, the mean values of carbon concentration (CC) in SHD were significantly higher than what achieved in KSNP; mean difference = -15.15729, t (104.378) = -3.540, p-value = 0.001.

Table 4.26: Results Independent Sample T-test for Area Groups in Soil

		OC	CC
Area			
KSNP		16.4695	101.0239
SHD		21.6293	116.1812
Mean Difference		-5.15983***	-15.15729**
T-test	t	-7.174	-3.540
	df	108.610	104.378
	Sig (p-value)	.000	.001
	Significant Difference	Yes	Yes

. Difference is significant at the 0.01 level (2-tailed); *. Difference is significant at the 0.001 level (2-tailed)

As shown in Table 4.27, the results of the One-Way ANOVA test indicated that there were significant differences between the groups of season toward the overall organic carbon (OC); F=12.090, p-value = 0.000. Further, the results of the Welch ANOVA test indicated that there were significant differences between the groups of season toward the overall carbon concentration (CC); F=18.737, p-value= 0.000.

Table 4.27: Results of One Way and Welch ANOVA test for Season Groups in Soil

	OC	CC
One-Way/Welch ANOVA Statistic	12.090***	18.737***
Sig (p-value)	0.000	0.000W
Significant Difference	Yes	Yes

***. Difference is significant at the 0.001 level (2-tailed); W: Welch ANOVA test

Therefore, the chapter showed that the degree of litter fall was higher in the degraded mangrove (0.09-8.82 g m^2 day). However, the plant carbon sequestration potential of the natural mangrove forest (KSNP) was more pronounced than the degraded one (SHD). KSNP recorded 125.85 t C ha^{-1} yr^{-1} while SHD recorded 97.15 t C ha^{-1} yr^{-1}. Investigation into the soil carbon storage potentials of the study areas revealed that both mangrove forests were high. Comparatively, the degree of soil carbon storage in the degraded mangrove forest was slightly higher (116.72 t C ha^{-1} yr^{-1}) than found on the soil of the natural mangrove forest of Peninsular Malaysia.

CHAPTER FIVE

GENERAL DISCUSSION

The estimation of mangrove forest biomass and associated carbon pool have been carried out in this study as seen in the two preceding chapters (chapters 3 & 4). It is pertinent to note that the research is informed on the prevalent fact that economic interest had left an unavoidable increase in greenhouse gas emission, especially CO_2, which do not only draw environmental debates but have left vivid major impacts; global warming, biodiversity loss and overall disruption of the ecosystem. Hence, it became imperative to identify cognitive steps that will forestall such environmental concern. However, mitigation and regulatory dimensions are only adopted when critical information or data are generated in relation to the environmental usefulness. Therefore, the foregoing study has elucidated the mangrove forest structure and biomass of both natural and degraded ones as highlighted in chapter 3, alongside the associated carbon pool in chapter 4 while the present chapter will give a general summary of both components.

5.1. Mangrove Forest Structure and Biomass of KSNP and SHD

Structurally the mangrove forests studied are typically characterized of tropical features considering their geographical locations which are situated in the dense vegetation arrangement of Peninsular Malaysia. Kuala Selangor Nature Park

denoted as “KSNP” and Sungai Haji Dorani denoted as “SHD” are considered natural and degraded mangroves, respectively due to presence and absence of anthropogenic activities associated to them.

The forest trees distribution with the study areas gave a population count of 704 individual trees; 302 individuals for KSNP and 402 for SHD. Further investigation among the trees population revealed that species diversity was higher in SHD (5 species) than those found in KSNP (4 species). While *A. marina, B. cylindrica, E. agallocha, X. mekongensis* characterized SHD, and *A. officinalis, B. parviflora, R. mucronata* characterized KSNP, yet a tree species was common to both areas; *S. alba.* This was to imply that the overall richness in terms of species distribution is more pronounced in SHD which despite being classified degraded appear to demonstrate the potential to conserve biodiversity. However, the diversity seen may not be over emphasized in terms of species richness as it is still a far from any dense species diversity of Semporns mangrove forest (Lo *et al.*, 2011) which is a better example for eco-conserved area.

Generally, the biggest tree (DBH) from both sides was the *S.alba* found in KSNP (22±0 cm). However, due to its species distribution (6 trees ha^{-1}), importance shifted to *B. parviflora* (1406 trees ha^{-1}) and *B. cylindrica* (955 trees ha^{-1}) also found in KSNP and SHD, respectively. Also high similarity was recorded in terms of mangrove forest class stages namely pre-juvenile, juvenile and adult. Such similarity is a surprise if one is to consider the degraded nature of SHD and as

such will expect much higher value in KSNP as it had little or no human interferences. Hence, the species diversity and similarity of both mangrove forests were elucidated with Shanon-Weiner Index, Simpson Index and Sorenson's Similarity Index; wherein species diversity of SHD (0.91) is considered to be tending towards being a more complex ecological community and associated complex food web than KSNP (0.55) (Mac Arthur, 1969).

The other core part of the section is the biomass assessment which is the totality of the available organic material of both above- and below- ground, and even both living and dead components of the forest (FAO, 2004). Such assessment was to establish the carbon stock of the mangrove forests of Peninsular Malaysia. Therefore, both areas had a total above- ground biomass of 428.24 t ha^{-1} yr^{-1}; 305.46 t ha^{-1} yr^{-1} from KSNP and 122.78 t ha^{-1} yr^{-1} from SHD. The most pronounced above-ground biomass species were *B. parviflora* (266.74 t $ha^{-1}yr^{-1}$) for KSNP and *A. marina* (108.63 t ha^{-1} for SHD). Hence, when both species were further assessed, it was found that the highest percentage of above-ground biomass in tree components was recorded from the stem; 61.62 t ha^{-1} yr^{-1} for *B. parviflora* and 49.66 t ha^{-1} yr^{-1} for *A. marina.* Despite the higher species density associated to SHD; its estimated above-ground biomass was less than result from KSNP. Possibility that it was a reflection of vegetation exploitation or over-logging activities on SHD seem apparent (Tomlinson, 1986) just as it is established that both environmental factors (Komiyama *et al*., 2008) and interferences can induce smaller size characteristic on trees. However, the below-

ground biomass from SHD turned out to be higher that what was found in KSNP; 12.12 t ha^{-1} yr^{-1} of root biomass (SHD) against 4.60 t ha^{-1} yr^{-1} (KSNP). Yet both study areas had high density of root biomass at 10 cm height which might be due to tolerance ability of the species, especially on salinity, softness and resilience (Briggs, 1977; Tamooh *et al.*, 2008).

5.2. Carbon Pool

Litter production was the first component tackled under this section. The year round production of litter by the mangrove forest tree species showed that there exists some degree of similarity across the months whereas variations appear distinct among the three seasons; dry, wet and intermediate seasons. In relation to other studies (Woodroffe, 1992; Sasekumar & Loi 1983), the bulk part of produced litter came from leaves (70% of total litter) and branches of forest trees. Leaf litter was predominant in the dry season (61.39%) but the difference between leaf litter production between both mangrove forests was not significant. Unlike leaf litter, the flower litter was not significantly considered as part of the total litter production because its generation was highly limited to intermediate season in mangrove forests of Malaysia. Propagule production was prevalent in dry season as both study areas recorded 55.13 % (SHD) and 56.04% (KSNP) in July. Bracts and branches were also part of the produced litter.

In general, the rate of litter production individually ranged from 0.08 to 6.59 g m^2 day and 0.09 to 8.82 g m^2 day for SHD and KSNP, respectively. The maximum

individual rate was found in propagules litter where 8.82 g m^2 day was recorded in KSNP and 4.36 g m^2 day found in SHD. Such development might depict an enriched nature of KSNP as an undisturbed mangrove forest. The foregoing litter production assessment was in agreement with study by Sasekumar and Loi (1983) that described the Malaysian mangrove as having similarity to Queensland where litter production rate was 5.36 g m^2 day (Duke *et al.,* 1981).

For carbon concentration evaluation in the produced litter, the maximum was found in the leaf, 0.42 t C ha^{-1} yr^{-1} during wet season. However, carbon concentration in branch and propagules were high in intermediate season than dry season. The result appear to be influenced by some complex factors because in most cases carbon concentration tend to be higher during dry season due to evapotranspiration that gives room for vertical transport of organic carbon (Cerón-Bretón *et al.,* 2011). Hence some plants characteristics especially storage potential might have led to higher degree of carbon concentration in branch and propagules during intermediate and wet season instead.

Also the carbon sequestration potential of the produced litter from both study areas showed that KSNP possess higher sequestration rate, 41.63 t C ha^{-1} yr^{-1}, than SHD that recorded 37.94 t C ha^{-1} yr^{-1}. The mangrove forests nature and growth characteristics of trees species might have significantly influenced such disparity (Jana *et al.,* 2009).

Similarly, standing crop showed that carbon storage was most prevalent in the propagules part in both mangrove forests; 44.93% (KSNP) and 45.38% (SHD). One might assume that the biochemical activities that take place in the studied plant parts influenced the trend. When carbon concentration was compared across the seasons, it was found that while the highest levels 0.46 t C ha^{-1} yr^{-1} (SHD) and 0.43 t C ha^{-1} yr^{-1}(KSNP) were recorded in dry and intermediate seasons, respectively, the least concentration, 0.34 t C ha^{-1} yr^{-1} was obtained in wet season for both study areas. Varied tree responses to seasons as relates different plant species could have influenced the result.

The carbon sequestration of the standing crop across seasons projected propagules potential to sequester carbon in dry season alone as it cannot be found in wet and intermediate seasons. Therefore, the leaf part showed higher sequestration potential over branches and propagules.

