CARBON STORAGE IN FOREST ECOSYSTEMS OF POPA MOUNTAIN PARK, MYANMAR

HELEN

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THESIS: CARBON STORAGE IN FOREST ECOSYSTEMS OF POPA MOUNTAIN PARK, MYANMAR

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ABSTRACT

Forest ecosystems are sources of carbon that are stored in their biomasses. The carbon storage of forest biomass, as well as soil, were evaluated in one of the protected area systems, called Popa Mountain Park, which is the only extinct volcano located in the central dry zone of Myanmar. The study was conducted in four forests ecosystems: dry hill evergreen forest, dry mixed deciduous forest, deciduous dipterocarp forest and dry forest found in the study area.

Stratified random sampling was conducted with 6 sample plots of 30×30 m^2 in each forest ecosystem, in total 24 sample plots. Vegetation sampling was performed within 9 sub-plots of 10×10 m^2 for diameter at breast height (dbh) ≥ 4.5 cm of all trees. In 5×5 m^2, dbh < 4.5 cm with height ≥ 1.3 m, saplings and shrubs were collected. Litter, undergrowth and grass, were collected within 1×1 m^2 plots. Soil samples were randomly collected at three points in three sub-plots of 10×10 m^2 at two layers: 0-15 cm and 15-30 cm, a total of 144 samples. For carbon content estimation of forest vegetation, allometric equations, developed from tree dbh and height, were used.

The largest carbon content in forest biomass was found in dry hill evergreen forest with 59.57 ton/ha followed by dry mixed deciduous forest with 35.68 ton/ha, deciduous dipterocarp forest with 26.98 ton/ha and dry forest with 17.70 ton/ha, respectively. All mean values of soil organic carbon (SOC %) showed higher in soil depth of 0 - 15 cm above 15 - 30 cm. The total soil carbon storage of 0 - 30 cm contained 215.34 ton/ha in dry hill evergreen forest, 76.28 ton/ha in dry mixed deciduous forest, 56.31 ton/ha in deciduous dipterocarp forest and 36.12 ton/ha in dry forest, respectively. The research assessed soil organic carbon storage as being nearly two times more than the forest's carbon storage. The study found the current total carbon storage is 740,473.30 ton above-ground and below-ground of focused forest ecosystems. The research suggested the carbon storage status in different forest ecosystems of the protected forest area, which would be useful data for guiding policy making and forest conservation planning at both national and international levels.

KEY WORDS: CARBON STORAGE/ POPA MOUNTAIN PARK/ MYANMAR/ ALLOMETRIC EQUATION

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LIST OF ABBREVIATIONS

Abbreviation	
GHGs	Greenhouse Gases
ppm	Part Per Million
IPCC	Intergovernmental Panel on Climate Change
UNFCCC	United Nations Framework Convention on Climate Change
AMUNC	Asia Pacific Model United Nations Conference
MOF	Ministry of Forestry
DZGD	Dry Zone Greening Department
UNEP	United Nations Environment Program
REDD	Reduce Emissions from Deforestation and Forest Degradation
IUCN	International Union for Conservation of Nature
FORDA	Forest Research and Development Agency
JICA	Japan International Cooperation Agency
PFE	Permanent Forest Estate
WDPA	World Data Base on Protected Areas
RF	Reserved Forest
PPF	Protected Public Forest
NCNPP	Nature Conservation and National Park Project
NWCD	Nature and Wildlife Conservation Division
dbh	Diameter at Breast Height

CHAPTER I
INTRODUCTION

1.1 Background and justification

Global warming and Climate change have become the crucial environmental challenges of the 21st century that threaten to human society, politics, economics, ecosystems and natural resources at both national and international levels. Climate change effects such as increased temperatures, rise of sea level, melting of glaciers as well as changes in precipitation and in the frequency of extreme climatic events are just some of the changes occurring (IPCC, 2007b). Global warming is caused by accumulation of greenhouse gases (GHGs) in the atmosphere that trap the thermal radiation and prevent reflection of radiation into the space, causing warming to the earth. Generally, GHGs include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFCs), tropospheric ozone (O_3), and stratospheric water vapor (H_2O) (Ledley et al., 1999). Among them, CO_2 is the most significant GHGs results from anthropogenic activities that cause climate change and global warming.

Before industrial revolution, scientists believed that the production and sequestration of carbon by the earth was in balance. But, since the time of industrial revolution, the accumulation of CO_2 in the atmosphere was increasing with an accelerating rate decade by decade. Atmospheric carbon dioxide (CO_2) concentrations increased to 379 ppm in 2005 relative to pre-industrial levels of 280 ppm. Increasing of CO_2 level has mainly been caused by emissions from the burning of fossil fuels such as coal, gasoline, and petroleum, accounting for about 80% of human-caused emissions. Land disturbance processes such as burning, loss and degradation of forests, rangeland and soils, etc., account for the remaining 20% (IPCC, 2007a). Deforestation and forest degradation alone release 1.6 billion tons of carbon to the atmosphere each year (IPCC, 2007c). Unless there are any actions to mitigate the accumulation of GHGs in the atmosphere, these increases might pose a serious threat to ecological and socio-economic systems (Karl et al., 1997) and the global climate change is expected to accelerate in the future. The IPCC presented the climate change projections based on the new IPCC emissions scenarios is that global mean surface temperature is projected to increase by 1.4°C to 5.8°C between 1990 and 2100 which is a much more rapid rate of warming than during the 20th century (Ruosteenoja et al., 2003).

The mitigation measures are urgently needed to offset GHGs emissions into the atmosphere. The international communities have been concerned about global climate change and considered the strategies how to tackle. As a result, the United Nations Framework Convention on Climate Change (UNFCCC) was created in 1992 for providing a framework for policy making to mitigate climate change. The ultimate aim of the UNFCCC is to stabilize the atmospheric GHGs at a sufficiently low level to prevent dangerous anthropogenic influence on the climate. In 1997, the Kyoto Protocol was formed as a keystone document in international climate change policy (AMUNC, 2009). The negotiations on the Kyoto Protocol to UNFCCC had set the targets to reduce the emissions of six GHGs: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6) to 7% below 1990 levels during a commitment period between 2008- 2012 (Fletcher, 2004). Myanmar also ratified Kyoto Protocol in 2003 as one of the Non-Annex I Parties. According to Kyoto Protocol, it allows any activity for the removals of GHGs. It includes some activities in the land-use change and forestry sector such as establishing and financing of afforestation and reforestation projects in the developing countries to assist industrialized countries for their emission reduction targets (Oo, 2011). The enhanced GHGs effects can be mitigated either by increasing terrestrial carbon sinks or by reducing the carbon sources. Establishing of forest plantations and maintaining of existing natural forested areas could be provided an energy conscious world with a clean, efficient means of absorbing some of excess in atmospheric CO_2 (Razakamanarivo, 2011).

Therefore, forests are carbon pools that store more carbon than any other terrestrial ecosystems and are an important natural “brake” on climate change. Forest biomasses are organic materials that store carbon both in aboveground and belowground biomass, litter, dead wood and soil organic matter. When the forests are cleared or degraded, the stored carbon is released into the atmosphere as CO_2. It was stated that the largest source of GHGs emissions in most tropical countries is due to deforestation and forest degradation. Clearing of tropical forests destroy globally important carbon sinks which are currently sequestering CO_2 from the atmosphere and are critical to future climate stabilization. It is estimated that tropical deforestation released 1 - 2 billion tons of carbon per year during 1990s, roughly 15 - 25% of annual global GHGs emissions (Malhi and Grace, 2000; Fearnside and Laurance, 2003, 2004; Houghton, 2005). Thus, conservation measures of existing carbon sinks are necessary both at national and international levels.

In Myanmar, Myanmar Forest Policy 1995 has been formalized the commitment and intent of the Government to ensure sustainable development of the forest resources while conserving wildlife, plants and ecosystems. The forest policy also aims at a balanced and complimentary land use, designating 30% of the total land area as reserved forests and 5 - 10% as protected area systems (MOF, 1995). In order to estimate the carbon content stored in forest ecosystems, the biomass content of aboveground and belowground are necessary for considering total carbon content stored in forest ecosystems. Biomass density of each area in forests can widely varies in accord with climate, elevation, soil type, age, and forest utilization (Birdsey and Heath, 1995).

In the research, estimation of carbon storage in forest ecosystems was approach to one of the protected areas in Myanmar called Popa Mountain Park, which is situated in the central dry zone of Myanmar. This area is selected as the study area as it possesses diverse forest ecosystems where most of forests have already disappeared in the dry zone area. It can be also said as the victory landmark area in forest restoration program from Myanmar Forest Department. To find the carbon content in each forest ecosystem of Popa Mountain Park, it is required to evaluate not only in forest biomass but also in soil carbon content, for achieving useful database on carbon content, in the protected forest area of Myanmar. These would be led to implementation of beneficial database in designing framework of national policy for sustainable forest management as well as forest carbon storage management.

