

TREE COMMUNITY STRUCTURE AND CARBON STOCK OF A
SECONDARY FOREST IN UNIVERSITI TEKNOLOGI MALAYSIA CAMPUS

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This thesis specially dedicated to my husband, daughter and family.

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ABSTRACT

Recently, anthropogenic activities such as forest logging, plantation and urban development have influenced the growth of secondary forests throughout the tropics. In Universiti Teknologi Malaysia (UTM), secondary forest has emerged after the removal of rubber plantation, which has led this study to identify secondary forest composition, estimate the amount of carbon stock from the above-ground biomass (AGB), below-ground biomass (BGB) and soil organic carbon, and identify tree distribution based on soil, chemical and physical properties. In this study, 200 plots with an area of 100 m² each were established within UTM's secondary forest. The diameter at breast height (DBH), the tree height, coordinates for each tree species and soil samples were collected. Top-soil samples in 50 selected plots were collected and analysed for texture, pH, base cation and available nutrients, including Mg, P and K. Shannon diversity index was applied in measuring species diversity. Then, a satellite image acquisition from Pleiades and spectral radiometer data collection were carried out to compile spectral data of fresh leaves from 25 species. For species composition, a total of 1,917 tree stands, comprising 25 species from 17 genera and 15 families were enumerated in all the study plots. Euphorbiaceae is the largest family with a total basal area (BA) of 29.6 m²/ha which contributes to the high density in UTM secondary forest. The Shannon Diversity Index in UTM secondary forest was 2.248 ($H_{\max}= 3.219$) which is lower than for primary forest. The total tree biomass was 84.6 t/ha, which was composed of AGB of 61.3 t/ha and BGB of 23.3 t/ha. The amount of carbon stock in this forest was 40.1 t/ha for AGB (28.8 t/ha), BGB (11 t/ha), and in the soil (0.79 t/ha). The total amount of soil organic carbon in UTM was 37.39 t/ha. Finally, ordinations by using Canonical Correspondence Analysis (CCA) indicated that soil, chemical and physical factors had no relationship with vegetation distribution. According to supervised classification for carbon stock estimation, the total carbon stock from 173.80 hectares of secondary forest in UTM amounted to 11,731.5 tonnes of carbon. Therefore, the secondary forest in UTM should be conserved as a carbon reservoir.

ABSTRAK

Kebelakangan ini, aktiviti manusia seperti pembalakan hutan, perladangan dan pembangunan bandar telah mempengaruhi pertumbuhan hutan sekunder di kawasan tropika. Di Universiti Teknologi Malaysia (UTM), hutan sekunder telah muncul selepas pemansuhan ladang getah, dengan itu kajian ini menjurus kepada mengenalpasti komposisi hutan sekunder, menganggarkan jumlah simpanan karbon daripada biojisim atas dan bawah tanah serta karbon organik di dalam tanah, dan mengenalpasti taburan pokok berdasarkan ciri kimia dan fizikal tanah. Dalam kajian ini, sejumlah 200 plot berkeluasan 100 m² setiap satu telah dikenalpasti di hutan sekunder UTM. Diameter paras dada (DBH), tinggi pokok, koordinat bagi setiap pokok dan sampel tanah telah diambil. Sampel tanah atas di 50 plot terpilih daripada 200 plot telah diambil dan dianalisis terhadap tekstur, pH, bes kation dan nutrien tersedia termasuk Mg, P dan K. Indeks kepelbagaian Shannon telah digunakan bagi menganggarkan kepelbagaian spesies. Kemudian, imej satelit diperolehi daripada Pleiades dan data spektral radiometer dari daun segar telah dijalankan bagi mengumpulkan spektral data bagi 25 spesies. Bagi komposisi hutan, sejumlah 1,917 batang pokok, merangkumi 25 spesies daripada 17 genus dan 15 famili telah dikenalpasti dalam semua plot kajian. Jumlah keluasan pangkal pokok (BA) bagi famili Euphorbiaceae adalah 29.6 m²/ha dalam kesemua plot sekaligus menjadi penyumbang tertinggi kepada kepadatan hutan. Indeks Kepelbagaian Shannon di hutan sekunder UTM adalah 2.248 ($H_{\max} = 3.219$), lebih rendah dari hutan primer. Jumlah biojisim pokok adalah 84.6 t/ha, 61.3 t/ha dari AGB dan 23.3 t/ha dari BGB. Jumlah simpanan karbon di hutan sekunder UTM adalah 40.1 t/ha untuk AGB (28.8 t/ha), BGB (11 t/ha), dan di dalam tanah (0.79 t/ha). Jumlah simpanan organik karbon di UTM adalah 37.39 t/ha. Akhirnya, Analisis Kesepadanan Kanonikal (CCA) menunjukkan faktor kimia dan fizikal tanah tiada perkaitan dalam taburan tumbuhan. Berdasarkan kajian pengelasan untuk menganggarkan jumlah simpanan karbon adalah 11,731.5 tan karbon bagi 173.8 hektar hutan sekunder. Oleh itu, hutan sekunder perlu dipelihara sebagai takungan karbon.