Furthermore, high organic carbon was found in the root, stem, branch, leaf and bark when the living parts of the mangrove forest trees were analyzed. Total organic carbon in roots composition was 47.63% in KSNP. The highest was found in stem, hence the order was stem > bark > branch > leaf < root. Among species, *R. mucronata* demonstrated highest average organic carbon concentration (44.57% of selected parts composition), ahead of *B. parviflora* and *A. officinalis*. In SHD, the maximum was found in *A. marina* (50.58%). Seasonal comparison showed wet season as the peak of organic carbon content in the living parts of the

study areas. The carbon concentration in KSNP was pronounced in the stem of *B. parviflora* (31.87 t C ha^{-1} yr^{-1}) and *A. officinalis* (14.31 t C ha^{-1} yr^{-1}), and it directly influenced the corresponding carbon sequestration potential of the plant parts where 126.37 t C ha^{-1} yr^{-1} and 54.46 t C ha^{-1} yr^{-1} were found in *B. parviflora* and *A. officinalis*, respectively. Though the stem contained highest carbon concentration in SHD as well, yet it did not directly influence corresponding carbon sequestration potential trend as in the case of KSNP. The total carbon sequestration potential of the living plant parts of KSNP was 125.83 t C ha^{-1} yr^{-1} while SHD recorded 97.15 t C ha^{-1} yr^{-1}. Such variation in the organic carbon content, carbon concentrations and carbon sequestration potentials of different parts of the mangrove species can be due to biological activities of plants (Santa Regina, 2000), plant species and physiological age of plant tissue (Salazar *et al.*, 2010).

Soil analysis indicated high organic matter level in both study areas. However, the particle size varied with soil depths; 10cm, 20cm and 30cm with KSNP being smaller than that of SHD. Impact of anthropogenic activities on SHD may not be ruled out as a potential cause in regards to this as it had higher porosity (79%) than KSNP (75%). Texturally, both soils are clayey with slight colour variation. High pH values that revolved around neutrality were observed in both areas during the wet season which seem to influence the vegetation dominance. However, SHD recorded higher salinity levels which could affirm the reason for its higher species diversity than found in KSNP. Whereas a high similarity exist in

the moisture content of both areas but SHD had more wetness which is due to its nearness to sea, hence it is prone to more tidal flooding than KSNP. This seem to also reflect in the organic carbon content of both sides; KSNP (101.41 t C $ha^{-1}yr^{-1}$) and SHD (116.72 t C ha^{-1} yr^{-1}), yet both recorded highest organic carbon values at 20-30 cm depth. This trend partly disagreed with Cerón-Bretón *et al.,* (2011) in Mexico where the present study observed that increased depth in soil showed gradual rise in organic carbon content; hence it fits the trend found within tropical forest. SHD seem to have higher soil organic carbon content because of the higher concentration of species known to be black mangrove (Guerra -Santos *et al*., 2011). Also the carbon storage rate found in both mangrove forests projects them as good potentials for carbon pool.

Finally, the net primary productivity showed that KSNP (14.92 t ha^{-1} yr^{-1}) than SHD (13.86 t ha^{-1} yr^{-1}) despite the higher species diversity found in SHD. This may be due to species types and some other associated environmental factors. Most significantly may be the degree of forest interferences; KSNP is devoid of activities like logging and as such possess an optimal plant growth condition over SHD. Similarly other factors cannot be ruled out such as geographical location, stand density and stand age (Ong *et al.,* 1985; Mahmood *et al.,* 2008).

CHAPTER SIX

CONCLUSION

The study concludes that the forest structure of the natural mangrove (KSNP) and the degraded mangrove (SHD) forests of Peninsular Malaysia are typical of tropical mangrove forest. It was established that the individual trees population and species diversity is more in the degraded mangrove than the natural mangrove. Only one tree species is common to both areas; hence implying wide species distribution across the mangrove forests. Both mangrove forests are dominant with plant species in the adult class. Most dominant mangrove tree is *Bruguiera* species.

Also both mangrove forests possess significant levels of above-ground biomass, yet the natural mangrove forest demonstrated more biomass in this respect than the degraded one. Based on individual plant species, *B. parviflora* was characterized with the highest above- ground biomass. However, the below-grounded biomass is more pronounced in the degraded mangrove than natural mangrove.

The study concludes that biomass increment was progressive with increase in time (years). However, both study areas significantly varied in species types, hence comparison was not feasible. Yet, the study concludes that *R. mucronata*

and *B. cylindrica* have the highest biomass increment potential in natural and degraded mangrove forests of Malaysia, respectively.

It is also concluded that the most produced litter is leaf in both mangrove forest types of Malaysia. The least leaf litter produced is common to both areas during the dry season.

As regards the carbon pool, the study established that carbon concentration in litter product is prevalent in leaf part of trees in both mangrove forests. On the other hand; carbon storage in standing crop is most prevalent in propagules part. Organic carbon is most commonly found in the stem portion of the mangrove trees, and the same is concluded for carbon concentration. Therefore in overall assessment, it is established that the natural mangrove forest possess higher carbon pool than the degraded mangrove.

The physico-chemicals analysis proved that both mangrove forests are characterized of highly rich organic soil that is also clayey in nature. Similarity in pH level is high and revolves around neutrality range. However porosity in conjunction with soil texture and salinity influenced carbon distribution across soil depth which can be assumed to determine higher species density in degraded mangrove forest.

Carbon sequestration by mangrove plants is a bit complex in the natural and degraded mangrove forest of Malaysia. Sequestration potential due to litter production and living plant parts is more established in natural mangrove than the degraded one. Hence the study concludes that forest nature and growth characteristics of tree species influenced disparity between the two.

Net primary productivity of the natural mangrove is higher than the degraded mangrove regardless of species diversity. Therefore, it can be concluded that optimal growth condition for trees abound in the natural mangrove forest than the degraded one.

Finally, natural and degraded mangrove forests of Malaysia are characterized of dense vegetation, and have significant carbon pool and carbon sequestration potential. However, anthropogenic activities which caused the degradation of mangrove, have the potential to drastically reduce or even eliminate such sequestration potentials. Hence there is need for stringent actions plans to ensure adequate mangrove production on Malaysia.

REFERENCE

Adekayode FO and Akomolafe DT (2014). A Digital Soil Textural Class Determination from the Percentages of Silt and Clay. *African Journal of Soil Science* 2 (3): 072-076.

Aboal JR, Arevalo JR, and Fernandez A (2005). Allometric Relationships of Different Species and Stand above Ground Biomass in the Gomera Laurel Forest (Canary Island), *Flora Morphology, Distribution, Functional Ecology of Plants* 200(3): 264-274.

Adams JM and Piovesan G (2005). Long Series Relationships between Global inter Annual CO_2 Increment and Climate: Evidence for Stability and Change in Role of the Tropical and Boreal-Temperate Zone. *Chemosphere* 59: 1595-1612.

Aksornkoae S (1993). Ecology and Management of Mangroves. IUCN. Bangkok, Thailand.

Allen SE, Grimshaw HM, Parkinson JA, and Quarmby C (1974). *Chemical analysis of ecological materials*. New York: Wiley.

Alongi DM (2002). Present State and Future of the World's Mangrove Forests, *Environmental Conservation* 29(3): 331-349.

Alongi DM, Wattayakorn G, Pfitzner J, Tirendi F, Zagorskis I, Brunskill GJ, Davidson A and Clough BF (2001). Organic Carbon Accumulation and Metabolic Pathways in soil of Mangrove Forests in Southern Thailand. *Marine Geology 179*: 85–103.

Araujo TM, N Higuchi, and Carvalho JA (1999). Comparison of Formulae for Biomass Content Determination in a Tropical Rain Forest Site Forest Site in the State of Para, Brazil, *Forest Ecology and Management* 117(1-3): 43-52.

Arevalo CBM, Volk TA, Bevilacqua E and Abrahamson L (2007). Development and Validation of above-ground Biomass Estimations for four Salix Clones in Central New York, *Biomass and Bioenergy* 31(1): 1-12.

Ashton EC and Macintosh D (2002). Preliminary Assessment of the Plant Diversity and Community Ecology of the Semantan Mangrove Forest, Sarawak, Malaysia. *Forest Ecology and Management* 166: 111–129.

Azahar M, Nik Mohd Shah NM (2003). A Working Plan for the Matang Mangrove Forest Reserve Perak: the Third 10-Year Period (2000-2009) of the Second Rotation. State Forestry Department of Perak Darul Ridzuan, pp 319.

Badola R and Hussain SA (2005). Valuing Ecosystem Functions: an Empirical Study on the Storm Protection Function of Bhitarkanika Mangrove Ecosystem, India, *Environmental Conservation* 32 (1): 85–92.

Bagust Phil, Tout-Smith, Lynda (2005). The Native Plants of Adelaide. Department for Environment and Heritage, pp 100, ISBN 0-646-44313-5.

Bandaranayake WM (2002). Bioactivities, Bioactive Compounds and Chemical Constituents of Mangrove Plants, *Wetlands Ecology and Management* 10(6): 421-452.

Bandaranayake WM (1998). Traditional and Medicinal Uses of Mangroves, *Mangroves and Salt Marshes* 2: 133–148.

Basuki TM, Van Laake PE, Skidmore AK, Hussin YA (2009). Allometric Equations for Estimating the Above-ground Biomass in Tropical Lowland Dipterocarp Forests. *Forest Ecology and Management* 257: 1684-1694.

Barbier EB, Koch EW, Silliman BR, Hacker SD, Wolanski E, Primavera J, Granek EF, Polasky S, Aswani S, Cramer LA, Stoms DM, Kennedy CJ, Bael D, Kappel CV, Perillo GME and Reed DJ (2008). Coastal Ecosystem–Based Management with Nonlinear Ecological Functions and Values. *Science* 319: 321-323.