1.1 Statement of Problems

Climate change and global warming have caused lots of damages to socio-economic of every country and become a serious threat to survival of biological organisms around the world. For Southeast Asia countries, an increasing trend of mean surface air temperature during 1951 - 2000 is increased with 0.1 - 0.3°C (IPCC, 2007a). Furthermore, rainfall has been reduced, sea levels up at the rate of 1- 3 mm per year, and the frequency of other extreme weather events has increased like massive flooding, landslides and droughts in many parts of the regions causing extensive damage to properties, assets and human lives (MOF, 2010).

Although Myanmar has not encountered serious environmental problems in the past time, the consequences of climate change have become noticeable recently and the risk is likely to be aggravated. Some examples of natural disaster faced in Myanmar are cyclone Nargis that hit in Irrawaddy delta region on May 2008 and cyclone Giri that made landfall in Rakhine State on October 2010 as well as other events like floods and landslides in Rakhine State, Kachin State and Mandalay Division which are the consequences of climate change. According to climate change impacts, it was significantly changed rainfall pattern and rainfall intensity in some parts of the country. Consequently, lesser inflows into the reservoirs resulting in irrigation water shortage problems particularly in dry season (MOF, 2010).

The dry zone of central Myanmar is one of the environmental problematic regions in terms of degradation of land resources because of continued deforestation and its extreme climatic conditions. The total area of that region is about 8.72 million ha covering 13 districts in Magway, Mandalay and Sagaing Dividions. Most of the lands in the dry zone area have been degraded long time ago due to repeated cutting of trees for fuel-wood, incorrect cultivation practices, overgrazing and extreme climatic conditions. The dry zone area is a difficult environment for farmers and rural households to survive. Monthly temperature range from a minimum of about 10°C in winter and 43°C in summer. The area is semi-arid and in some locations, even arid with low annual rainfall, the rainfall pattern is highly variable throughout the season and unevenly distributed. It only receives 3.2 % of the country's total rainfall with the average annual rainfall of about 711 mm. These deteriorations lead to the occurrence of some patches of desert-like formation although there is no desert in the dry zone area. It is reported the first worst drought that hit the area was occurred during 1979 - 1980, the second worst drought that hit lower Sagaing and Mandalay took place during 1982-1983, and the third worst drought hit the whole area of the central dry zone during 1993 and 1994 (DZGD, 2007). It can be concluded these are the consequences of unsustainable uses of natural forests that cause the extreme climatic conditions threatening the social-economic of local people and its environment.

Under such conditions, establishment of protected areas play a significant role, for maintaining ecological balances as well as the restoration of carbon stocks, on not only for dry lands but also for national and international levels helping to combat climate change and global warming effects. There might be many approaches to evaluate carbon storage in protected forest areas. The current study was conducted in one of the protected areas of Myanmar called Popa Mountain Park for the estimation of carbon storage in each forest ecosystems. It was included the carbon estimation of aboveground (stems, branches, leaves, litter, undergrowth, grass) and belowground (root and soil organic carbon) of each forest ecosystem of the study area.

1.3 Objectives of the study

The study was intended to meet the following relative objectives:

1. To identify plant community characteristics and soil properties in forest ecosystems of Popa Mountain Park.
2. To estimate the carbon storage of forest biomass and soil organic carbon in forest ecosystems of Popa Mountain Park.
3. To compare carbon storage in forest ecosystems of Popa Mountain Park.

1.4 Key research questions

To reach the objectives, the following questions were required to answer:

1. What are the plant community characteristics and soil properties in forest ecosystems of Popa Mountain Park?
2. What amount of carbon is stored in forest ecosystems of Popa Mountain Park?
3. What are the differences of carbon storage in forest ecosystems of Popa Mountain Park?

1.5 Scope of the research

The research was intended to focus one of the protected areas in Myanmar in order to identify carbon storage capacity in forest ecosystems of Popa Mountain Park. The carbon storage in forest ecosystems included aboveground carbon (stems, branches, leaves, litter, undergrowth, grass) and belowground carbon (root and soil carbon) content. Carbon for aboveground and belowground forest biomasses were calculated by using allometric equations. By means of multiplying with the carbon conversion factor 0.5, the dry biomass was converted into carbon content in the forest ecosystems of the study area. For soil organic carbon, it was analyzed in the laboratory.

1.6 Scope of the research area

The research area is located in the central dry zone which is the only prominent extinct volcano in Myanmar with the area of 100 km^2. Its elevation ranges from 300 to 1,500 m above the sea level. It is famous for high plant diversity including shrubs, herbs and medicinal plants. As the vegetation types, grassland, pine plantation and Dry hill evergreen forest occur above 1,000m. Dry mixed deciduous forest is dominant vegetation type below 1,100m. Than-dahat dry forest is found below 450m. Scrub indaing forest or dipterocarp forest is observed between 400 and 700m. Eucalyptus and xylia plantation are found between about 750 and 900m. Shrub/bush vegetation consists of shrubs, regeneration, isolated trees and bare-land. All forests in the study area are second or third growth after cutting and clearing for agriculture in the early 20th century. The pine, eucalyptus and xylia plantations were established during the period 1955–1972 (Htun et al., 2011). According to the forest type classification, dry hill evergreen forest, dry mixed deciduous forest, than-dahat dry forest and scrub indaing dipterocarp forest are seen to be major forest vegetation types while others such as pine, eucalyptus, xylia plantations, grasslands and shrub/bush vegetation are seen to be minor forest types.