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LIST OF ABBREVIATIONS

| | | |
|------------------|---|---|
| ANOVA | - | Analysis of Variance |
| a.s.l. | - | Above sea level |
| C | - | Carbon |
| cm | - | Centimetre |
| COP | - | Conference of Parties |
| CO ₂ | - | Carbon dioxide |
| DBH | - | Diameter at breast height |
| DN | - | Digital numbers |
| FAO | - | Food and Agriculture Organization of United Nations |
| FCCC | - | Framework Convention on Climate Change |
| FGV | - | FELDA Global Venture |
| FRA | - | Forest Resource Assessment |
| g | - | gram |
| GHG | - | Greenhouse Gases |
| GPS | - | Global Positioning System |
| Gt | - | Gigatonne |
| ha | - | Hectare |
| ha ⁻¹ | - | per hectare |
| HA | - | Humic acids |
| IPCC | - | Intergovernmental Panel on Climate Change |
| ITTO | - | International Tropical Timber Organization |
| IVI | - | Important Value Index |
| KBR | - | Khangchendzonga Biosphere Reserve |
| KWR | - | Krau Wildlife Reserve |
| m | - | Meter |
| M | - | Mega |
| MEA | - | Millennium Ecosystems Assessment |

| | | |
|------------------|---|---|
| meq | - | milliequivalents |
| Mg | - | Megagram |
| ml | - | Millilitre |
| MLC | - | Maximum Likelihood Classifier |
| Mt | - | Megaton |
| NPP | - | Net Primary Productivity |
| Pg | - | Petagram |
| ppm | - | Parts per million |
| PVC | - | Polyvinyl Chloride |
| REDD | - | Reduced Emission from Deforestation and Forest Degradation |
| RH | - | Relative Humidity |
| RM | - | Ringgit Malaysia |
| SIC | - | Soil Inorganic Carbon |
| SOC | - | Soil Organic Carbon |
| t/ha | - | tonne per hectare |
| UHI | - | Urban Heat Island |
| UNFCCC | - | United Nation Framework on Climate Change |
| UPM | - | Universiti Putra Malaysia |
| USD | - | United State Dollar |
| USDA | - | United State Department of Agriculture |
| UTM | - | Universiti Teknologi Malaysia |
| yr ⁻¹ | - | per year |

LIST OF SYMBOLS

| | | |
|--------------------|---|----------------|
| \pm | - | Plus-minus |
| $^{\circ}\text{C}$ | - | Degree Celsius |
| % | - | Percent |
| Al^{3+} | - | Aluminium Ion |
| Ca^{2+} | - | Calcium Ions |
| CH_4 | - | Methane |
| H^+ | - | Hydrogen Ion |
| K^+ | - | Potassium Ion |
| M | - | Molar |
| Mg^{2+} | - | Magnesium Ions |
| Na^+ | - | Sodium Ion |
| P | - | Phosphate |

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Tropical forests play an important role in the global carbon cycle. They contain 40% of the global terrestrial carbon, which accounts for more than half of the global gross primary productivity, and they keep large amounts of CO₂ from the atmosphere (Ngo *et al.*, 2013). Rapid urban and industrial development, which commenced in the 1970s, may account for the prevalent formation of secondary forests in Malaysia. Deforestation happens when more space is needed by humans for farming and other developments, and this has resulted in forests being made to serve non-forest functions, such as housing, plantations and industrial activities. Tropical secondary forests are continuously increasing due to the increase in anthropogenic pressure along with the population migration to urban centres (Ngo *et al.*, 2013).

Malaysia is not the only nation confronted with secondary forest formation issues, as other countries within the ASEAN region are facing similar issues. One such country is Thailand, where the country's primary forests were recently made into secondary forests due to prevalent farming activities practised by various ethnic groups in the country (Podong and Poolsiri, 2013). In addition, the Indonesian tropical forests were extensively logged from the year 2000 through to 2010, which resulted in the formation of 23 million hectares of secondary forests, and they accounted for 80% of the country's yearly emission of greenhouse gases (Rutishauser *et al.*, 2013; Kartawinata *et al.*, 2001). Although secondary forests are

of less concern, it is noteworthy that these forests play a crucial role after most of the primary forests have been changed into secondary forest landscapes.