Berger U, Rivera-Monroy VH, Doyle TW, Dahdouh-Guebas F, Duke N, Fontalvo M, Hildenbrandt H, Koedam N, Mehlig U, Piou C and Twilley RR, (2008). Advances and Limitations of Individual-Based Models to Analyze and Predict Dynamics of Mangrove Forests: a Review. *Aquatic Botany* 89(2): 260-274.

Bledsoe CS, Fahey TJ, Day FP and Ruess RW (1999). Measurement of Static Root Parameters-Biomass, Length, and Distribution in the Soil Profile. In: Robertson GP, Coleman DC, Bledsoe CS, Sollins P (eds) Standard Soil Methods for Long-Term Ecological Research. Oxford University Press, New York.

Blake GH (1965). Particle density. p. 371-373. In C.A. Black et al. (ed.) Methods of soil analysis. Part. 1. 'Agron. Monogr. 9. ASA, Madison, WI

Bollandsas OM, Rekstad I, Naesset E and Rosberg I (2009). Models for Predicting Above-ground Biomass of Betula Pubescens spp. Czerepanovii in Mountain Areas of Southern Norway, *Scandinavian Journal of Forest Research* 24:318-332.

Bouillon S, Alberto V. Borges AV, Castañeda-Moya E, Diele K, Dittmar T, Duke NC, Kristensen E, Lee SY, Marchand C, Middelburg JJ, Rivera-Monroy VH, Smith III TJ and Twilley RR (2008). Mangrove Production and Carbon

Sinks: A Revision of Global Budget Estimates. *Global Biogeochem Cycles* Volume 22, Issue 2, DOI: 10.1029/2007GB003052.

Bouillon S, Moens T, Koedam N, Dahdouh-Guebas F, Baeyens W and Dehairs F (2004). Variability in the Origin of Carbon Substrates for Bacterial Communities in Mangrove Sediments. *FEMS Microbiology – Ecology* 49(2): 171-179.

Bousquet P, Peylin P, Ciais P, Le Quere C, Friedlingstein P and Tans PP (2000) Regional Changes in Carbon Dioxide Fluxes of Land and Oceans Since 1980. *Science* 290: 1342–1346.

Bosire JO, Kairo JG, Kazungu J, Koedam N and Dahdouh-Guebas F (2005). Predation on Propagules Regulates Regeneration in a High-Density Reforested Mangrove Plantation. *Marine Ecology Progress Series* 299: 149-155.

Bosire JO, Dahdouh-Guebas F, Kairo JG, Kazungu J, Dehairs F and Koedam N (2005). Litter Degradation and CN Dynamics in Reforested Mangrove Plantations at Gazi Bay, Kenya. *Biological Conservation* 126: 287-296.

Bosire JO, Dahdouh-Guebas F, Walton M, Crona BI, Lewis III RR, Field C, Kairo JG, Koedam N (2008). Functionality of Restored Mangrove: a Review. *Aquatic Botany* 89(2): 251-259.

Bridgham SD, Megonigal JP, Keller JK, Bliss NB and Trettin C (2006). The Carbon Balance of North American wetlands, *Wetlands* 26:889–916.

Briggs SV (1977). Estimates of Biomass in a Temperate Mangrove Community, *Australian Journal of Ecology* 2:369-373.

Brown S (2002). Measuring Carbon in Forests: Current Status and Future Challenges, *Environmental Pollution* 116: 363–372.

Brown S (1997). Estimating Biomass and Biomass Change of Tropical Forests: a Primer (FAO foredtry paper-134) Rome: FAO, United Nations.

Bipal KJ, Soumyajit B, Mrinmoy M, Pankaj KR and Asis M (2009). Carbon Sequestration Rate and Above-ground Biomass Carbon Potential of Four Young Species. *Journal of Ecology and Natural Environment* 1: 15-24.

Cahoon D, Hensel P, Rybczyk J, McKee K, Proffitt E and Perez C (2003). Mass Tree Mortality Leads to Mangrove Peat Collapse at Bay Islands, Honduras after Hurricane Mitch. *Journal of Ecology* 91: 1093–1105.

Caloz R and Collet C (1997). Geographic Information Systems (GIS) and Remote Sensing in Aquatic Botany: Methodological Aspects. *Aquatic Botany* 58: 209–228.

Cannicci S, Burrows D, Fratini S, Smith III TJ, Offenberg J and Dahdouh-Guebas F. (2008). Faunal Impact on Vegetation Structure and Ecosystem Function in Mangrove Forests: A review, *Aquatic Botany* 89: 186–200.

Cerón-Bretón, JG, Cerón-Bretón R.M, Rangel-Marron, M, Muriel-Guerra M, Córdova-Quiroz AV and Estrella-Cahuich A (2011). Determination of Carbon Sequestration Rate in Soil of a Mangrove Forest in Campeche Mexico, *International Journal of Energy and Environm*ent 5(3):133-143.

Chandra IA, Seca G and Abu Hena MK (2011). Above-ground Biomass Production of *Rhizophora apiculata* Blume in Sarawak Mangrove Forest, *American journal of Agricultural and Biological Sciences* 6 (4): 469-474.

Chan HT, Ong JE, Gong WK and Sasekumar A (1993). The Socio-economic, Ecological and Environmental Values of Mangrove Ecosystems in Malaysia and their Present State of Conservation. The Economic and Environmental Values of Mangrove Forests and their Present State of Conservation in the South-East Asia/Pacific Region, *Mangrove Ecosystems Technical Reports* 3:41–81.

Chapman VJ (1977). *Wet Coastal Ecosystems*, Ecosystems of the World 1. Elsevier Scientific Publishing Co., Amsterdam 428 pp.

Chave J, Andalo C, Brown S, Cairns MA, Chambers JQ, Eamus D, Folster H, Fromard F, Higuchi N, Kira T, Lescure JP, Nelson BW, Ogawa H, Puig H, Rie´ra B and Yamakura T (2005). Tree Allometry and Improved Estimation of Carbon Stocks and Balance in Tropical Forests, *Oecologia Journal* 145: 87–99.

Chmura GL, Anisfeld SC, Cahoon DR and Lynch JC (2003). Global Carbon Sequestration in Tidal, Saline Wetland Soils, *Global Biogeochemical Cycles* 17: 1111–1120.

Christensen B (1978). Biomass and Primary Production of *Rhizophora apiculata* in a Mangrove in Southern Thailand, *Aquatic Botany* 4: 43–52.

Chung SY, Yim JS, Cho HK, Jeong JH, Kim SH, Shin MY (2009). Estimation of Forest Biomass for Muju County Using Biomass Conversion Table and Remote Sensing Data, *Journal of Korean Forest Society* 98(4):409-416 (in Korean with English abstract).

Cintrón G and Schaeffer-Novelli Y (1984b). Methods for Studying Mangrove Structure, In: Snedaker SC, Snedaker JG. Editors, The Mangrove Ecosystem: Research Methods. UNESCO, Paris, France, pages 91–113.

Cintron G, Novelli SY (1984). Methods for Studying Mangrove Structure. In The Mangrove Ecosystem Research Methods, ed. Snedaker CS and Snedaker JG, pp 91-113. United Kingdom: Unesco.

Claus A and George E (2005). Effect of Stand Age in Fine- Root Biomass and Biomass Distribution in three European Forests Chronosequence. *Canadian Journal of Forest Research* 35: 1617-1625.

Clough BF (1992). Primary productivity and growth of mangrove forests, In: Robertson AI and Alongi DM (Eds.) Tropical Mangrove Ecosystems, Coastal and Estuarine Studies 41. American Geophysical Union, Washington, D.C. pp. 225-250.

Clough BF, Dixon P and Dahdouh O (1997). Allometric relationships for estimating biomass in multi-stemmed mangrove trees, *Australian Journal of Botany* 45: 1023-1031.

Clough BF, Scott K (1989). Allometric Relationships for Estimating Above-ground Biomass in Six Mangrove Species, *Forest Ecology and Management* 27: 117-127.

Cochran WG (1963). Sampling Techniques, 2nd Ed., New York: John Wiley and Sons, Inc.

Comley BWT and Mc Guinness KA (2005). Above- and Below-ground Biomass, and Allometry, of Four Common North Australian mangroves, *Australian Journal of Botany* 53:431-436.

Colin F (1995). *Journey among Mangroves*, International Society for Mangrove Ecosystems, pp.70-116.

Cole TG and Ewel JJ (2006). Allometric Equations for Four Valuable Tropical Tree Species, *Forest Ecology and Management* 229(1-3): 351-360.

Crooks S, Herr D, Tamelander J, Laffoley D and Vandever J (2011). Regulating Climate Change through Restoration and Management of Coastal Wetlands and near-Shore Marine Ecosystems: Challenges and Opportunities. Environment Department Papers, Marine Ecosystem Series. Paper 121.

Cummings DL, Kauffman JB, Perry DA and Hughes RF (2002). Above-ground Biomass and Structure of Rainforest in the Southwestern Brazilian Amazon. *Forest Ecology and Management* 163: 293-307.

Cuong DT, Bayen S, Wurl O, Subramanian K, Wong KKS, Sivasothi N, Obbard JP (2005). Heavy Metal Contamination in Mangrove Habitats of Singapore, *Baseline/Marine Pollution Bulletin* 50: 1713-44.

Dahdouh-Guebas F and Koedam N (eds.) (2008). Mangrove Ecology-applications in Forestry and Coastal Zone Management, Aquatic Botany Special Issue, Elsevier, Amsterdam, The Netherlands, 197 pp.

Dahdouh-Guebas F and Koedam N (2006). Empirical Estimate of the Reliability of the use of the Point-Centred Quarter Method (PCQM): Solutions to Ambiguous Field Situations and Description of the PCQM+ protocol. *Forest Ecology and Management* 228(1-3): 1-18.