1.7 Conceptual framework of the study

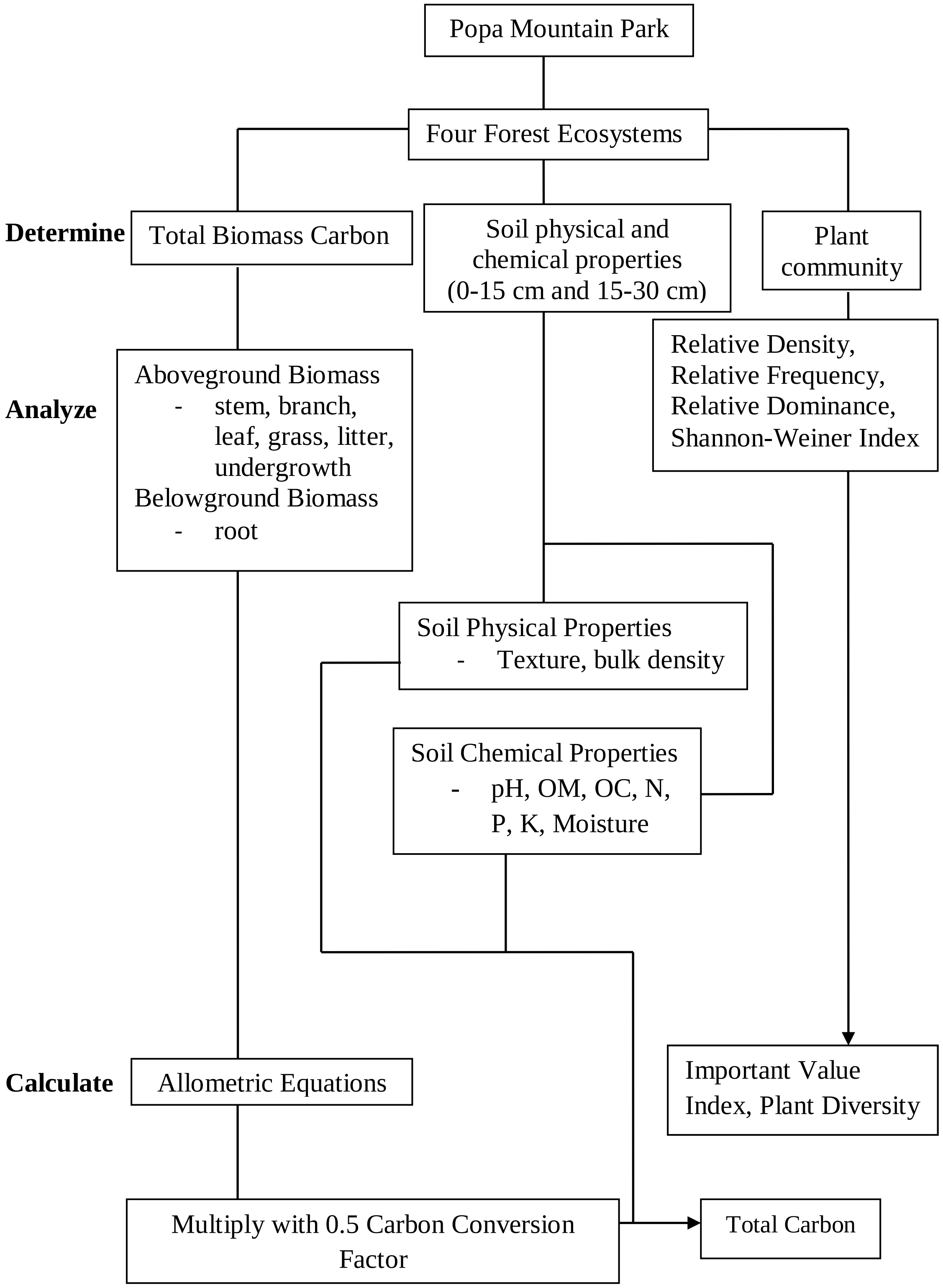


Fig. 1.1 Conceptual framework of the study

1.8 Expected outcomes of the study

After the completion of the study, the current carbon storage status in forest ecosystems of the study area could be estimated. It could be also compared the different capacity of carbon stored in different forest ecosystems of Popa Mountain Park. Furthermore, forest plant community characteristics as well as soil properties of each forest ecosystem could be observed. The study would be provided as a database for future studies in estimating carbon storage of other protected forest areas. This could also be led for the enhancement of forest restoration program towards sustainable forest management in Myanmar.

CHAPTER II
LITERATURE REVIEW

2.1 Climate change and the global warming potential

Climate change refers to a change in the state of the ultimate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcing or to persistent anthropogenic changes in the composition of the atmosphere or in land use (IPCC, 2007a).

Climate change is not a new phenomenon in the Earth's history. The earth's climate is always changing through the series of warming and cooling cycles. The recent anthropogenic influences have led to dramatic changes within this system. As a result, the earth has entered into a warming cycle of unprecedented speed and it is difficult to predict precisely for the time of entering to cooling cycle (Gray, 2002). Climate change has been occurred every 100,000 year since over thousands of years ago (Timothy et al., 2004). But past climate changes are natural in origin whereas most of the warming of the past 50 years is due to human activities. The largest temperature changes during the ice age and warm interglacial periods has caused global mean temperature rising up from 4°C to 7°C but the process was taking about 5,000 years. Compare to current rate of climate change, it is clear that the current rate is more rapid and very unusual relative to past changes. The present events such as increase in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level prove that the global climate system is unequivocal (Oo, 2011).

2.1.1 Causes of climate change

Climate change is occurred naturally as a result of a change in the sun's energy or Earth's orbital cycle, i.e., natural climate forcing, or it can be occurred as a result of persistent anthropogenic forcing by the addition of GHGs to the atmosphere. The most significant among the causes of climate change is the increase in the atmospheric concentrations of GHGs due to human activities. According to the Third Assessment Report of IPCC, most of the observed warming over the last 50 years is likely to have been due to the increase in GHGs concentrations. The Fourth Assessment Report also concluded that most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic GHGs concentrations. Undesirable human influences now extend to other aspects of climate, including ocean warming, continental-average temperatures, temperature extremes and wind patterns (Oo, 2011).

Among GHGs, CO_2 accounts for 60% of global warming effects while CH_4, N_2O and others (hydrofluorocarbons) account for 20%, 6% and 14% respectively. The fact is that CO_2 emissions are the predominant contributor for global warming (McCarthy et al., 2001). According to the palaeo-atmospheric data from air trapped in ice over hundreds of millennia, the increase in CO_2 concentration is said to be during the Industrial Era (IPCC, 2001). The global atmospheric concentration of carbon dioxide has increased in about 280 ppm from a pre-industrial time to 379 ppm in 2005. The annual carbon dioxide concentration growth rate was larger during the last 10 years (1995–2005 average: 1.9 ppm per year) than it has been since the beginning of continuous direct atmospheric measurements (1960–2005 average: 1.4 ppm per year). The primary source of the increased atmospheric concentration of carbon dioxide since the pre-industrial period results from fossil fuel use, with land-use change providing another significant but smaller contribution. Annual fossil carbon dioxide emissions increased from an average of 23.5 Gt per year in the 1990s to 26.4 Gt per year in 2000–2005. Carbon dioxide emissions associated with land-use change are estimated to be 5.9 Gt per year over the 1990s (Oo, 2011). Some characteristics of major GHGs covered by Kyoto Protocol are summarized in Table 2.1.

Table 2.1 Major GHGs and their Global Warming Potential (GWP)

GHGs	Lifetime (years)	WP	Main emission sources related to human activities
Carbon dioxide (CO_2)	5 - 200	1	Fuel combustion, industrial process
Methane (CH_4)	12	21	Agriculture, landfill, gas leak, fuel combustion
Nitrous oxide (N_2O)	14	310	Fuel combustion, agriculture, industrial process

Source: Oo (2011)

2.1.2 Impacts of climate change

Climate change affects the natural system causing the enlargement and increased numbers of glacial lakes, increase in ground instability in permafrost regions and rock avalanches in mountain regions, changes in some Arctic and Antarctic ecosystems including those in sea-ice biomes and also predators high in the food chain. It also affects the terrestrial biological systems such as earlier timing of spring events like leaf unfolding, bird migration and egg-laying, and pole-ward and upward shifts in ranges in plant and animal species (IPCC, 2007a).

Moreover, climate change impacts on forest ecosystems which has a major influence on rates of photosynthesis and respiration as well as the shorter term processes in forests such as frequency of storms and wildfires, herbivory and species migration. Warming might be increased net primary productivity in temperate and arctic ecosystems because of the increased length of the seasonal and daily growing cycles whereas decreased in net primary productivity in water stressed ecosystems as it increases water loss (Lloyd and Taylor, 1994). The fact is that if the global climate changes, forest ecosystems will change as the physiological tolerances of species may be exceeded and the rates of biophysical forest processes will be altered. Forests are complex with self organizing systems and multiple natural processes that respond to internal and external drivers. If the climate change results in a significant reduction of water availability, the forest system will naturally change in species composition. The vegetation will reach such a condition with insufficiently tall and dense to comprise a forest as well as with the changes in the dominant taxonomic composition of the plant community. Thus, climate change affects forest ecosystems in changing albedo, altering carbon cycle dynamics, energy fluxes and moisture exchange (Thompson et al., 2009). Changes in rainfall patterns might affect plant water availability and the length of the growing season, especially in arid and semi arid regions. Climate change also affect the distribution of plants and the incidence of disturbances such as fire, wind, insect and pathogen attacks which could directly or inversely affect to carbon content of the forest ecosystems. The warmer ocean surface temperature might be increased precipitation. Consequently, the global trend in the tropics might increase net primary productivity but changing precipitation patterns could lead doughtiness that might reduce net primary productivity and increasing fire frequency in the affected regions (IPCC, 2001).

According to IPCC (2007a), the findings on impacts of climate change and vulnerability of forest ecosystems highlighted the following points:

- Populations of threatened species are expected to be at greater risk, i.e., species that are currently classified as critically endangered will become extinct, one third to two third of species will be at risk of extinction and biodiversity will be lost
- Species composition and dominance will be altered resulting in ecosystem changes
- Shifts in forest types of altitude and latitude boundary
- Forest die-back and mortality, i.e., climate will change faster than the capacity of plant to migrate
- Increase and later decrease in biomass productivity

2.1.3 Climate change future projections

By 2100, carbon cycle models projected the atmospheric CO_2 concentration will be 540 to 970 ppm which is 90 to 250% above the concentration of 280 ppm in 1970. It also documented that CO_2 will be reduced by 40 to 70 ppm if all carbon released by historic land use changes to the terrestrial biosphere are restored, e.g., by means of reforestation (Timothy et al., 2004). Pandey (2002) also supported the IPCC projection that the global mean temperature worldwide will increase 1.4°C to 5.8°C by 2100 as a result of growing GHGs in the atmosphere. Besides, fossil fuel CO_2 emissions are also required to remain the dominant control over trends in atmospheric CO_2 concentration during this century (IPCC, 2001). The estimation of confidence in observed and projected changes in extreme weather and climate events are shown in table 2.2.