In 1995, there was a shortage of supply in forest resources in Malaysia, i.e., an insufficient hardwood supply, which could not support the increasing demand for wood products (Ang *et al.*, 2014). Most of the pioneer species within secondary forests are generally classified as less known wood species (LKS), including Mahang (*Macaranga* sp.), Sesenduk (*Endospermum* sp.) and Terap (*Artocarpus* sp.). Although, these woods are available in massive amounts in secondary forests, wood-based industries in Malaysia are reluctant to use these LKS due to their poor properties, such as dimensional instability, inferior mechanical strength, and low durability. Thus, these tree species require some wood modifications, for instance, bulking, internal coating or crosslinking, to upgrade low quality timbers for potential applications (Ang *et al.*, 2014). However, conserving secondary forests is a major task since the decline in primary forests contributes high concentrations of CO₂ into the atmosphere, which leads to climate change and global warming (Lasco and Cardinoza, 2006). In Article 1 of the United Nations Framework Convention on Climate Change (FCCC), climate change is defined as a change of climate that is attributed directly or indirectly to human activity which alters the composition of the global atmosphere and which is in addition to the natural climate variability observed over comparable time periods (United Nations, 1992). Climate change also reportedly results in the disappearance or reversal of the putative terrestrial carbon sink by approximately 1.6 Pg per year, which is equal to 1.6×10^9 tonnes (White *et al.*, 1999).

In recent years, tropical forests have been under threat due to the massive impact of human activities, such as illegal logging, deforestation, and farming. In the year 2000 alone, approximately 10% of Malaysian land was covered by palm trees, and the west coast of Peninsular Malaysia was mostly planted with these trees due to its soil fertility and productive areas (Henson, 2005). An equal increase of the population in towns and cities also caused high land area demands for urban development. In 2009, the world's forest cover was at 4 billion hectares, but this number soon dwindled as a result of deforestation and forest degradation (Fonseca *et*

al., 2011). Food and Agriculture Organisation of the United Nations (FAO) defines forest degradation as the reduction of a forest capacity to provide goods and services (FAO, 2011). Forest degradation has many and varied perceptions, depending on the driver of degradation and the goods or most interested services. For example, a manager who replaces a natural forest with a plantation to supply desired wood products is unlikely to perceive his forest as degraded. On the other hand, his plantation is capable of providing many goods and services that a fully functioning natural forest would provide on the same site, partly because of the reduced biodiversity that is generally associated with a plantation, which would otherwise constitute a degraded site. Meanwhile, deforestation is defined as the conversion of forest to other land use or the long-term reduction of the tree canopy cover below the minimum 10% threshold (FAO, 2010). Moreover, deforestation implies long-term or permanent forest cover loss and transformation into another land use. Such a loss can only be caused and maintained by a continued human-induced or natural perturbation.

Changes in land use may also have an impact on carbon cycling through the emission of CO₂ as a major greenhouse gas. Tropical deforestation accounted for almost 12% of anthropogenic CO₂ emissions in 2008 and keeps increasing every year (Morton *et al.*, 2011). Approximately 1.8 gigatons of carbon were released into the atmosphere, which resulted from deforestation. However, only 1.1 to 1.8 gigatons of carbon can be sequestered in 50 years (Heng and Tsai, 1999).

A similar scenario was observed in tropical countries, including Malaysia, in which the total annual deforestation rate between 2005 and 2010 was at 0.41% (Aisyah *et al.*, 2015). Large amounts of green areas were made to serve non-forest functions, which resulted in an increase of carbon accumulation in the atmosphere. Carbon is retained in different natural stocks available in the environment. Natural stocks refer to oceans, fossil fuel deposits, terrestrial systems and the atmosphere. As mentioned earlier, a tree is one of the carbon stocks for the terrestrial system; it sequesters carbon from the atmosphere during photosynthesis (Suryawanshi *et al.*, 2014). Moreover, from a resource management perspective, sequestering carbon in trees is viewed as relatively safer, environmentally more acceptable, aesthetically

more appealing, and in many cases, more cost-effective in reducing additional atmospheric CO₂ (Merry *et al.*, 2013). Moreover, secondary forests play a crucial role as contributors in carbon stocking by replacing the primary forests. According to Poorter *et al.* (2016), newly grown rainforest, which refers to secondary forest, can absorb 11 times as much carbon from the atmosphere as older forests. From their study in the Neotropics, it was proven that secondary forests play an important role in sequestering carbon. Therefore, it is important to estimate the amount of carbon stock which remains inside the secondary forest, including those located in the Universiti Teknologi Malaysia (UTM).

Although trees are well known for mitigating the amount of carbon in the atmosphere during photosynthesis, there is a continued increase in deforestation activities. In many cases, deforestation has altered the primary forests into secondary forests, and these forests are mostly located in urban areas, especially in developing countries. From 1990 to 2005, the forest cover in Malaysia reportedly was decreasing by 1,486,000 ha annually and was predicted to result in 6.64% of the total Malaysian forest area (Amlin *et al.*, 2014). Primary rainforest in Kalimantan, Indonesia also faced a similar issue, where the primary forest was lost through exploitation, large scale fires and conversion into agricultural use. Forests naturally encounter challenges, but on relatively small scales, such as tree fall because of diseases associated with trees. In summary, forests in developing countries, including Malaysia, are facing large scale disturbances which are mostly from human interventions for large scale developments (Verburg *et al.*, 2001).