Dahdouh-Guebas F, Hettiarachchi S, Lo Seen D, Batelaan O, Sooriyarachchi S, Jayatissa LP and Koedam N (2005a). Transitions in Ancient Inland Freshwater Resource Management in Sri Lanka Affect Biota and Human Populations in and Around Coastal Lagoons. *Current Biology* 15(6): 579-586.

Dahdouh-Guebas F, Jayatissa LP, Di Nitto D, Bosire JO, Seen D Lo and Koedam N (2005b). How Effective Were Mangroves as a Defense against the Recent Tsunami? *Current Biology* 15(12): 443-447.

Department of Meteorology (2012). Annual Report of the Meteorology Department, Peninsular Malaysia.

Daniel CD, Kauffman JB, Daniel M, Sofyan K, Melanie S and Markku K (2011). Mangroves among the most Carbon-rich Forests in the Tropics, *Nature Geoscience* 4: 293 –297.

Day JW, Conner WH, Ley-Lou F, Day RH and Machado A (1987). The Productivity and Composition of Mangrove Forest, Laguna de Terminos, Mexico, *Aquatic Botany* 27: 267-284.

Day JW, Coronado-Molina C, Vera-Herrera FR, Twilley R, Rivera-Monroy VH, Alvarez-Guillen H, Day R and Conner W (1996). A 7 Year Record of Above-ground Net Primary Production in a Southeastern Mexican Mangrove Forest, *Aquatic Botany 55*: 39–60.

De Gier A (2003). A New Approach to Woody Biomass Assessment in Woodlands and Shrublands, In: P. Roy (Ed), Geo-informatics for Tropical Ecosystems, India, pp. 161-198.

De Gier A (1999). Woody Biomass Assessment in Woodlands and Shrublands, off-Forest Tree Resources of Africa, Arusha, Tanzania.

De Gier A (1989). Woody Biomass for Fuel: Estimating the Supply in Natural Woodlands and Shrublands. Ph.D Thesis, Albert Ludwigs University Freiburgi Br, Germany, 186 pp. ITC Publ. No.9 (1989), Internat Ins. For Aerospace Survey and Earth Sciences, Enschede. The Netherlands 102 pp.

Dinerstein E, Oslon DM, Graham DJ, Webster AL, Primm SA, Bookbinder MP and Ledec GA (1995). Conservation Assessment of the Terrestrial Eco-regions of Latin America and the Carrbbean, World Wildlife Fund and World Bank. Washington, D. C.

Di Nitto D, Dahdouh-Guebas F, Kairo JG, Decleir H and Koedam N (2008). Digital Terrain Modeling to Investigate the Effects of Sea Level Rise on Mangrove Propagule Establishment. *Marine Ecology Progress Series* 356: 175-188.

Dittmar T, Hertkorn NKG and Lara RJ (2006). Mangroves, a Major Source of Dissolved Organic Carbon to the Oceans. *Global Biogeochemical Cycles* 20, GB1012. DOI: 10.1029/2005GB002570

Dixon RK, Brown S, Houghton RA, Solomon AM, Trexler MC and Wigniewgki J (1994). Carbon Pools and Flux of Global Forest Economy, *Science* 263: 785-790.

Donato DC, Kauffman JB, Murdiyarso D, Kurnianto S, Stidham M and Kanninen M (2011). Mangroves among the most Carbon-rich Forests in the Tropics. *Nature Geoscience* 4:5.

Duke NC, Meynecke JO, Dittmann S, Ellison AM, Anger K, Berger U, Cannicci S, Diele K, Ewel KC, Field CD, Koedam N, Lee SY, Marchand C, Nordhaus L and Dahdouh-Guebas F (2007). A World without Mangroves? *Science* 317: 41-42.

Duke NC, Bunt JS and Williams WT (1981). Mangrove Litter Fall in Northeastern Australia. I. Annual Totals by Component of Selected Species, *Australian Journal of Botany* 29:547-553.

Ellison AM (2008). Managing Mangroves with Benthic Biodiversity in Mind: Moving Beyond Roving Banditry, *Journal of Sea Research* 59(1-2): 2–15.

Ellison AM (2002). Macro-ecology of Mangroves: Large-Scale Patterns and Processes in Tropical Coastal Forests. *Trees-Structure and Function* 16(2/3):181-194.

FAO (2007). The World's Mangroves 1980-2005, FAO Forestry Paper 153, Food and Agricultural Organization, Rome, Italy, 77pp.

FAO (2004). Carbon Sequestration in Dryland Soils. World Soil Resources Reports 102.

FAO (2003). FAO's Database on Mangrove Area Estimates, By Wilkie ML, Fortuna S and Souksavat O. Forest Resources Assessment Working Paper No. 62. Forest Resources Division, FAO, Rome (Unpublished).

FAO (2001). The Status of the World's Forests. Food and Agriculture Organization of the United Nation.

Farnsworth EJ and Ellison AM (1997). The Global Conservation Status of Mangroves. *Ambio* 26(6): 328-334.

Fehrmann L, Lehtonen A, Kleinn C and Tomppo E (2008). Comparison of Linear and Mixed-Effect Regression Models and K-Nearest Neighbor Approach for Estimation of Single-Tree Biomass. *Canadian Journal of Forest Research* 38(1):1-9.

Fortunaso KL, Barton CVM, Cowie AL, George BH, Montagu KD, Rawson A and Wilson BR (2008). Carbon Sequestration Predictor for Land Use Change in Inland Areas of New South Wales – Background, User Notes, Assumptions and Preliminary Model Testing. Version 3.1. NSW DPI Science and Research Division.

Fuchs H, Magdon P, Kleinn C and Flessa H (2009). Estimating Above-ground Carbon in a Catchment of the Siberian Forest Tundra: Combining Satellite Imagery and Field Inventory. *Remote Sensing of Environment* 113: 518–531.

Furnival GM (1961). An Index for Comparing Equations Used in Constructing Volume Tables. *Forest Science* 7: 337-341.

Gee GW and Bauder JW (1986). *Particle-size analysis.* p. 383-411. In Klute A (ed.) Methods of Soil Analysis, Part 1. Physical and Mineralogical Methods, Agronomy Monograph No. 9 (2ed). American Society of Agronomy/Soil Science Society of America, Madison, WI.

GFC (2001). National Mangrove Management Action Plan Guyana Forestry Commission, Georgetown, Guyana.

Giesen W, Wulffraat S, Zieren M and Scholten L (2006). *Mangrove Guidebook for Southeast Asia*. FAO and Wetlands International.

Gilman E, Ellison J, Duke NC and Field C (2008). Threats to Mangroves from Climate Change and Adaptation Options: A Review, *Aquatic Botany* 89(2): 237-250.

Gilman EH, Lavieren V, Ellison J, Jungblut V, Wilson L, Areki F, Brighouse G, Bungitak J, Dus E, Henry M, Sauni I, Kilman M, Matthews E, Teariki-Ruatu N, Tukia S, Yuknavage K (2006). *Pacific Island Mangroves in a Changing Climate and Rising Sea*. UNEP Regional Seas Reports and Studies No. 179. United Nations Environment Programme, Regional Seas Programme, Nairobi, KENYA.

Giri C, Ochieng E, Tieszen LL, Zhu Z, SinghA, Loveland T, Masek J and Duke N (2011). Status and Distribution of Mangrove Forests of the World Using Earth Observation Satellite Data, *Global Ecology and Biogeography* 20 (1):154–159.

Goessens A, Satyanarayana B, Stocken TVD, Zuniga MQ, Lokman HM, Sulong I, Dahdouh-Guebas F (2014) Is Matang Mangrove Forest in Malaysia Sustainably Rejuvenating after More than a Century of Conservation and Harvesting Management? *PLOS ONE* Volume 9, Issue 8.

Gonzalez M, Etchevers B, Hidalgo M (2008). Organic Carbon in Hillside Soils: Factors to Determine its Change Along Time. *Agrociencia* 42 (7): 741-751.

Achard F, Brown S, Brady M, DeFries R, Grassi G, Herold M, Mollicone D, Pandey D, Souza C (2011). A Sourcebook of Methods and Procedures for Monitoring and Reporting Anthropogenic Greenhouse Gas Emissions and Removals Caused by Deforestation, Gains and Losses of Carbon Stocks in Forests Remaining Forests, and Forestation. GOFC-GOLD Report version COP16-1, (GOFC-GOLD Project Office, Natural Resources Canada, Alberta, Canada.

Goldsmith FB, Harison and Marton AJ (1986). Description and the Analysis of Vegetation. In: Moore PD, Chapman SB (eds.) Methods in Plant Ecology. Blackwell Scientific Publication, London, pp 437-527.

Grace J, Malli Y, Higuchi N and Meir P (2001). Productivity of Tropical Forest, In: (Roy J, Samgier B and Mooney HA, eds) Terrestrial Global Productivity. Academic Press, *San Diego*. pp. 401-426.

Guerra Santos J, Cerón Bretón RM, Cerón Bretón JG, Sánchez Junco RC, Damián Hernández DL, Muriel M and Alderete Chavez A (2011). Preliminary Study of Carbon Storage Rate in Mangrove Soils in Atasta Peninsula, Campeche, México, Proceedings of the 8th WSEAS (World Scientific and Engineering Academy and Society)International Conference on Heat and Mass Transfer. ISBN: 978-960-474-268-4 Stevens Point, Wisconsin, USA, pp 111-116.

Guo LB, Sims REH and Horne DJ (2006). Biomass Production and Nutrient Cycle in *Eucalyptus* Short Rotation Energy Forest in New Zealand: II. Litter fall and Nutrient Return, *Biomass and Bioenergy* 30: 393 – 404.