Table 2.2 Estimation of confidence in observed and projected changes in extreme weather and climate events

Confidence in Observed Changes (later half of the 20th century)	**Changes in Phenomenon**	**Confidence in Projected Changes (during the 21st century)**
Likely	Higher maximum temperatures and more hot days over nearly all land areas	Very likely
Very likely	Higher minimum temperatures, fewer cold days and frost days over nearly all land areas	Very likely
Very likely	Reduce diurnal temperature range over most land areas	Very likely
Likely, Over many areas	Increase of heat index* over land areas	Very likely, Over most areas
Likely, over many Northern Hemisphere mid-to high latitude land areas	More intense precipitation events^	Very likely, Over many areas
Likely, in a few areas	Increased summer continental drying and associated risk of drought	Likely, Over most mid-latitude continental interiors (Lack of consistent projections in other areas)
Not observed in the few analyses available	Increase in tropical cyclone peak wind intensities#	Likely, Over some areas
Insufficient data for assessment	Increase in tropical cyclone mean and peak precipitation intensities#	Lively , Over some areas

Note: *Heat index: A combination of temperature and humidity that measures effects on human comfort

^For other areas, there are either insufficient data of conflicting analyses

#Past and future changes in tropical cyclone location and frequency are uncertain

Source: IPCC (2001)

2.2 Role of forests in global carbon cycle

A highly concern about global climate change has led to interest in reducing emissions of CO_2. In such condition, forests are a significant part of the global carbon cycle. Plants use sunlight to convert CO_2, water and nutrients into sugars and carbohydrates accumulating in leaves, twigs, stems, and roots. They also respire and release CO_2 to the atmosphere. When they eventually die, their stored carbon is released to atmosphere or to the soil where it decomposes slowly and increase soil carbon levels. For herbaceous plants, the aboveground biomass die annually and begins to decompose but for woody plants, some of the aboveground biomass continuous to store carbon until the plant dies and decomposes. In the forest, carbon cycle has to be seen as the net carbon accumulation with the vegetation growth and carbon releasing when they die. Thus, the amount of carbon sequestered in a forest is constantly changing with growth, death and decomposition of vegetation (Gorte, 2009).

The role of soil carbon in forest ecosystem is also important. Generally, the amount of carbon is soil is greater than the amount in living vegetation (Post and Kwon, 1999). Soils are major terrestrial carbon sinks with the estimated mass of 1200-1600×10^9 Mg of carbon (Batjes, 1996; Eswaran et al., 1993; Zech et al., 1997). Soil carbon pool contains in both organic and inorganic forms. Soil organic carbon includes plant, animal and microbial residues in all stages of decomposition (Post and Kwon, 1999). The distribution of the forms strongly depends on climate at a global scale and generally, SOC content increases as increased in precipitation with the highest levels in humid and cold climates (Marks et al., 2009). The concentration of soil organic carbon ranges from a low in soils of the arid regions to high in soils of the temperate regions, and extremely high in organic or peat soils. It also varies widely among eco-regions, i.e., higher in cool and moist than warm and dry regions. It is concluded that the total soil carbon is four times the biotic (e.g., forest trees) pool and about three times the atmospheric pool (Lal, 2004). SOC storage depends on SOC stabilization. The driving process of SOC stabilization can be abiotic, i.e., directly or indirectly depending on temperature and precipitation, or biotic, i.e., productivity and organic matter decomposition and it can also be modified according to management (Trumbore, 1997; Thornley and Cannell, 2001; Schulze, 2006).

There are two factors that have been influenced on the long term net flux of carbon between terrestrial ecosystems and atmosphere, i.e., changes in the area of forests and per hectare changes in forest biomass resulting from management and forest regrowth (Houghton, 2005). Although forests are continuously recycling carbon through photosynthesis and decomposition process, the period of carbon sequestration by net storage in vegetation and soil can range from years to centuries. This is according to species, site conditions, and disturbance as well as management practices. Forest management practices to conserve and sequester carbon can be grouped into four categories: 1) maintain existing carbon pools by means of slow deforestation and forest degradation, 2) expand existing carbon sink and pools through forest management, 3) create new carbon sink and pools by expanding tree and forest cover, and 4) substitute renewable wood based fuels for fossil fuels (Dixon et al., 1994).

Forest ecosystems cover more than 4.1 billion hectares of the Earth's land area. In global scale, forest vegetation and soil contained approximately 37% of carbon in low-latitude forests whereas 14% in mid-latitude and 49% at high latitude. The components of primary forest carbon budget pool include all aboveground and belowground tree biomass, biomass of non-tree vegetation, soil organic matter, coarse woody debris, and fine litter (Dixon et al., 1994). The amount of forest carbon stocks that sequester and release vary with different forest ecosystems. The following table 2.3 shows average carbon levels that sequestered in vegetation and soils for several forest biomes and the weighted average for all biomes.

Table 2.3 Average carbon stocks for various forest biomes

Biomes	**Plants**	**Soil**	**Total**
Tropical forests	54	55	109
Temperate forests	25	43	68
Boreal forests	29	153	182
Tundra	3	57	60
Croplands	1	36	37
Tropical savannas	13	52	65
Temperate grasslands	3	105	108
Desert/Semi-desert	1	19	20
Wetlands	19	287	306
Weighted Average	**14**	**59**	**73**

Source: Gorte (2009)

Table 2.3 shows the tropical forests possess the highest amount of carbon stock relative to other forests ecosystems since an enormous diversity of hardwood species are contained. It can be concluded that half of the carbon in moist tropical forests contain in their vegetation which accounts for nearly 110 tons per acres. For forest soil organic carbon, the tropical forests seem to have only modest carbon levels when compare with other biomes because the dead biomass rapidly decomposes in the warm humid conditions and the minerals rapidly leach out of tropical forest soils. UNEP (2008) also supported that tropical forest ecosystems possess a significant portion of carbon stock out of 2,000 billion tons in the Earth's terrestrial ecosystems. Temperate forests consist of less carbon relative to tropical forests which generally averaging nearly 70 tons per acre. More than one third of the carbon is stored in the vegetation whereas nearly two third is in the soil. When compared to tropical forest soil, the higher proportion of carbon but lower level is due to slower decomposition rates. Boreal forests contain more carbon in the soil than temperate or tropical forests averaging more than 180 tons per acre. Carbon accumulation in high levels in boreal forest soils is also because of very slow decomposition rates due to the short summers and high acidity of conifer forest soils (Gorte, 2009).

Forest ecosystems have a high potential to protect natural ecosystems to help in storing carbon and to supply many other important goods and services. On the other hand, many ecosystems are disturbing without being sinks to sources of carbon due to forest degradation and climate change. In such conditions, protected areas are the most effective tool for maintaining carbon in natural vegetation. A research from UNEP World Conservation Monitoring Centre reported that there is far less carbon lost in protected areas than in other forests in tropical countries. Protected areas can provide a ready-made delivery mechanism for carbon storage and sequestration which are suitable for voluntary carbon markets and Reducing Emissions from Deforestation and Forest Degradation (REDD) related schemes. Protected areas will be the useful mechanisms for ecosystem-based climate change adaptation, disaster mitigation (e.g., protecting against typhoons, drought, earth quakes), health (e.g., malaria control, medical herbs and pharmaceutical drugs), and food and water security (e.g., protecting crop wild relatives, fisheries, water quality and other supply) (West African Countries Report, 2011).

2.3 Protected area as a tool for reducing carbon emissions

In a global scale, carbon emissions from deforestation accounts for an estimated 20% of the total carbon emissions (IPCC, 2007a). In order to reduce GHGs emissions from land cover change, effective strategies for protecting natural habitats are required. In such conditions, designation of new protected areas and strengthening of the current protected area network could be one effective strategy for reducing GHGs emissions. Protected area could also be a useful mechanism not only for conserving biodiversity but also for the maintenance of ecosystem services including climate regulation through carbon storage. To be successful conservation, the practical guidance on effective conservation measures would be necessary. Such guidance may come from the evaluating and monitoring the effectiveness of the protected areas. Therefore, evaluating and monitoring the protected areas would facilitate the information needed for promoting the effective conservation interventions.

IUCN definition of protected area is an area of forest especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means (Locke and Dearden, 2005). According to Locke and Dearden (2005), they are further subdivided into six categories:

- Category Ia : Strict nature reserve/wilderness protection area managed mainly for science or wilderness protection
- Category Ib : Wilderness area: protected area managed mainly for ecosystem protection and recreation
- Category II : National Park: protected area managed mainly for ecosystem protection and recreation
- Category III : Natural monument: protected area managed mainly for conservation of specific natural features
- Category IV : Habitat/species management area : protected area managed mainly for conservation through management intervention
- Category V : Protected landscape/seascape: protected area managed mainly for landscape/seascape conservation or recreation
- Category VI : Managed resource protected area: protected area managed mainly for sustainable use of natural resources

Protected areas might be contained many ecosystems which may own carbon storage capacity. According to Campbell et al. (2008), global protected area network possessed 15.2% of the global carbon stock. There may be a large number of potential reasons for the high carbon benefit of protected areas, e.g., tropical forests could be high carbon storage areas to be protected. Table 2.4 highlights the global terrestrial carbon storage in protected areas with IUCN categories.