Generally, forest gap formation is due to human disruption that stimulates the growth of secondary forest species: the bigger the gap, the greater the amount of solar radiation reaching the forest floor. This process initiates the seeds of pioneer species to grow since they are tolerant of high temperatures and poor nutrient conditions (Swaine and Whitmore, 1988). On the other hand, their seeds are shade intolerant, so they require direct access to sunlight to germinate, and once they establish themselves in the secondary areas, they will partially fill the forest gaps and create a forest canopy (Schnitzer *et al.*, 1991). Secondary forests are also relatively higher in relation to the photosynthesis rate since much nitrogen accumulates after

forests are damaged (Okuda *et al.*, 2003; Kenzo *et al.*, 2010). Moreover, pioneer species in secondary forests contain higher photosynthetic pigments; therefore, the photosynthesis rate is much higher than in primary forests (Silvestrini *et al.*, 2007).

After primary forests are disturbed, they enter a new phase of regeneration. Secondary forests, which replace primary forests, consist of pioneer species that fill forest gaps. This regeneration is important because it determines the future tropical forest structure, dynamics and composition (Brokaw *et al.*, 1987). Moreover, the heterogeneity of a forest depends on gap dynamics in tropical forests especially in relation to light quality and intensity (Silvestrini *et al.*, 2007).

The increase in the amount of carbon dioxide from 280 ppm to 387 ppm in the atmosphere after the Industrial Revolution in 1760 had a crucial impact on the equilibrium of natural greenhouse gases (Hemati *et al.*, 2014). This situation became worse after researchers revealed that the higher amount of carbon dioxide had contributed to the increase in the global temperature (Heimann and Reichstein, 2008). Then, carbon dioxide was classified as a primary greenhouse gas, which was mostly emitted from human activities. The concentration of carbon dioxide kept increasing after anthropogenic activities degraded the forest areas for urbanisation and development purposes. Initially, Global Forest Resource Assessment (FRA), the United Nation Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol of 1997 concentrated only on climate change issues. It was only after they started to notice the amount of carbon dioxide having a severe impact on global temperature that they decided to reveal the changes observed in the carbon pool.

The urban temperature is slightly higher than the temperature in rural areas. This phenomenon is called the urban heat island (UHI) effect and was first discovered in 1818 by the meteorologist Luke Howard (Bristow *et al.*, 2010). Since early 1818, the global temperature started to increase due to the Industrial Revolution and deforestation, which influenced the temperature in urban areas. Carbon emissions increased in the atmosphere, and at the same time, humans were removing forests as the carbon pool, which resulted in a warmer environment in urban areas. Therefore, increasing the secondary forest landscape protects the Earth

by controlling local temperatures, especially in urban areas, where it can reduce the UHI effect.

Wang (2013) stated that urbanisation, economic development and growth lead to land use and land cover change (LULCC). This LULCC increases tree mortality, which affects terrestrial carbon sinks and sources (Ren *et al.*, 2012). As mentioned before, trees play a crucial role in reducing the amount of carbon in the atmosphere without any cost by means of their daily natural process, that is, photosynthesis.

1.2 Research Background

Global carbon emissions of carbon dioxide had increased by 18% and had reached the highest level since 1750 (Chavan and Ganesh, 2012). Attempts by certain quarters to exploit lands to the advantage of human use have largely affected the environment, natural phenomena, and ecological processes, including soil condition and carbon sequestration (Cheng *et al.*, 2007). As shown in Table 1.1, a study by Malaysia National Communication in the UNFCCC showed that Land Use, Land Use Change and Forestry (LULUCF) was the second largest sector that contributed to the emission of greenhouse gases for the year 2000.

Table 1.1: Greenhouses gases inventory in Malaysia for the year of 2000

| Sector | Emissions (Mt CO ₂ eq) |
|----------------------|-----------------------------------|
| Energy | 147.00 |
| Industrial Processes | 14.13 |
| Agriculture | 5.91 |
| LULUCF | 29.59 |
| Waste | 26.36 |
| Total | 222.99 |

Source: Malaysia National Communication to the UNFCCC (2000)

Sequestration is defined as the net removal of carbon dioxide from the atmosphere into long-lived carbon pools (Chavan and Ganesh, 2012). According to