Guo LB, Sims REH and Horne DJ (2002). Biomass Production and Nutrient Cycle in *Eucalyptus* Short Rotation Energy Forest in New Zealand: I. Biomass And Nutrient Accumulation. *Boiresource Tehnology* 85: 273 – 283.

Hamilton LS, Snedaker SC (1984). Handbook for Mangrove Area Management, IUCN/UNESCO/UNEP, East-West Center, Honolulu, Hawaii.

Hart PBS, Clicton PW, Allen RB, Nordmeyer AH, Evans G (2003). Biomass and Macro-Nutrients (Above- and Below-ground) in a New Zealand Beech (*Nothofagus*) Forest Ecosystem: Implications for Storage and Sustainable Forest Management, *Forest Ecology and Management* 174(1-3):281-294.

Havemann T (2009). Measuring and Monitoring Terrestrial Carbon: The State of the Science and Implications for Policy Makers. The United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries.

Heald EJ (1971). The Production of Organic Detritus in a South Florida Estuary. Univ. Miami Sea Gant Tech. Bull. No. 6, pp.110.

Hemati ZH, Mahmood H and Rozainah MZ (2014 a). Biodiversity and Biomass of a Natural and Degraded Mangrove Forest of Peninsular Malaysia, *Environmental Earth Sciences* 71:4629-4635.

Hemati ZH, Mahmood H, Emenike CU and Rozainah MZ (2014b). Rate of Carbon Storage in Soil of Natural and Degraded Mangrove Forest in Peninsular Malaysia. *Clean-soil, Air, Water* DOI 10.1002/clen.201400034.

Hemati ZH, Mahmood H and Rozainah MZ (2013). Litter Production in both Natural and Degraded Mangrove Forest of Peninsular Malaysia, Proceedings on 2013 International Conference on Materials, Architecture and Engineering Technology (ICMAET 2013) ISBN: 978-1-60595-168-3.

Hooijer A, Silvius M, Wösten H and Page S (2006). PEAT-CO2: Assessment of CO2 Emissions from Drained Peatlands In SE Asia, Delft Hydraulics report Q3943, Netherlands.

Hogarth PJ (1999). *The Biology of Mangroves*. Oxford Univ. Press, New York.

Hosoda K, Iehara T (2010). Above-ground Biomass Equations for Individual Trees of Cryptomeria Japonica, Chamaecyparis Obtuse and Larix kaempferi in Japan. *Journal of Forest Research* 15:299– 306.

Hou D (1958). Rhizophoraceae. In: van Steenis, CGGJ (ed.), Flora Malesiana, ser. 1, 5: 429- 493. Noordhoff- Kolff NV, Djakarta, Indonesia.

Houck M and Neill R (2009). Plant Fact Sheet for Black Mangrove (*Avicennia germinans*) USDA-Natural Resources Conservation Service, Louisiana Plant Materials Center, Galliano, Louisiana 70354.

Husch B, Beers TW, Kershaw JA (2003). Forest Mensuration, John Wiley & Sons, Inc, New Jersey.

IPCC (2007). Summary for Policymakers, In: Solomon S, qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds) Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

IPCC (2001). Climate Change 2001: Working Group I: The Scientific Basis. Cambridge University Press, New York.

Iverson LR, Brown S, Prasad A, Mitasova H, Gillepie AJR and Lugo AE (1994). Use of GIS for Estimating Potential and Actual Forest Biomass for Continental South and Southeast Asia. Pp. 67–116 in Dale, V. H. (Ed.) *Effects of Land-Use Change on Atmospheric CO_2 Concentrations: South and Southeast Asia as a Case Study*. Springer-Verlag, New York.

James FC and Shugart HH (1970). A Quantitative Method of Habitat Description, *Audubon Field Notes* 24:727-736.

Jana BK, Biswas S, Majumder M, Roy PK and Mazumdar A (2009). Carbon Sequestration Rate and Above-ground Biomass Carbon Potential of Four Young Species, *Journal of Ecology and Natural Environment* 1(2): 15-24.

Kaakinen S, Joikkonen A, Iivonen S, Vapaavuori E (2004). Growth, Allocation and Tissue Chemistry of Picea Abies Seedlings Affected by Nutrient Supply During the Second Growing Season. *Tree Physiol* 24:707-719.

Kairo JG, Dahdouh-Guebas F, Bosire J and Koedam N (2001). Restoration and Management of Mangrove Systems – a Lesson for and from the East African Region. *South African Journal of Botany* 67: 383-389.

Kamali B, Hashim R, Akib S (2010). Efficiency of an integrated habitat stabilisation approach to coastal erosion management. *International Journal of the Physical Sciences* 5 (9): 1401–1405.

Kaplan M, Renaud FG and Lüchters G (2009). Vulnerability Assessment and Protective Effects of Coastal Vegetation During the 2004 Tsunami in Sri Lanka, *Natural Hazards and Earth System Sciences* 9: 1479–1494.

Kathiresan, K and Rajendran N (2005). Coastal mangrove forests mitigated tsunami. *Estuarine, Coastal and Shelf Science* 65: 601-606.

Kathiresan K and Bingham BL (2001). Biology of Mangroves and Mangrove Ecosystems, *Advances in Marine Biology* 40: 81-251.

Kauffman JB, Heider C, Cole T, Dwire KA and Donato DC (2011). Ecosystem C Pools of Micronesian Mangrove Forests: Implications of Land Use and Climate Change, *Wetlands* 31: 343-352.

Kauffman JB and Cole T (2010). Micronesian Mangrove Forest Structure and Tree Response to a Severe Typhoon, *Wetlands* 30: 1077-1084.

Kauppi P and Sedjo R (2001). Technical and Economic Potential of options to Enhance, Maintain and Manage Biological Carbon Reservoirs and Geo-Engineering, In: (Metz B, Davidson O, Swart R and Pan J eds) Climate Change 2001: Mitigation. Contribution of Working Group III to the Third Assessment Report of the IPCC, Cambridge University Press, Cambridge, UK. pp. 301–344.

Keng H (1990). The Concise Flora of Singapore: Gymnosperms and Dicotyledons. Singapore University Press, Singapore. pp. 73-74.

Ketterings QM, Coe R, Noordwijik MV, Amagau Y abd Palm CA (2001). Reducing Uncertainty in the Use of Allometric Biomass Equations for Predicting Above- ground Tree Biomass in Mixed Secondary Forest. *Forest Ecology and Management* 146: 199–209.

Kim C, Jeong J, Kim RH, Son YM, Lee KH, Kim JS and Park IH (2011). Allometric Equations and Biomass Expansion Factors of Japanese Red Pine on the Local Level. *Landscape and Ecological Engineering* 7:283–289.

Kimmins JP (2004). Forest Ecology: A Foundation for Sustainable Forest Management and Environmental Ethics in Forestry. Pearson Education, Inc., NJ.

Klaus SL (2010). Comparative Impacts of Fossil Fuels and Alternative Energy Sources. Issues in Environmental Science and Technology, 29, Carbon Capture: Sequestration and Storage, Hester RE, Harrison RM (Eds), Royal Society of Chemistry.

Kochummen KM (1989). Rhizophoraceae. In: Ng, F.S.P. (ed.), Tree Flora of Malaya. *A Manual for Foresters* 4: 302-323. Longman Malaysia.

Komiyama A, Ong JE and Poungparn S (2008). Allometry, Biomass, and Productivity of Mangrove Forests: A Review. *Aquatic Botany* 89: 128-137.

Komiyama A, Poungparn S and Kato SH (2005). Common Allometric Equations for Estimating the Tree Weight of Mangroves, *Journal of Tropical Ecology* 21: 471-477.

Kongsanchai J (1994). Conservation of Mangroves into other Uses in Thailand. In: Proceedings of the Workshop on International Tropical Timber Organization Project, Yokohama, Japan. Pp. 30-38.

Korner C, (2003). Carbon Limitation in Trees, *Journal Ecology* 91:4-17.

Kraenzel M, Castillo A, Moore T, Potvin C (2003). Carbon Storage of Harvest Aged Teak (*Tectona grandis*) Plantation, Panama, *Forest Ecology and Management* 173(1-3): 213-225.

Krauss KW, Lovelock CE, Mc Kee KL, Lopez-Hoffman L, Ewe SM and Sousa WP (2008). Environmental Drivers in Mangrove Establishment and Early Development: A Review, *Aquatic Botany* 89(2): 105-127.

Kristjansson JK and Schönheit P (1983). Why Do Sulfate-Reducing Bacteria out Compete Methanogenic Bacteria for Substrates? *Oecologia Journal* 60: 264–266.

Kristensen E, Bouillon S, Dittmar T and Marchand C (2008). Organic Matter Dynamics in Mangrove Ecosystems, *Aquatic Botany* 89: 201-219.

Laclau P (2003). Biomass and Carbon Sequestration of Ponderosa Pine Plantations and Native Cypress Forests in Northwest Patagonia, *Forest Ecology and Management* 180(1-3): 317-333.

Laffoley D and Grimsditch G (2009). The Management of Natural Coastal Carbon Sinks. IUCN, 64pp.

Lauff G (1967). Estuaries American Association for the Advancement of Science, Washington, DC.

Lee SK, Tan WH and Havanond S (1996). Regeneration and Colonization of Mangrove on Clay Filled Reclaimed Land in Singapore. *Hydrobiologia* 319:23-35.

Lehtonen A, Makipaa R, Heikkinen J, Sievanen R and Liski J (2004). Biomass Expansion Factors (BEFs) for Scots Pine, Norway Spruce and Birch according to Stand Age for Boreal Forests. *Forest Ecology and Management* 188:211-224.