Table 2.4 Global terrestrial carbon storage in protected areas

Protected area category	**%Land cover protected**	**Total carbon stored (Gt)**	**% Terrestrial carbon stock in protected areas**
IUCN category I-II	3.8	87	4.2
IUCN category I-IV	5.7	139	6.8
IUCN category I-VI	9.7	233	11
All WDPA Sites	**12.2**	**312**	**15.2**

Source: Campbell et al. (2008)

Campbell et al. (2008) also reported that the largest carbon stores are found in North Eurasia, North America, South America and Africa. Table 2.5 shows the estimated carbon storage within protected areas by region.

Table 2.5 Estimated carbon storage within protected areas by region

Region	Terrestrial carbon Stock (Gt)		Carbon in protected areas % (calculated from tons)
	Total	**In protected areas**	
North America	88	59	15.1
Greenland	5	2	51.2
Central America & Caribbean	16	4	25.2
South America	341	91	26.8
Europe	100	14	13.6
North Eurasia	404	36	8.8
Africa	356	49	13.7
Middle East	44	3	7.8
South Asia	54	4	7.2
East Asia	124	20	16.3
South East Asia	132	20	15.0
Australia/New Zealand	85	10	12.0
Pacific	3	0.1	4.3
Antarctic & peripheral islands	1	<0.1	0.3

Source: Campbell et al. (2008)

Campbell et al. (2008) also explained that the regions may vary carbon storage potential in accord with carbon storage totals, densities and levels of protection. It could not be concluded that the lower carbon stock regions have more vulnerable to release carbon while the higher carbon stock regions have higher amount of carbon storage. The fact is that if there are less pressures acting to the land of lower carbon stock regions, the region cannot be said to be vulnerable. On the other hand, if the land is affected by pressures such as high deforestation rate, it is suggested that increased conservation and protection measures are necessary. The implementation of climate policy such as REDD on a large scale is unlikely to be successful without supporting of indigenous and local communities. The official recognition and encouragement of community-based forest management are required and could become an essential role as a component or complement to protected areas in reducing deforestation.

2.4 Status of carbon stock conservation in Myanmar

Myanmar is still endowed with the forest cover of about 52% of the total land area. The complex variations of topography and climatic conditions combined with the extensive river network support the high diversity richness in Myanmar. Myanmar is home for about 11,800 plant species, 250 mammal species, 400 reptile and amphibian species, 1,000 avifauna species and 1,000 butterfly species (Forest Department, 2003; Tordoff et al., 2005).

Natural forests in Myanmar can be categorized as mangroves and estuarine forests in the delta region; deciduous and dipterocarp forests in the regions with pronounced dry season; evergreen forest in areas of high moisture and rainfall; hill evergreen and sub-alpine forests in high altitudes subtropical regions; and dry thorn forests in places with less rainfall (Oo, 2011). The tropical evergreen forest is mainly represented in Myanmar dominated by high value commercial species such as the evergreen *Dipterocarpus* species. The mixed deciduous forest is the major forest type of Myanmar and is characterized by the high value timber species of *Tectona grandis*, commonly known as teak which is found in associated with *Xylia xylocarpa* and different species of Terminalia. The mixed deciduous forest is associated with bamboo species. The dry forest represented by thorn and scrub forest is dominated by *Terminalia oliveri* and *Tectona hamiltoniana* where the rainfall is less than 1,000 mm. A number of thorny *Acacia* species are also occurred. The deciduous dipterocarp forest is mostly found at higher altitudes characterized by open canopy of deciduous Dipterocarpaceae. The hill and temperate evergreen forest is found in high rainfall areas with slopes between 900 m and 1,800 m, i.e., hill forest and over 1,800 m, it is called montane forest. This forest type is dominated by the species *Quercus*, *Castanopsis*, *Schima*, Fagaceae, Magnoliaceae, Lauraceae and Ericaceae. This forest type is characterized by many climber species and rich in undergrowth. Beyond the coniferous forests, sub-alpine forest and alpine meadows are found at the highest elevations on the mountains, before the level of snow and ice. Mangrove forests or tidal forests are occurred along alluvial flats of river deltas and on muddy coastal areas. They are salt tolerant and flooded by seawater during high tide. Beach and dune forest represents a minority of total forest area in Myanmar. It is found in narrow strips on beach and dunes along the coasts usually dominated by *Casuarina equisetifolia*.

The swamp forest was found in the Ayeyawaddy Delta and in the floodplains of other rivers, lakes and wetlands which are high ecological importance for many bird species and aquatic species (Istituto Oikos and BANCA, 2011). The major forest types of Myanmar are shown in Table 2.6.

Table 2.6 Area coverage of the major forest types, dominant species and rainfall range

Forest types	**Typical rainfall (mm/year)**	**Dominant tree species**	**Area (km^2)**	**% of total forest area**
Tidal, beach, dune and swamp forest	>3,500	*Rhizophora apiculata, Bruguiera gymnorhiza, Heritiera fomes*	13,750	4
Hill and temperate evergreen forest	>3,000	*Pinus insularis, P. khasya, Quercus serrata, Syzygium cummini, Bischofia javanica*	89,378	25
Evergreen forest	2,500-4,000	*Dipterocarp spp., Eugenia spp., Syzygium spp., Credrela spp.*	55,004	16
Mixed deciduous forest	1,250-2,500	*Tectona grandis, Xylia xylocarpa, Pterocarpus macrocarpus, Gmelina arborea, Millettia pendula*	134,068	38
Deciduous dipterocarp forest	900-1,250	*Pentacme siamensis, Shorea oblongifolia, D. tuberculatus, Terminalia tomentosa*	17,187	5
Dry forest	< 900	*Acacia catechu, Tectona hamiltoniana, Terminalia oliveri, A.leucophloea*	34,377	10
Fallow land			9,983	2
Total			**53,747**	**100**

Source: Forest Department (2010) (Unpublished) cited by Oo (2011)

Currently, Myanmar is managing the forests using the following some important instruments:

1) Forest law (1992);
2) Forest rules (1995);
3) Protection of wildlife and wild plants and conservation of natural areas law (1994);
4) Community forestry instructions (1995);
5) Myanmar Agenda 21 together with environmental policy;
6) National forestry action plan (1995);
7) Criteria and indicators for sustainable forest management (1999);
8) Format and guidelines for district forest management plans (1996);
9) National code of forest harvesting practices in Myanmar (2000); and
10) National framework for environmental law.

As the conservation of carbon stocks, main features of the Myanmar forest management plan are directed to address the forest degradation control in Myanmar. Forest land in Myanmar is legally classified as reserved forests, protected areas and public protected or unclassified forests. Reserved forests (RF), protected public forests (PPF) and protected areas system (PAS) include permanent forest estate (PFE). Under the Myanmar Forest Law 1992, RF and PPF enjoy almost equal legal status and protected areas system is administered in accordance with the Protection of Wildlife, Wild Plants and the Conservation of Protected Areas Law (Oo, 2011). So far 13 million ha of the forest area (37.8% of the total) have been corresponded to Permanent Forest Estate (PFE), of which 3.3 million ha are designated as conservation reserves (i.e., protected areas) and the remaining 9.7 million ha are defined as forests reserves (i.e., production forest) (Forest Department, 2003). Myanmar Forest Policy (1995) mandated to increase the coverage of protected areas system up to 5% in the short term and 10% in the long term (Ministry of Forestry, 1995). The status of PFE of Myanmar in 2002 is provided in Table 2.7.

Table 2.7 Permanent Forest Estates (PFE)

Legal classification	Area (km^2)	% of land area
Reserved forest	123,373.23	18.23
Public protected forest	39,880.48	5.89
Protected area system	26,613.47	3.93
Area of PFE	**189,867.18**	**28.05**

Source: Forest Department (2010) (Unpublished) cited by Oo (2011)

In Myanmar, the first protected area was established in 1918 but modern conservation efforts have started in the early years of 1980s. Between 1981 and 1984, a project namely Nature Conservation and National Park Project (NCNPP) was launched under the joint implementation of United Nations Development Program (UNDP) and Myanmar government. During the NCNPP, the Ministry of Forestry established the Nature and Wildlife Conservation Division (NWCD) which takes the responsibility for nature conservation and protected areas. Since then, the establishment of protected area has increased. Until 1996, PAs constituted < 1% of the total land with individuals ranging in size from 4.5 km^2 to 2,150 km^2. Establishment of PAs shifted from protection of certain species or habitat to protection of entire landscapes or ecosystems and 22 new PAs ranging in size from 0.5 km^2 to 15431.15 km^2 were added under protected area system between 1996 and 2006. Generally, protected areas in Myanmar can mainly be categorized into National Park, Marine Park, Wildlife Sanctuary, Nature Reserve and Zoo Park (Htun, 2011). The trends of growing protected areas status in Myanmar can be found in figure 2.1.