IPCC (2000), carbon sequestration is defined as an increase in carbon stocks in any non-atmospheric reservoir. Carbon sequestration by trees from the atmosphere is a function of land use, time for growing, and technological progress (Baral and Guha, 2004). Trees help to reduce carbon emissions in two ways. One is direct carbon sequestration by reforestation and afforestation that yields a stock of carbon in standing trees. The second way is by using forest products as substitutes for fossil fuels or fossil fuel intensive goods, such as steel and concrete. Carbon sequestration through forestry has the potential to play a significant role in improving environmental problems on a global scale, such as the atmospheric accumulation of greenhouse gases and climate change (Moura-costa, 1996; Kridiborworn *et al.*, 2012). Forest ecosystems contribute approximately half of global net primary production (NPP). Therefore, they have a great influence on the terrestrial ecosystem's ability to accumulate carbon (Pregitzer *et al.*, 2008). NPP is defined as the balance between the light energy fixed through photosynthesis (gross primary production) and the portion lost through respiration and mortality, which results in net carbon sequestration from the atmosphere by vegetation or trees (Zhao *et al.*, 2010).

In recent years, the carbon cycle was out of a state of equilibrium as a result of two classes of major perturbations. According to Grace *et al.* (2014), the two classes of major perturbations, which were perpetrated by the rich countries of the world, are fossil fuel burning and the removal of forests in tropical countries. Therefore, alteration of primary forests into secondary forests will change the carbon cycle in an ecosystem. Currently, secondary forests have emerged close to human territory and act as a carbon reservoir instead of primary forests. Moreover, pioneer species grow naturally, are fast-growing and require a lower cost compared to street trees, which are cultivated. In Malaysia, these forests are widely available or located in both new towns and on institutional campuses. Therefore, it is significant to estimate the carbon stock in institutional campuses since there are more than 20 public universities in Malaysia.

Further, estimating carbon, particularly estimating the changes in different carbon pools, is highly relevant for the international conventions and processes

related to climate change. The international conventions, such as the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol, are interested in empirical reports that may assist them in estimating carbon stock and stock changes in tree biomass, including above ground biomass (AGB) and below-ground biomass (BGB).

In managing carbon dioxide emissions, a few organisations were formed at both local and international levels. This was evidenced from the development of the Kyoto Protocol in 1997 for the international level and Local Agendas for the local level. This committee is responsible for overseeing the carbon dioxide emissions and ensuring the non-excessive volume of this gas. The Kyoto Protocol is one of the important agreements that aim to reduce anthropogenic greenhouse gases; it was prepared by the United Nations in the Framework of Convention on Climate Change which specifies the Clean Development Mechanism (CDM). Malaysia has also been part of this agreement since 1997. The Kyoto Protocol was adopted to achieve a greater reduction in greenhouse gases in the post-2000 period. Countries participating in this protocol have a legally binding commitment to reducing six greenhouse gases between 2008 and 2012 to at least 5%, based on the 1990s levels. As spelt out in Article 3.3 of the Kyoto Protocol, carbon credits may be claimed for any net increase in the carbon stock by means of direct human-induced activities arising from LULUCF (Beets *et al.*, 2011). Consequently, monitoring carbon stocks is an advantage mainly for developing countries, as it allows them to claim carbon credits.

In order to plan for a low carbon society (LCS) in Malaysia, it is more effective to examine urban areas, as they are the engines of economic growth as well as the main contributors of CO₂ emissions (Universiti Teknologi Malaysia *et al.*, 2009). Moreover, the World Bank (2010) stated that cities all around the world that serve as centres of settlements and economic activities are responsible for consuming two-thirds of the world's energy and thus generating an estimated 70% of global carbon emissions. Indeed, in 2012, carbon dioxide emissions in urban and metropolitan areas contributed more than 80% of the volume of standard global

emissions (Chen and Chen, 2012), and the total carbon emissions in urban areas are increasing every year.

Another plan in mitigating climate change is the Local Agenda 21 (LA21). It was implemented in Malaysia after the United Conference on Environment and Development, commonly known as the Earth Summit, which was held in June, 1992, in Rio de Janeiro. During the Earth Summit declaration, it was reported that an increasing amount of global carbon dioxide emissions had led to global warming and climate change (Chavan and Ganesh, 2012). Therefore, LA21 was developed at the Earth Summit as a supportive action after the declaration for a local sustainable development was made.

The Copenhagen Summit in 2009 was another United Nations' Climate Change Conference; it was held at the Bella Centre in Copenhagen, Denmark, between 7 and 18 December. The conference included the 15th Conference of the Parties (COP 15) to the United Nations Framework Convention on Climate Change (UNFCCC) and the 5th Meeting of the Parties (MOP 5) to the Kyoto Protocol. According to recent reports on the Copenhagen UNFCCC, held on the 26 December 2009, a report from Asian Developing Bank (ADB) revealed that Southeast Asia, of which Malaysia is a part, may suffer from more climate change than observed elsewhere in the world. Southeast Asia emitted over 1 billion metric tons (bt) of carbon dioxide in 2008, i.e., approximately 4% of global energy-related emissions.