Lewis SL, Lopez-Gonzalez G, Sonké B, Affum-Baffoe K, Baker TR, Ojo LO, Phillips OL, Reitsma JM, White L, Comiskey JA, Djuikouo KMN, Ewango CEN, Feldpausch TR, Hamilton AC, Gloor M, Hart T, Hladik A, Lloyd J, Lovett JC, Makana JR, Malhi Y, Mbago FM, Ndangalasi HJ, Peacock J, Peh KSH, Sheil D, Sunderland T, Swaine MD, Taplin J, Taylor D, Thomas SC, Votere R and Wöll H (2009). Increasing Carbon Storage in Intact African Tropical Forests. *Nature* 457: 1003-1006.

Li X, Yi MJ, Son Y, Park PS, Lee KH, Son YM, Kim RH and Jeong MJ (2010). Biomass Expansion Factors of Natural Japanese Red Pine Forests in Korea. *Journal of Plant Biology* 53:381–386.

Lim JH, Shin JH, Jin GZ, Chun JH and Oh JS (2003). Forest Stand Structure, Site Characteristics and Carbon Budget of the Kwangneung Natural Forest in Korea. *Journal of Agricultural and Forest Meteorology* 5(2): 101-109 (in Korean with English abstract).

Lo Man Wah, Andy R. Mojiol and Ejria Saleh (2011). Diversity of Mangroves Ecosystem in Semporna Mangrove Forest, Borneo Science 28: March 2011.

Losi CJ, Siccama TG, Condit R and Morales JE (2003). Analysis of Alternative Methods for Estimating Carbon Stock in Young Tropical Plantations, *Forest Ecology and Management* 184(1-3): 355-368.

Lovelock CE, Ruess RW and Feller IC (2011). CO_2 Efflux from Cleared Mangrove Peat, *PLOS ONE* 6(6): 1-4.

Lovelock CE (1993). *The Field Guide to the Mangroves of Queensland*, Australian Institute of Marine Science (AIMS).

Lu DS (2006). The Potential and Challenge of Remote Sensing-Based Biomass Estimation, *International Journal of Remote Sensing* 27(7): 1297-1328.

Lucas RM, Mitchell AL, Rosenqvist A, Proisy CH, Meliu A and Ticehurs (2007). The Potential of L-band SAR for Quantifying Mangrove Characteristics and Change: Case Studies from the Tropics. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 17(3): 245-264.

Lugo AE and Snedekar SC (1974). The Ecology of Mangrove, *Annual Review of Ecological Systems* 5: 36-64.

Mac Arthur RH (1969). Patterns of Species Diversity, *Biological Reviews* 40:510-533.

Machiwa JF and Hallberg RO (2002). An Empirical Model of the Fate of Organic Carbon in a Mangrove Forest Partly Affected by Anthropogenic Activity. *Ecology Model* 147: 69-83.

Mahmood H (2014). Carbon Pools and Fluxes in *Bruguiera parviflora* Dominated Naturally Growing Mangrove Forest of Peninsular Malaysia, *Wetlands Ecology and Management* 22: 15-23.

Mahmood H, Saberi O, Japar Sidik B and Misri K (2008). Net Primary Productivity of *Bruguiera parviflora* (Wight & Arn.) Dominated Mangrove Forest at Kuala Selangor, Malaysia, *Forest Ecology and Management* 255: 179-182.

Mahmood H, Saberi O, Japar Sidik B and Misri K (2005). Litter Flux in Kuala Selangor Nature Park Mangrove Forest, Malaysia, *Indian Journal Forest* 28 (3): 233-238.

Mahmood H (2004). Biomass, Litter Production and Nutrients in *Bruguiera parviflora* Dominated Mangrove Forest Ecosystem at Kuala Selangor, Malaysia. PhD thesis, University Putra Malaysia.

Mahmood H, Saberi O, Japar Sidik B, Misri K and Rajagopal S (2004). Allometric Relationships for Estimating Above and Below-ground Biomass of Saplings And Trees of *Bruguiera parviflora* (Wight and Arnold). *Malaysian Applied Biology Journal* 33(1): 37–45.

Mahmood H, Japar Sidik B, Saberi O and Misri K (2003). *Bruguiera parviflora* Leaf Litter Loss at Kuala Selangor Mangrove Forest, Malaysia. in: Aquatic Resource and Environmental Studies of the Straits of Malacca, ed. B. Japar Sidik, A. Aziz, Z. Muta Harah, and A. Kawamura, pp. 153-164. MASDEC, JICA, Faculty of Science and Environmental Studies, UPM, Malaysia.

Marquardt J and M Trevena (2009). *Protecting Mangroves, Benefits for People and the Environment, Reforestation Efforts and Experience from San Agustin. an Education Kit.* CERV Philippines Inc.

Melana DM, Atchue J, Yao CE, Edwards R, Melana EE and Gonzales HI (2000). *Mangrove Management Handbook.* Department of Environment and Natural Resources, Manila, Philippines through the Coastal Resource Management Project, Cebu City, Philippines. 96 p.

Moya E, Twilley RR, Monroy VHR, Marx BD, Molina CC and Ewe SML (2011). Patterns of Root Dynamics in Mangrove Forests along Environmental Gradients in the Florida Coastal Everglades, USA. *Ecosystem* 14:1178-1195.

McKee KL, Cahoon DR, and Feller I (2007). Caribbean Mangroves Adjust to Rising Sea Level Through Biotic Controls on Change in Soil Elevation. *Global Ecology Biogeography* 16: 545–56.

Mcleod E, Chmura GL, Bouillon S, Salm R, Bjork M, Duarte CM, Lovelock CE, Schlesinger WH, and Silliman BR (2011). A Blueprint for Blue Carbon: Toward an Improved Understanding of the Role of Vegetated Coastal Habitats in Sequestering CO_2. *Frontiers in Ecology and the Environment* 9:552-560.

Mendelssohn IA and McKee KL (2000). *Saltmarshes and Mangroves*, Pp. 501-536. In Barbour M and Billings WD (eds.), North American Terrestrial Vegetation, 2nd edition , Cambridge University Press, Cambridge.

Menezes M, Berger U and Worbes M (2003). Annual Growth Rings and Long-Term Growth Patterns of Mangrove Trees from the *Braganca Peninsula*, North Brazil. *Wetlands Ecology and Management* 11: 233-242.

Michael M (1997). *Mangroves: The Forgotten Forest between Land and Sea*, Tropical Press, pp. 93-102.

Miller DM (1984). Reducing Transformation Bias in Curve Fitting, *the American Statistician* 38(2): 124-126.

Mitra A, Sengupta K, Banerjee K (2011). Standing Biomass and Carbon Storage of Above-ground Structures in Dominant Mangrove Trees in the Sundarbans. *Forest Ecology and Management* 261: 1325-1335.

Mitsch WJ, Lefeuvre JC and Bouchard V (2002) Ecological engineering applied to river and wetland restoration. Ecol. Eng. 18, 529–541.

Montagnini F and Porras C (1998). Evaluating the Role Of Plantations as Carbon Sinks: an Example of an Integrating Approach from the Humid Tropics. *Environmental Management* 22: 459-470.

Montagu KD, Duttmer K, Barton CVM and Cowie AL (2005). Developing General Allometric Relationships for Regional Estimates of Carbon Sequestration- an Example Using Eucalyptus Piplularis from Seven Contrasting Sites. *Forest Ecology and Management* 204(1): 115-129.

Montes N, Gauquelin T, Badri W, Bertaudiere V, Zaoui YE (2000). A non-Destructive Method for Estimating Above-ground Forest Biomass in Threatened Woodlands, *Forest Ecology and Management* 130 (1-3): 37-46.

MOSTI (2003). *Wetlands: Conservation and wise use*. Ministry of Science, Technology and the Environment, Malaysia, 60 pp.

Muller-Landau HC (2009). Carbon Cycle: Sink in the African Jungle. *Nature* 457: 969-970.

Mumby PJ, Edwards AJ, Arias-Gonzalez JE, Lindeman KC, Blackwell PG,Gall A, Groczynska MI, Harborne AR, Penken H, Wabnitz CCC, Llewellyn G (2004). Mangroves Enhance the Biomass of Coral Reef Fish Communities in the Caribbean. *Nature* 427: 533-536.

Nagelkerken I, Blaber SJM, Bouillon S, Green P, Haywood M, Kirton LG, Meynecke JO, Pawlik J, Penrose HM, Sasekumar A and Somerfield PJ (2008). The Habitat Function of Mangroves for Terrestrial and Marine Fauna: a Review. *Aquatic Botany* 89: 155–185.

Nazli M F and Hashim NR (2010). Heavy metal concentrations in an important mangrove species, Sonneratia Caseolaris, in Peninsular Malaysia. *Environment Asia* 3: 50-55.

Nellemann C, Corcoran E, Duarte CM, Valdés L, DeYoung C, Fonseca L and Grimsditch G (eds) (2009). *Blue carbon: a Rapid Response Assessment*. United Nations Environment Programme, GRID-Arendal.

Nibedita Mukherjee, Sutherland WJ, Khan MNI, Berger U, Schmitz N, Dahdouh-Guebas F and Koedam N (2014). Using Expert Knowledge and Modeling to Define Mangrove Composition, Functioning, and Threats and Estimate Time Frame for Recovery, *Ecology and Evolution* 4(11): 2247–2262.

Noske RA (1993). *Bruguiera hainesii*: another Bird- Pollinated Mangrove? *Biotropica* 25:481-483.

Olwig MF, Sorensen MK, Rasmussen MS, Danielsen, F, Selvam V, Hansen LB, Nyborg L, Vestergaard KB, Parish F and Karunagaran VM (2007). Using Remote Sensing to Assess the Protective Role of Coastal Woody Vegetation Against Tsunami Waves. *International Journal of Remote Sensing*, 28(13): 3153-3169.