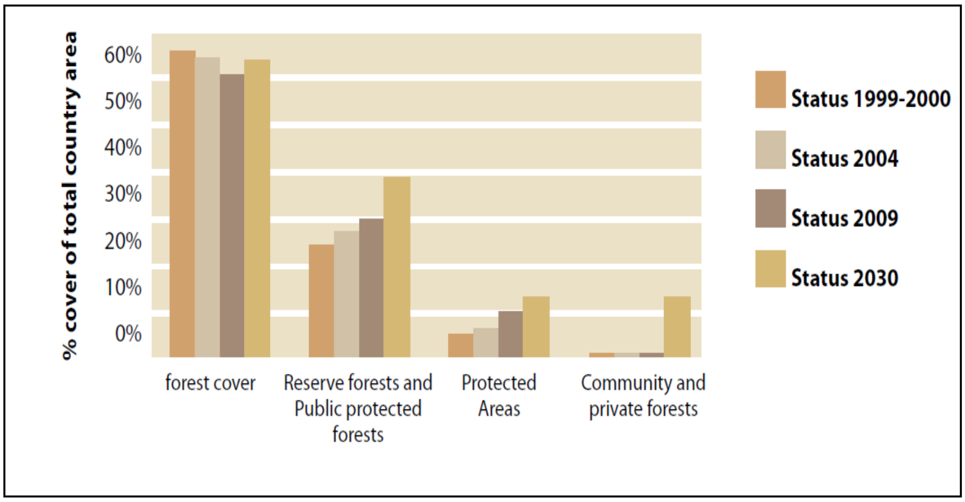


Fig. 2.1 Status of PFE in Myanmar

(Source: Istituto Oikos and BANCA, 2011)

According to Oo (2009), the carbon storage in one of the national parks in Myanmar, called Alaungdaw Katapa National Parks which is dominated by deciduous forest, consisted of 227.7 ton/ha as aboveground carbon, 45.5 ton/ha as root carbon, 4.2 ton/ha as litter fall carbon, 7.9 ton/ha as undergrowths carbon and 195.2 ton/ha as soil carbon.

2.5 Allometric for estimating forest biomass

The 3rd Conference of the Parties (COP3) of UNFCCC in Kyoto already defined that afforestation and reforestation could be considered as sinks and used for achieving GHGs emissions reduction commitment in 1997. To report whether there is improvement or not, the participants for afforestation and reforestation project have to measure and monitor all significant changes in five carbon pools: 1) aboveground biomass, 2) belowground biomass, 3) litter, 4) dead wood and 5) soil organic matter. One of the most reliable ways to estimate biomass and carbon sequestration in a forest stand, it is required to select the sample tree. However, receiving the representative sample of trees for estimating biomass might be very difficult and expensive for felling the trees, digging out their root systems, drying and weighing their biomass, etc. Therefore, applying the allometric equations using variables such as diameter at breast height (dbh) and tree height (h) can be accurately measured in the field.

Estimating of forest stand biomass using allometric equations could be saved the cost as well as work and time consuming (Segura and Kanninen, 2005).

Allometry is time and cost saving useful tool for calculating forest biomass to estimate forest carbon. It allows the total tree biomass of a forest or a stand to be estimated without having to cut down all the trees, take them back to the lab, dry the species in an oven and then weight all the pieces. The main carbon pools in tropical forest ecosystems are the living biomass of trees, understory vegetation, the dead mass of litter, wood debris and soil organic matter. Mostly, the largest amount of carbon is stored in the aboveground living biomass of trees. Estimating aboveground forest biomass carbon is the most critical step in quantifying carbon stocks and fluxes from tropical forests (Gibbs et al., 2007).

The carbon content per unit mass of plant tissue varies little within a species and tissue type but can vary significantly between tissue types (e.g., fruits vs. wood) and function groups of plants (e.g., trees vs. grasses). Default values that are suitable to support for the forest types are required (IPCC, 2000).

There are two approaches for estimating aboveground biomass in trees: a direct approach using allometric equations and an indirect approach using biomass expansion factors. One way to estimate the amount of forest biomass is the application of allometric equations. Allometry is the relation between the size of an organism and the size of any of its parts, and allometric equation is usually expressed in power-law form or in logarithmic form. Using allometric equation, the forest biomass can be estimated in a forest stand using just a simple measurement of diameter and height. The general form of allometric equation is:

$$y = bx^{a} \quad \text{or} \quad \text{In}y = \text{In}b + a\text{In}x,$$

Where b is a constant (allometric coefficient) and a is the allometric exponent. In regression analysis, the coefficient is goodness-of-fit in determination that takes the value between 0 and 1. If the value is closer to 1, then it means a better fit. For instance, the coefficient in determination of 0.9012 means 90% of the total variation in y. That determine the relationship between x and y while the other 10% is undetermined (FORDA & JICA, 2005).

The error in estimating of aboveground biomass of tropical forest is occurred in accord with many influence factors such as soil type, soil properties, soil depth, nutrients, climate, disturbance regime, succession status, topographic position, etc. The ecology conditions are known to influence the allometric equation (Mani and Parthasarathy, 2007; Porkar, 2008). In the report of Panaadisai (2011), it is indicated that the factors affecting on plant growth and biomass condition in a unit area are climate, soil, topography, forest fire, humans, animals and plants. All environmental factors have influences toward appearance, existence, change and loss of the area, but the influences of each factor were relatively different. In a plant community, each plant species naturally related by means of physical structures and environmental factors.

2.6 Some research findings of Carbon storage in different forest ecosystems from previous studies

Forests generally go through the series of growth and death, sequestering and releasing carbon. As they become established, carbon stored on the site increases along with woody biomass increases (Gorte, 2009). Carbon stocks are generally measured conducting inventories over small spatial scales. Allometric equations or statistical relationships are used in order to determine biomass and carbon stocks over a given area. Other approaches include ecosystem modeling and mapping combination with remote sensing techniques. Soil carbon stocks estimation includes the organic carbon content of soil profiles and the spatial distribution of the various soil or vegetation types (Campbell et al., 2008).

According to Senpaseuth et al. (2009), aboveground carbon content in dry evergreen and dry dipterocarp forests of Sang Khom District, Nong Khai Province, Thailand belonged to 331.75 ton/ha and 142.95 ton/ha respectively. In the case of dry mixed deciduous forest, Ogawa et al. (1965) found 155.50 ton/ha and Terakunpisut et al. (2007) investigated 48.14 ton/ha for Thong Pha Phum National Forest, Thailand. Moreover, the estimation of carbon storage in aboveground carbon content in mixed deciduous forest of Hauy Kha Kaeng Wildlife Sanctuary showed that the mixed deciduous forest has a great potential of carbon storage where it can store 17.60 ton/ha (Petsri et al., 2007). In the case of dry forest, Juwarkar et al. (2011) observed 112.19 ton/ha for natural reserve forest in central India. One of the researches from northwestern Mexico estimated that tropical dry forest in that area stored carbon of 4.2 Mg/ha and 7.1 Mg/ha (i.e., 4.2 ton/ha and 7.1 ton/ha whereas, 1 Mg = 10^6 grams = 1 metric ton) for total tree and total aboveground biomass respectively (Na'var, 2010). One of the previous researches by Panaadisai (2011) also estimated the carbon contents in Khao Yai National Park, i.e., hill evergreen forest, mixed deciduous forest, deciduous dipterocarp belonged to 212.00 ton/ha, 42.42 ton/ha and 36.89 ton/ha respectively. For soil organic carbon at 0 - 30 cm layer, hill evergreen forest possessed 125. 25 ton/ha, mixed deciduous forest possessed 88.43 ton/ha, deciduous dipterocarp forest belonged to 66.89 ton/ha respectively.

In the regards of soil carbon stock, one of the research found 125.25 ton/ha for hill evergreen forest, 65.79 ton/ha for mixed deciduous forest and 66.89 ton/ha for deciduous forest in 0 - 30 cm depth (Panaadisai, 2011). Another study showed soil carbon stock in natural forests ranges from 18.67 ton/ha to 60.38 ton/ha in 0 - 30 cm soil depth (Jaiarree et al., 2011).

Carbon stock estimation may vary in accord with the methodology selected, the comprehensiveness of the inventories, ecosystem model parameters selected, allometric and statistical equations used, and the land cover maps used for spatial representation (Potter, 1999).