In 2004, the Ministry of Natural Resources and Environment (MNRE) was established in Malaysia to address climate change issues (Ministry of Natural Resources and Environment Malaysia, 2000a). Later, in November 2009, the Malaysian cabinet endorsed the Malaysian Policy on Climate Change (Salahudin *et al.*, 2013). These actions reflect a serious commitment by the government with regard to the environment, especially climate preservation. Currently, in the Eleventh Malaysian Plan, two principle outcomes were established. The first is to reduce the intensity of GHGs emissions of GDP by up to 40% compared to the 2005 levels by 2020. This is parallel to the voluntary target announced by the Malaysian Prime Minister at the 15th Conference of the Parties to the UNFCC (Economic Planning

Unit, 2015). The second is to conserve at least 17% of terrestrial and inland water areas, as well as 10% of coastal and marine areas, as protected areas in line with the Aichi Biodiversity Targets. Therefore, it is now quite clear that mitigating the effect of greenhouse gases is an important task, considering that the issue was discussed in the Eleventh Malaysia Plan for the time period of 2016 through to 2020.

Other tasks that were carried out by MNRE in 2010 included a program to plant 26 million trees, which is equal to one tree per Malaysian by the year 2015. In addition, the Malaysian government allocated funds under NRE to establish the replanting project, that is, the National Tree Planting Program, along the coastal areas of Peninsular Malaysia, Sabah and Sarawak (Ibrahim *et al.*, 2007). Therefore, this effort by NRE shows the importance of trees in reducing carbon and avoiding climate change. The ability to estimate forest carbon stocks is essential and can be achieved by means of Reducing Emissions from Deforestation and Forest Degradation (REDD+) mechanisms developed under UNFCCC to establish reliable National Reference Emission Levels (NREL) and to estimate carbon stock changes (Rutishauser *et al.*, 2013). Furthermore, REDD+ seeks to reward actors for keeping or restoring forests as a means of reducing carbon emissions (Karsenty *et al.*, 2014).

Many actions have been considered in reducing carbon and simultaneously reducing climate change, which affects humans and the environment. Reducing the amount of carbon is the most important task, as it may help in making the environment stable, that is, no annual increase in temperature, even of 0.1°C. Therefore, conserving forests at the local level can make a contribution to reducing carbon.

1.3 Research Problem

The average surface air temperature was globally reported to have increased by 0.5°C in the 20th century, and it is expected to increase further by 1.5°C to 4.5°C by 2100 (Kanniah *et al.*, 2014). In 2015, the Paris Climate Conference (COP21)

aimed to achieve a legal binding and universal agreement on climate to keep global warming below 2°C (United Nations Framework Convention on Climate Change 2015). In a similar vein, IPCC predicts that anthropogenic emissions of greenhouse gases will raise the global mean surface temperature from 1.4°C to 5.8°C over the next century (Pala *et al.*, 2013). Carbon sequestration in forests can be affected by changes in surface temperature, which has increased by 0.8°C in the last 100 years, and is now reportedly increasing at a rate of 0.2°C per decade (Dai *et al.*, 2014a).

In recent years, tropical rainforests have been transformed into secondary forests due to conversion of land from serving its original forest functions into non-forest functions, such as residential, plantation, and industrial purposes. Tropical forest stores large amounts of carbon; indeed, approximately 40% to 50% of carbon is retained in terrestrial biomass (Martin and Thomas, 2011). An acre of tropical forest is capable of removing approximately 100 tons of carbon dioxide from the atmosphere (Webb, 1998). This clearly indicates that trees play an important role in sequestering carbon. On a global scale, the secondary forest landscape constitutes approximately 40% of forest cover (Brown and Lugo, 1990). In 1986, observations indicated that secondary forests of various sizes and phases were found throughout Kuala Lumpur, Malaysia (Ang, 1986). Moreover, most of the housing development projects in the 1970s took place in secondary forestland comprising abandoned rubber and oil palm plantations (Webb, 1998). The conservation and management of secondary forests is crucial since such forests provide valuable resources to the human community, retain significant amounts of biodiversity, and relieve the pressure on primary forests.

For ease of reference, a list of previous studies regarding estimating carbon stocks is presented in Table 1.2; estimating the biomass in tropical forests began as early as the 1980s (Brown and Lugo, 1984). At that time, researchers had already recognised the rise of CO₂ concentration in the atmosphere, and CO₂ is now being released into the atmosphere much faster than at any time in the past 80,000 years (Vashum, 2012). Based on the literature listed in the table, studies in estimating carbon stock have been increasing since 2000. However, the studies have concentrated on estimating the carbon stocks in primary forests at oil palm and

rubber plantations (Terakunpisut *et al.*, 2007; Thenkabail *et al.*, 2004; Petsri *et al.*, 2013). Therefore, this study is considered important, as to the researcher's knowledge, studies exploring forest structure and estimating carbon stocks in secondary forests located within a university campus are scarce. Moreover, secondary forests are recognised for their biodiversity conservation values and as important carbon sinks (Thompson *et al.*, 2012).