Ong JE and Gong WK (2013) *Structure, Function and Management of Mangrove Ecosystems*. ISME Mangrove Educational Book Series No. 2. International Society for Mangrove Ecosystems (ISME), Okinawa, Japan, and International Tropical Timber Organization (ITTO), Yokohama, Japan.

Ong JE, Gong WK, Wong CH (2004). Allometry and Partitioning of the Mangrove, *Rhizophora apiculata*, *Forest Ecology and Management*, 188: 395-408.

Ong JE, Gong WK, Clough BF (1995). Structure And Productivity of 20-Year-old Stand of *Rhizophora apiculata* Mangrove Forest, *Journal of Biogeography, 22*: 417–424.

Ong JE (1995). The Ecology of Mangrove Conservation and Management. *Hydrobiologia* 295: 343-351.

Ong JE, Gong WK and Wong CH (1985). Seven Years of Productivity Studies in a Malaysian Managed Mangrove Forest then Wath? 'In Coasts and Tidal Wetlands of the Australian Monsoon Region' (Eds Bardsley K, Davie J, woodroffe Cd) pp: 213-223. (North Australia Research Unit: Darwin)

Ong JE, Gong WK, Wong CH and Dhanarajan G (1984). Contribution of Aquatic Productivity in Managed Mangrove Ecosystem in Malaysia. In: Asian Symposium on Mangrove Environment Research and Management, pp 209-215.

Ong JE (1982). Mangrove and Mariculture. *Ambio* 11:252-257.

Oohata S and Shinozaki K (1979). A Statistical Model of Plant Form-Further Analysis Of The Pipe Model Theory, *Japan Journal Ecology* 29: 323–335.

Overman JPM, Witte HJL and Saldarriaga JG (1994). Evaluation of Regression Models for Above-ground Biomass Determination in Amazon Rainforest, *Journal of Tropical Ecology* 10: 207-218.

Page SE, Rieley JO, Banks CJ (2010). Global and Regional Importance of the Tropical Peatland Carbon Pool, *Global Change Biology* 17: 798-818.

Parresol R (1999). Assessing Tree and Stand Biomass: A Review with Examples and Critical Comparisons, *Forest Science* 45: 573-593.

Peter JH (1999). *The Biology of Mangroves, Biology of Habitat*, Oxford University Press Inc. London.

Peter KLN and Sivasothi N (1999). *A Guide to the Mangroves of Singapore I: The Ecosystem and Plant Diversity*, Singapore Science Centre, pp. 94-137.

Phat NK, Knorr W, and Kim S (2004). Appropriate Measures for Conservation of Terrestrial Carbon Stocks–Analysis of Trends of Forest Management in Southeast Asia. *Forest Ecology and Management* 191:283–99.

Phillips OL, Malhi Y, Higuchi N, Laurance WF, Núñez PN, Vásquez RM, Laurance SG, Ferreira LV, Stern M, Brown S and Grace J (1998). Changes in the Carbon Balance of Tropical Forests: Evidence from Long-Term Plots. *Science*, 282:439-442.

Polidoro B, Carpenter K, Collins L, Duke N, Ellison A, et al., (2010). the Loss of Species: Mangrove Extinction Risk and Geographic Areas of Global Concern. *PLOS ONE* 5(4), doi:10.1371/journal.pone.0010095.

Putz FE and Chan HT (1986). Tree Growth, Dynamics, and Productivity in a Mature Mangrove Forest in Malaysia. *Forest Ecology and Management* 17: 211–230.

Rabiatul Khairunnisa MR and Hasmadi M (2012). Biomass and Carbon in Mangrove: Measuring and Managing through Remote Sensing Technique.3-7 March, Holiday Inn Melaka.

Rayner PJ, Enting IG, francey RJ and Langenfelds R (1999). Reconstructing the Recent Carbon Cycle from Atmospheric CO_2 δ^{13} C and $0_2/N_2$ Observations. *Tellus* B 51:213-232.

Ross MS, Ruiz PL, Telesnicki GJ and Meeder JF (2001). Estimating Above-ground Biomass and Production in Mangrove Communities of Biscayne National Park, Florida (U.S.A.). *Wetland Ecology and Management* 9: 27−37.

Saenger P (2002). Mangrove Ecology, Silviculture and Conservation. Kluwer Academic Publishers, Dordrecht, the Netherlands. pp. 11-18.

Saint-Andre L, M'Bou AT, Maliala A, Mouvondy W, Jourdan CH, Roupsard O, Deleporte PH, Hamel O and Nouvellon Y (2005). Age-Related Equations for Above- and Below-ground Biomass of a *Eucalyptus* Hybrid in Congo, *Forest Ecology and Management* 205: 199-214.

Saenger P, Hegerl EJ and Davie JDS (1983). Global Status of Mangrove Ecosystems, *The Environmentalist* 3: 1-88.

Saenger P and Snedaker SC (1993). Pantropical Trends in Mangrove Above-ground Biomass and Annual Litterfall, *Oecologia Journal* 96(3): 293– 299.

Saglam M and Dengiz O (2012). Influence of Selected Land Use Types and Soil Texture Interactions on Some Soil Physical Characteristics in an Alluvial Land. *International journal of Agronomy and Plant Production* 3 (11): 508-513.

Salako FK, Kirchhof G and Tian G (2006). Management of a Previously Eroded Alfisol with Herbaceous Legumes: Soil Loss and Properties under Mound Tillage. *Soil and Tillage Research* 89: 185-195.

Salazar S, Sanchez LE, Galindo P, Santa-Regina I (2010). Above-ground Tree Biomass Equations and Nutrient Pools for Paraclimex Chestnut Stand and for a Climax Oak Stand in the Sierra de Francia Mountains, Salamanca, Spain. *Scientific Research and Essays* 5(11): 129-1301.

Santa Regina I (2000). Biomass Estimation and Nutrient Pools in Tour *Quercus pyrenaica* in Sierra de Gata Mountains, Salamanca, Spain. *Forest Ecology and Management* 132:127-141.

Salkind NJ (2003). Exploring research (5th ed.), Upper Saddle River, NJ: Prentice Hall.

Sasekumar A and Chong VC (2012). *Mangrove and Coastal Environment of Selangor Malaysia*, Institute of Ocean and earth Sciences, p.306.

Sasekumar A and Loi JJ (1983). Litter Production in Three Mangrove Forest Zones in the Malay Peninsula, *Aquatic Botany* 17: 283- 290.

Sathirathai S (2003). *Economic Valuation of Mangroves and the Roles of Local Communities in the Conservation of Natural Resources: Case Study of Surat Thani, South of Thailand by*, Research report.

Schadel C, Blochl A, Richter A, Hoch G (2009). Quantification and Monosaccharide Composition of Hemicelluloses from Different Plant Functional Types, *Plant Physiology Biochem* 47(1): 1-9.

Schimel DS (1995). Terrestrial Ecosystem and the Carbon Cycle, *Global Change Biology* 1:77-91.

Schulze MD, Seavy NE and Whitacre DF (2000). A Comparison of Phyllostomid Bat Assemblages in Undisturbed Neo-tropical Forest and in Forest Fragments of A Slash-and-Burn Farming Mosaic in Peten, Guatemala. *Biotropica* 32:174–184.

Schumacker RE and Lomax R G (2010). *A Beginners Guide to Structural Equation Modeling*. New York: Routledge.

Segura M and Kanninen M (2005). Allometric Models for Tree Volume and Total Above-ground Biomass in a Tropical Humid Forest in Costa Rica, *Biotropica Journal* 37 (1):2-8.

Sheue CR, Yong JWH and Yang YP (2005). The *Bruguiera* Species in the Mangroves of Singapore, Especially on the New Record and the Rediscovery, *Taiwania* 50(4): 251-260.

Shing YL, Primavera JH, Guebas FD , McKee K , Bosire JO, Cannicci S , Diele K , Fromard F , Koedam N, Marchand C, Mendelssohn I, ukherjee NM and Record S (2014). Ecological Role and Services of Tropical Mangrove Ecosystems: A Reassessment. *Global Ecology and Biogeography* 23: 726–743.

Shinozaki K, Yoda K, Hozumi K, and Kira T (1964). A Quantitative Analysis of Plant Form-the Pipe Model Theory, II. Further Evidence of the Theory and Its Application in Forest Ecology. *Japan Journal of Ecology* 14: 133–139.Li *et al.*, 2007.

Sherman RE, Fahey TJ, Martinez P (2003). Spatial Patterns of Biomass and Above-ground Net Primary Productivity in a Mangrove Ecosystem in the Dominican Republic. *Ecosystems* 6: 384-398.

Simpson EH (1949). Measurement of Diversity, *Nature* 163:688.

Smith TJ (1993). Forest structure, Pp. 101-136. In Robertson Ian I and Alongi DM (eds.), Tropical Mangrove Ecosystems. American Geophysical Union, Washington, D.C.

Soares MLG, Schaeffer-Novelli Y (2005). Above-ground Biomass of Mangrove Species. I. Analysis of Models, *estuary coastal and shelf science* 65: 1-18.

Spalding M, Kainuma M and Collins L (2010). World Atlas of Mangroves. UNEP-WCMC, Cambridge, 336 pp.

Spalding M.D, Blasco F, Field CD (Eds.) (1997). World Mangrove atlas, The International Society for Mangrove Ecosystems, Okinawa, Japan, 178 pp.

Sprugel DG (1983). Correcting for Bias in Log-Transformed Allometric Equations, *Ecology* 64(1): 209-210.

Stafford-Deitsch J (1996). *Mangrove: the Forgotten Habitat*. Immel Publishing Limited, London, UK, pp 277.

Tamooh F, Huxham M, Karachi M, Mencuccini M, Kairo JG, Kirui B (2008). Below-ground Root Yield and Distribution in Natural and Replanted Mangrove Forest at Gazi bay, Kenya. *Forest Ecology and Management*, 256: 1290-1297.