2.7 Study area descriptions

The study area is called Popa Mountain Park and it is located in the central dry zone of Myanmar between 25°56 ' N and 55°16 ' E. It is about 34 miles (about 54 km) southeast of Bagan, an ancient capital of Myanmar on the bank of the Ayerrawady River and 10 miles (16 km) northeast of Kyaukpadaung town of the dry zone area. The area of the Park is about 100 km^2 with the elevation of 4981 ft (ranges from 300 m to 1500m by Htun et al., 2010) above sea level. Actually, it is the only prominent extinct volcano in Myanmar and possesses andosols soil. The volcano became extinct some thousands of years ago. A volcanic plug, called Taung-kalat, at the western foot of Mount Popa stands out as an easily recognizable landmark visible from 50 miles or more (Kyi and Moe, 1997). The basal area of the mountain is approximately 65 m^2 and roughly conical in shape. Its slopes rise gently at forest and then steeply towards the crater rim. This area is also famous for high plant diversity including shrubs, herbs and medicinal plants. After the eruption process of the volcano, over the years, evolution of the plant communities developed into various forest ecosystems. Many wild animals also evolved along with the formation of the vegetations. According to Istituto Oikos and BANCA (2011), Popa Mountain Park is within IUCN category IV. It has more than 100 springs in it supplying drinking and irrigation water to thousands of people in the surrounding area.

It was noted that even though it is in the dry zone area, it is almost always evergreen due to its elevation of 4,981 feet above sea level. Because of its high elevation, its climate is characterized by lower temperatures and high rainfall than the rest of the central dry zone of Myanmar. The mean maximum and minimum monthly temperatures for the period of 1994 - 2005 were 25.8°C and 15.6°C respectively. The mean annual rainfall for the same period was 1,038 mm. It is also one of the famous religious sites in Myanmar and several thousand people visit to it each year for religious and tourism purposes (Htun et al., 2011b).

Popa Mountain Park is famous for high plant diversity and as a source of medicinal plants. There are also found very limited populations of small mammals such as wild dogs (*Cuon alpinus*), muntjac (*Muntiacus muntjak*), wild pigs (*Sus-scrofa*), monkeys (*Macaca assamensis*) Langer (*Presbytis phayrei*). As the vegetation types, grassland, pine plantation and dry hill or dry evergreen forest (Quercus species, *Schima walichii* (DC.) Korth. and *Rapanea neriifolia* Mez.) occur above 1,000 m. Dry mixed deciduous forest (*Tectona grandis* Linn. f., *Xylia xylocarpa* (Roxb.) Taub. and *Adina cordifolia* Hook. f.) is dominant vegetation type below 1,100 m. Than-dahat dry forest (*Terminalia oliveri* Brandis, *Tectona halminltoniana* Wall. and *Acacia catechu* Willd.) is found below 450 m. Scrub indaing forest or dipterocarp forest (Dipterocarpus species) is observed between 400 and 700 m. Eucalyptus and xylia plantation are found between about 750 and 900 m. Shrub/bush vegetation consists of shrubs, regeneration, isolated trees and bare land. All forests in the study area are second or third growth after cutting and clearing for agriculture in the early 20th century. The pine, eucalyptus and xylia plantations were established during the period 1955 - 1972 (Htun et al., 2011a).

Mount popa is a monument for all of Myanmar people because of its long history, traditions and customs, religions and believe and cultural heritages. Popa Reserved Forest was launched in 1902. At that time, there were some villagers staying inside the park and cleared the forests for cultivation. In 1954-1955, forests surrounding the reserve were notified as Protected Forests to reserve as a buffer zone. The rehabilitation of Mt. Popa was initiated in the early 1980s. In 1982, it was established as Popa Mountain Park under the management of Forest Department. Infrastructure development activities for Popa Mountain Park were employed starting from 1982 under the Nature Conservation and National Parks Projects implemented jointly by the Myanmar Government and UNDP. Among the desert-like formation because of forest depletion, Mt. Popa stays as an oasis in the central dry zone of Myanmar. The following figure 2.2 shows the location of Popa Mountain Park.

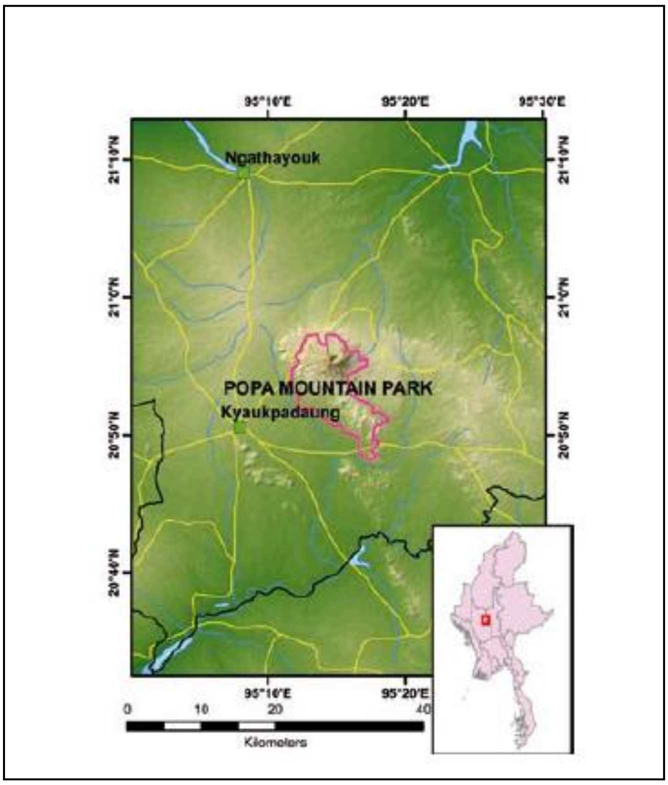


Fig. 2.2 Location of Popa Mountain Park (Source: Istituto Oikos and BANCA, 2011)

All classification of vegetation types from the previous study identified that dry mixed deciduous forest is found as the most prevalent vegetation types accounting for 40% of the total area of the park followed by Than- Dahat (dry forest) occupying 26-28%. Xylia plantation and grassland are found as the smallest areas. Reforestation work consisted of establishing plantations using pine (*Pinus insularis* Endl.), eucalyptus (*Eucalyptus camadulensis* Dehnh.) and pyin-ka-do (*Xylia xylocarpa* (Roxb.) Taub.), and encouraging natural regeneration of the native tree species. Then the vegetation gradually recovered in reclaimed areas (Htun, 2011). Figure 2.3 shows the vegetation types found in Popa Mountain Park area.

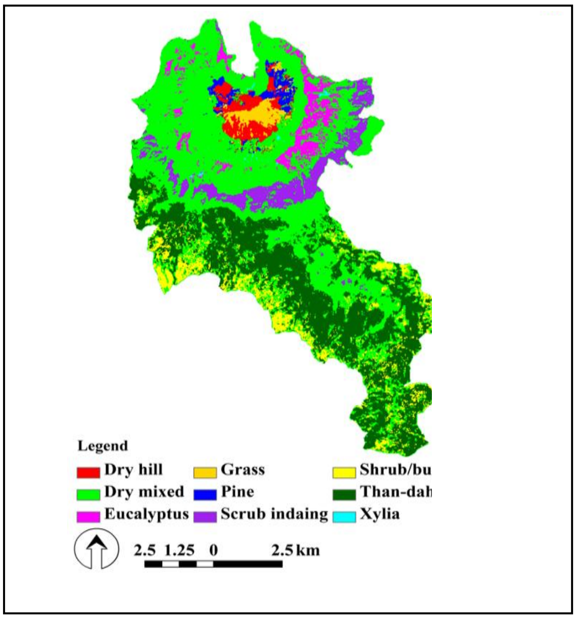
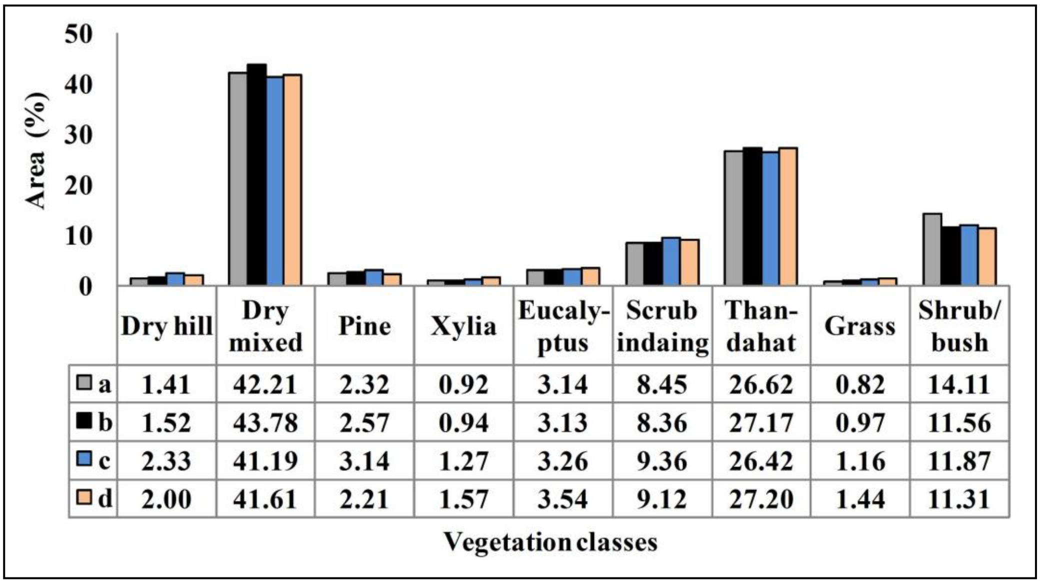