Research on commercially valued trees is now of more concern compared to non-commercial trees. Most Dipterocarpaceae species, such as *Shorea*, *Hopea*, and *Dryobalanops* are well studied (Saner *et al.*, 2012; Okuda *et al.*, 2004; Ch *et al.*, 2011; Okuda *et al.*, 2003). This study aimed to identify the potential of tree species in secondary forests to store carbon from their dendrometric characteristics (trunk diameter and height of the tree) by using a non-destructive methods of measurement to understand the factors that influence the occurrence of vegetation in relation to soil physical and chemical factors, which are described in Chapter 4.

Table 1.2: List of literature study in estimating carbon stock

| Source | Location | Carbon stock estimation site or specific tree |
|-----------------------------------|------------------------|--|
| Lasco <i>et al.</i> (2004) | Philippines | Secondary forest at mountain areas |
| Terakunpisut <i>et al.</i> (2007) | Thailand | Tropical rain forest, dry evergreen forest and mixed deciduous |
| Kenzo <i>et al.</i> (2009) | Sarawak, Malaysia | Tropical secondary forests |
| Eckert <i>et al.</i> (2011) | Madagascar | Two types of degraded forests: low degraded and degraded forest |
| Njomgang <i>et al.</i> (2011) | Cameroon | Six land use types: virgin forest, secondary forest, forest fallow, mixed crop field and old cocoa plantations |
| van Breugel <i>et al.</i> (2011) | Panama canal watershed | Secondary forest |
| Saner <i>et al.</i> (2012) | Sabah, Malaysia | Tropical lowland dipterocarp forest |
| Warren <i>et al.</i> (2012) | Sumatra | Tropical peat soil |
| Dirocco (2012) | Malaysia | Tropical dipterocarp forest |
| Pragasan and Karthick (2013) | India | Eucalyptus plantation and mixed species plantation in Bharathiar University campus at Coimbatore |
| Rathore and Jasrai (2013) | India | Sixty tree species in Gujarat University |
| Orihuela-Belmonte <i>et al.</i> | Mexico | Secondary forest |

| | | |
|----------------------------------|-------------------|--|
| (2013) | | |
| Pala <i>et al.</i> (2013) | India | Reserve and community forest |
| Rutishauser <i>et al.</i> (2013) | Indonesia | Unmanaged dipterocarp forest |
| Ekoungoulou <i>et al.</i> (2014) | Republic of Congo | Secondary forest and Gallery forest of Congo |
| Dai <i>et al.</i> (2014b) | Mexico | Secondary dry forest |

Secondary forests are formed as a result of human activities, especially in developing countries, including Malaysia. It has recently been reported that secondary forests dominate 40% of tropical forest cover (Li *et al.*, 2005). Formerly, primary forests used to be major carbon stock reservoirs compared to secondary forests. However, the capability of storing carbon decelerates after the trees become older because respiration begins to be either equal to or exceed primary production (Baral *et al.*, 2004).

Regenerating secondary forests was reported to have the potential to assimilate and store large quantities of carbon (Kueh *et al.*, 2014); this information helped to quantify their role in carbon storage and sequestration. However, there was lack of information on biomass accumulation by the secondary species that dominate early successional processes, especially in tropical Asia. To date, very few studies (Chokkalingam and Jong, 2001) have been carried out on tree species in secondary forests to determine their potential in carbon stocking, especially within the secondary forests located on institutional campus grounds.

UTM, one of the institutional campuses located within urban areas to have secondary forests, was selected to identify the secondary forest structure, measure its AGB and BGB and carbon stock, and finally, to identify the relationship between the soil and the tree community. The secondary forest in UTM emerged after the abandonment of rubber and oil palm plantations, development and unmanaged green areas, which in combination contributed towards creating a suitable environment for tree species to grow. The abandoned area, which consists of pioneer species, is well adapted with direct access to sunlight and without any forest cover.

1.4 Research Aim

The aim of this research is to identify the secondary forest composition in an institutional campus. The next step is to estimate the amount of carbon stock in UTM secondary forest tree species from AGB and BGB, and soil organic carbon. The final step is to identify tree distribution according to the soil physical and chemical properties at UTM secondary forest.

1.5 Research Objectives

The present research aimed to achieve the following three research objectives:

- 1) to determine tree community structure of UTM secondary forest
- 2) to estimate the amount of tree carbon stock and soil organic carbon of UTM secondary forest
- 3) to identify tree distribution based on soil physical and chemical properties between tree communities

1.6 Research Questions

In relation to the abovementioned research objectives, the aim is to answer the following four research questions:

- 1) How many secondary forest species have emerged in UTM secondary forest?
- 2) How much AGB and BGB is stored in UTM secondary forest?
- 3) How much is carbon stock is accumulated from UTM secondary forest tree species?
- 4) What is the relationship between tree distribution and soil physical and chemical properties based on CCA analysis?