Tan DD, Wan Juliana WA and Maimon A (2012). Community Structure and Productivity of Mangrove Forests in Two National Parks of West Malaysia, *The Malaysian Forester* 75 (2): 165-176.

Teobaldelli M, Doswald N and Dickson B (2010). Monitoring for REDD+: Carbon Stock Change and Multiple Benefits. Multiple Benefits Series 3. Prepared on behalf of the UN-REDD Programme. UNEP World Conservation Monitoring Centre, Cambridge, UK.

Teodorescu G (2010). Climatic Change Impact on Urban Ecosystems and Sustainable Development of Cities in Romania, WSEAS Transactions on Environment and Development. 6(2):103-113.

Ter-mikaelian MT and Korzukhin MD (1997). Biomass Equations for Sixty-Five North American Tree Species, *Forest Ecology and Management*, 97:1-24.

Tobin B and Nieuwenhuis M (2007). Biomass Expansion Factors for Sitka Spruce in Ireland, *European Journal Forest Research*, 126: 189-196.

Tomlinson PB (1986). The Botany of Mangrove, Cambridge University Press, Cambridge, pp 419.

Triest L (2008). Molecular Ecology and Biogeography of Mangrove Trees Towards Conceptual Insights on Gene Flow and Barriers: a review, *Aquatic Botany* 89(2): 138-154.

Turner IM and Yong JWH (1999). The Coastal Vegetation of Singapore. In: Briffett C and HC Ho (eds.). State of the Natural Environment in Singapore, Nature Society (Singapore), Singapore. pp. 5-23.

Valiela I, Brown JL and York JK (2001). Mangrove Forests: One of the World's Threatened Major Tropical Environments, *BioScience* 51(10): 807–815.

Valentine HT, Tritton LM and Furnival GM (1984). Subsampling Trees for Biomass, Volume, or Mineral Content, *Forest Science* 30: 673-681.

Van Lavieren H, Spalding M, Alongi D, Kainuma M, Clüsener-Godt M and Adeel Z (2012). Securing the Future of Mangroves, A Policy Brief. UNU-INWEH, UNESCO-MAB with ISME, ITTO, FAO, UNEP-WCMC and TNC, pp 53.

United Nations (1998). Kyoto Protocol to the United Nations Framework Convention on Climate Change, Kyoto, Japan.

Watson RT, Novel IR, Bolin B, Ravindranath NH, Verardo DJ, Dokken DJ (2000). *Land Use, Land-Use Change, and Forestry*, Cambridge University Press. pp. 21.

Watson JO (1928). Mangrove Forests of the Malay Peninsula. *Malayan Forest Records* 6: 1-275.

Walkley A. and Black IA (1934). An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* 37: 29-37.

Walters BB, Rönnbäck P, Kovacs P, Crona JM, Hussain B, Badola SA, Jurgenne R, Primavera H, Barbier E and Dahdouh-Guebas F (2008). Ethnobiology, socio-Economics and Management of Mangrove Forests: A Review, *Aquatic Botany* 89: 220-236.

Wayne Berry, Quirine Ketterings, Steve Antes, Steve Page, Jonathan Russell-Anelli, Renuka Rao and Steve DeGloria (2007). Nutrient Management Spear Program, Cornell University Agronomy Fact Sheet #29 (soil texture, http://nmsp.css.cornell.edu).

Whiting JG and Chanton JP (2001). Greenhouse Carbon Balance of Wetlands: Methane Emission versus Carbon Sequestration, *Tellus* 53B:521-528.

Woodroffe CD (1992). Mangrove Sediments and Geomorphology, In: Alongi, D., Robertson A (Eds.), *Tropical mangrove ecosystems*. American Geophysical Union, Coastal and Estuarine Studies, pp. 7–41.

Wiant H V and Harner E J (1979). Notes: Percent Bias and Standard Error in Logarithmic Regression, *Forest Science* 25(1): 167-168.

Xiaonan D, Xiaoke W, Lu F and Zhiyun O (2008). Primary Evaluation of Carbon Sequestration Potential of Wetlands in China, *Acta Ecologica Cínica* 28(2):63−469.

Xiao CW, Ceulemans R (2004). Allometric Relationships for Below- and Above-ground Biomass of Young Scots Pines, *Forest Ecology and Management* 203:177-186.

Ximenes FA, Gardner WD and Kathuria A (2008). Proportion of Above-ground Biomass in Commercial Logs and Residues Following the Harvest of Five Commercial Forest Species in Australia, *Forest Ecology and Management* 256: 335-346.

Wei CF, Ni JP, Gao M, Xie DT and Hasegawa SC (2006). Anthropic Pedogenesis of Purple Rock Fragments in Sichuan Basin. *China Catena* 68(1): 51–58.

Wyatt-Smith J (1953). The Malayan Species of *Bruguiera, Malayan Forester* 16: 156-161.

Zenner E K and Hibbs D E (2000). A New Method for Modeling the Heterogeneity of Forest Structure, *Forest Ecology and Management* 129: 75-87.

Zhang HB, Luo YM, Wong MH, Zhao QG, Zhang GL (2007). Soil Organic Carbon Storage and Changes Reduction in Agricultural Activities in Hong Kong. *Geoderma* 139:412– with 419.

Zhenga D, Rademacherb J, Chena J, Crowc T, Breseea M, Moined JL, Ryu SR (2004). Estimating aboveground biomass using Landsat 7 ETM+ data across a managed landscape in northern Wisconsin, USA. *Remote Sensing of Environment* 93: 402–411.

Zianis D and M Mencuccini (2004). On Simplifying Allometric Analyses of Forest Biomass, *Forest Ecology and Management* 187: 311–332.

APPENDIX A

List of Plant Species Found in the Mangrove Forests in Malaysia

Family	Species	Common name (in Malay)
Acanthaceae	*Acanthus ilicifolius*	Jeruju puteh
Arecaceae	*Nypa fruticans*	Nipah
Asteraceae	*Pluchea indica*	Beluntas
Avicenniaceae	*Avicennia alba*	Api-api puteh
Avicenniaceae	*A. lanata*	Api-api bulu
Avicenniaceae	*A. marina*	Api-api jambu
Avicenniaceae	*A. officinalis*	Api-api ludat
Combretaceae	*Lumnitzera littorea*	Teruntum merah
Combretaceae	*L. racemosa*	Teruntum putih
Euphorbiaceae	*Excoecaria agallocha*	Buta-buta
Meliaceae	*Xylocarpus granatum*	Nyireh bunga
Meliaceae	*X. meluccensis*	Nyireh batu
Myrsinaceae	*Aegiceras corniculatun*	Kachangkachang
Pteridaceace	*Acrostichum aureum*	Piai raya
Pteridaceace	*A. speciosum*	Piai lasa
Rhizophoraceae	*Bruguiera cylindrica*	Berus
Rhizophoraceae	*B. gymnorrhiza*	Tumu merah
Rhizophoraceae	*B. parviflora*	Lenggadai
Rhizophoraceae	*B. sexangula*	Tumu putih
Rhizophoraceae	*Ceriops decandra*	Tengar
Rhizophoraceae	*C. tagal*	Tengar
Rhizophoraceae	*Rhizophora apiculata*	Bakau minyak
Rhizophoraceae	*R. mucronata*	Bakau kurap
Sapotaceae	*Planchonella obovata*	Menasi
Sonneratiaceae	*Sonneratia alba*	Perepat
Sonneratiaceae	*S. caseolaris*	Berembang
Sonneratiaceae	*S. ovata*	Gedabu
Sterculiaceace	*Heritiera littoralis*	Dungun
Leguminosae	*Caesalpinia crista*	Unak
Leguminosae	*Derris trifoliata*	Tuba laut
Leguminosae	*D. uliginosa*	Setui
Malvaceae	*Thespesia populnea*	Bebaru
Pandanaceae	*Pandanus odoratissimus*	Pandan
Tiliaceae	*Brownlowia argentata*	Kiei

Source: (Saenger *et al.*, 1983; Ashton & Macintosh, 2002; MOSTI, 2003)

List of Publications and Conferences

- Zhila Hemati, Hossain Mahmood & M. Z. Rozainah (2014). Biodiversity and biomass of a natural and degraded mangrove forest of Peninsular Malaysia. Environ Earth Sci.71:4629-4635 (ISI-Cited Publication)
- Zhila Hemati, Hossain Mahmood, Emenike C.U& M. Z. Rozainah (2014). Rate of Carbon Storage in Soil of Natural and Degraded Mangrove Forest in Peninsular Malaysia. Clean-soil, Air, Water. DOI 10.1002/clen.201400034. (ISI-Cited Publication)
- Zhila Hemati, Hossain Mahmood & M. Z. Rozainah (2013). Litter Production in both Natural and Degraded Mangrove Forest of Peninsular Malaysia. Proceedings on 2013 International Conference on Materials, Architecture and Engineering Technology (ICMAET 2013) ISBN: 978-1-60595-168-3 (ISI-Cited Publication)
- Zhila Hemati, Hossain Mahmood & M. Z. Rozainah (2014). Determination of Carbon and Nitrogen in Litter Fall of Mangrove ecosystem of Peninsular Malaysia (under review)
- Zhila Hemati, Hossain Mahmood & M. Z. Rozainah (2012). Biomass estimation in a juvenile and degraded mangrove forest of Malaysia., 1st ASEAN Congress on Mangrove Research and Development., 03-07 Dec 2012, Manila, Philippine (International)
- Zhila Hemati, Hossain Mahmood & M. Z. Rozainah (2013). Litter Production in both Natural and Degraded Mangrove Forest of Peninsular

Malaysia., international conference on agriculture science environment engineering (ICASEE). 19-20 Dec 2013, Beijing, China (International)