1.7 Scope of the Study

The focus of this study is to identify forest structure and to estimate carbon stock in AGB and BGB, which includes soils and roots in UTM secondary forest. All trees in the established plot were measured. This study also examined tree distribution based on soil physical and chemical properties. Moreover, this study determined the relationship between tree communities and soil variables by using a multivariate analysis. The tree distribution was mapped using satellite images according to the spectral reflectance from each species. UTM was selected as the study area since it comprised a secondary forest. UTM secondary forest was formed from an abandoned plantation and unmanaged greenery.

1.8 Significance of Study

Secondary forests have replaced areas which were previously dominated by primary forests. Since UTM consists of a large green area, remote sensing should be applied to assist in estimating the carbon stock for the whole green area in UTM. Satellite imagery also helps to map tree distribution in UTM secondary forest. The findings of this study will help UTM management in conserving trees in the secondary forest and trees that were replanted. More importantly, to the researcher's knowledge, the literature is devoid of any studies that explore carbon stock within secondary forests located on campuses of higher educational institutions. Moreover, the findings also revealed the factors that influenced the occurrence of vegetation in relation to the soil factors.

Estimating carbon stock at UTM is an advantage because it gains monetary values, such as carbon credits. In the United Nations Conference on Environment and Development (UNCED) in Rio in 1992, forest management in developing countries attracted much attention, while carbon stock management in forests among developing countries received similar attention during the Kyoto Protocol in 1997. The Kyoto Protocol also started with the idea of carbon credits where it was stated under Article 12 of the CDM (Kim Phat *et al.*, 2004). Carbon credits is a proposed

solution to tropical forest degradation (Dirocco, 2012). A credit is a measure representing one megaton, a mass equal to 1000 kg of carbon dioxide. Later, in 2005, REDD) also recommended similar actions to slow down the deforestation rates and help safeguard threatened forest species, as these actions may enhance the opportunities for providing substantial economic benefits for developing countries (Laurance, 2007).

In 2010, at the COP15, as set out in the Cancun Agreement, REDD was made into REDD+ to reflect the addition of a new component. REDD+ is used as a broad term that encompasses a range of forest conservation and reforestation options and financing mechanisms which are being negotiated at both global and national levels to reduce deforestation and forest degradation (Evans *et al.*, 2014). Furthermore, it also enhances forest carbon stocks to mitigate climate change. REDD+ is a policy that was developed under UNFCCC. During the REDD phase, UNFCCC provided financial incentives for developing countries that voluntarily reduced national deforestation rates and associated carbon emissions below the reference level (Venter *et al.*, 2009). Current market value for carbon in a hectare of rainforest, if kept, could be worth approximately USD 400 to USD 8000 or more (Laurance, 2007). This value is considered higher compared to the costs involved in conserving the forest.

The price of carbon credits differs and may range from as low as USD 3.00 a tonne CO₂ equivalent (eq) to a high in excess of USD 40.00 a tonne. However, carbon prices for forestry-based activities range from USD 2.90 to USD 7.30 while the conservative price of USD 5.00 (RM 16) a tonne is usually assumed (Ministry of Natural Resources and Environment Malaysia, 2000b). Nevertheless, replanting a forest or plantation may cost RM 5000 per hectare, and may incur an additional cost of RM 150 per ha for maintenance (Ministry of Natural Resources and Environment Malaysia, 2000b). Therefore, to obtain a higher income in relation to carbon credits, these costs should be reduced. Considering this situation, secondary forest is potentially significant to contribute towards a good income in carbon credits. Meanwhile, secondary forest continues to exist naturally without any maintenance costs.

1.9 Structure of the Thesis

The thesis is divided into eight chapters. Chapter 1 introduces the research background, research problem, research gap, research aim, research objectives, research question, scope of study, and the study's significance. A comprehensive review of relevant and applicable literature is provided in Chapter 2. Next, Chapter 3 presents the general methodology and background of the study area, which includes the climate. Chapter 4 includes a discussion on the physical environment of UTM secondary forest, including soil physical and chemical properties. This is followed by Chapter 5, in which the floristic composition and diversity of trees from 200 established plots are described and compared with other previously similar or different studied habitats. Chapter 6 discusses the forest structure, biomass, and carbon stock of UTM secondary forest while Chapter 7 emphasises the tree distribution according to a supervised classification based on the spectral reflectant of each tree species and soil properties of the forest. This chapter also highlights the relationship between tree communities and soil variables by using a multivariate analysis. Finally, Chapter 8 provides the conclusion, implication and limitation of the study, including recommendations.

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