Fig. 2.3 Classified vegetation types in Popa Mountain Park
(Source: Htun et al., 2011a)

The area of each vegetation class was estimated by Htun et al. (2011a) using four maximum likelihood classification approaches and it was shown in figure 2.4. Table 2.8 show the estimated area (ha) according to Htun et al. (2011a) where the area covered of Popa Mountain Park is 100 km^2 (10000 ha).



a = single-step without elevation, b = two-step without elevation, c = single step with elevation, d = two-step with elevation

Fig. 2.4 Area of vegetation class (Source: Htun et al., 2011a)

Table 2.8 Estimated area of forest ecosystem (ha)

Area	Dry hill evergreen	Dry mixed deciduous	Deciduous dipterocarp	Dry forest	Others
a	1.41	42.21	8.45	26.62	Pine (2.56),
b	1.52	43.78	8.36	27.17	Xylia (1.18),
c	2.33	41.19	9.36	26.42	Eucalyptus (3.27),
d	2.00	41.61	9.12	27.20	Grass (1.10),
					Shrub/bush (12.21)
Average area (%)	**1.82**	**42.20**	**8.82**	**26.85**	**20.31**
Area (ha)	**182**	**4,220**	**882**	**2,685**	**2,031**

Note: a, b, c, d are area estimation of vegetation class approaches from Htun et al. (2011a)

CHAPTER III
METHODOLOGY

3.1 Field data collection methods

Field data collection was conducted to one of the protected areas in Myanmar called Popa Mountain Park during October 2 - 15, 2012. According to the time limitation, the research only focused on four different forest ecosystems: dry hill or dry hill evergreen forest, dry mixed deciduous forest, indaing or deciduous dipterocarp forest and than-dahat or dry forest which are found in that study area. They can be said as the natural forests where as others are found to be artificial plantations. In order to obtain more representative forest vegetation, stratified random sampling was applied. Stratification of the forest vegetation was undertaken according to the previous research in that study area using contour lines and landsat image. The sampling intensity is 1 plot per 1000 ha (Beckers and Binns, 2000). The total 24 temporary sample plots were set up which were 6 sample plots per each forest type. Each sample plot size was 30 × 30 m^2. Within 30 × 30 m^2, 9 quadrates with 10 × 10 m^2 were set. Then in each 10 × 10 m^2, a quadrate with 5 × 5 m^2 subplots was nested. Then other nested quadrates with 1 × 1 m^2 subplots were established in each 5 × 5 m^2 subplots (Zhang et al., 2011). For soil data collection, random sampling points were set inside the three diagonal 10 × 10 m^2 plots. For soil carbon estimation, it was only identified soil organic carbon storage in the research. Figure 3.1 shows the temporary sampling plot design for the research.

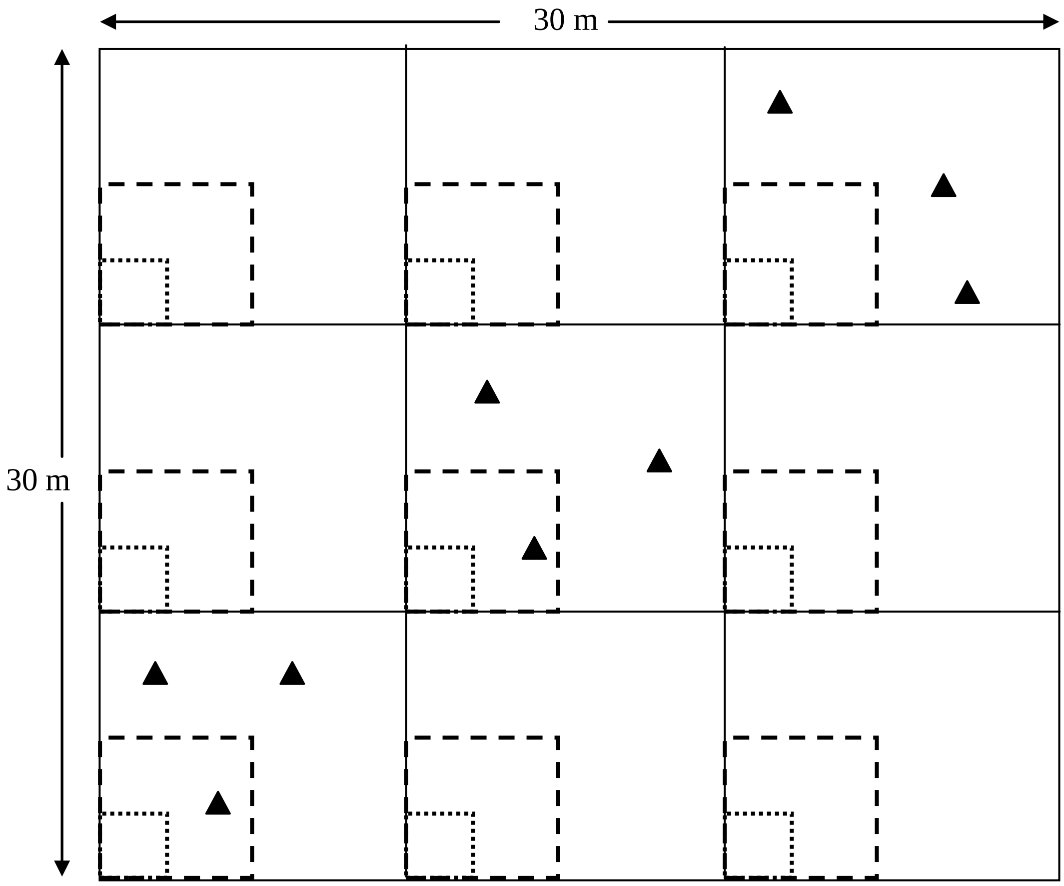


Fig. 3.1 Temporary sample plot design

Where	10×10 m^2	dbh ≥ 4.5 cm (dbh = diameter at breast height)
	5×5 m^2	dbh < 4.5 cm and height ≥ 1.3 m
	1×1 m^2	dbh < 4.5 cm and height < 1.3 m
	1×1 m^2	Soil sample plot

3.1.1 Vegetation Sampling

Within 10 × 10 m^2 sample plots, the diameters and heights of all trees with dbh ≥ 4.5 cm were measured by using diameter tape (Terakunpisut et al., 2007; Panaadisai, 2011). All kind of species were identified the scientific name as well as the local name, and recorded. Scientific name identification was due to Kyi and Moe (1997) and Smithsonian National Museum of Natural History for Botanical Exploration in Myanmar (Source: http://botany.si.edu/myanmar/).

Within 5 × 5 m^2 subplots, saplings and shrubs with dbh < 4.5 cm with the height of ≥ 1.3 m were measured the diameter and height as well as identified scientific name and local name.

Within 1 × 1 m^2 subplots, all plants with dbh < 4.5 cm with the height of < 1.3 m such as undergrowth (seedlings, shrubs, climbers, ferns, herbs) and also grass were collected and weighted. All litter were collected and weighted in order to obtain fresh weight. Later the random samples were dried for finding percentage of moisture content in order to calculate dry weight for estimating biomass later.

3.1.2 Soil Sampling

Soil sample were collected from 24 sample plots, i.e., 6 sampling plots per each forest type. In each temporary sample plot, soil samples were taken from 3 soil sampling points. Soil samples were collected about 1 kg at 2 levels: 0-15 cm and 15-30 cm for analyzing physical and chemical soil properties (Zhang et al., 2011).

3.2 Sample Analysis

3.2.1 Vegetation analysis

The important values index (IVI) of each species in each sample plot was calculated using the technique of Curtis and Mclntosh (1950). The density measurements shows as to how many individuals are present, the frequency measurements reflects how widely species is distributed among the same plots and the dominance measurements reflects which species is the largest in terms of its presence. Since it takes into accounts several properties of the species in vegetation, importance value is a reasonable measure to assess the overall significance of a species (REHP Report, 2006). Species diversity (SD) was estimated by using Shannon-Wiener index (Spellerberg and Fedor, 2003). Species diversity reflects the plentiful or less of different species in an area which has been related to the community or properties of the environment, spatial heterogeneity, stability, primary production, productivity, competition, predation, niche structure and evolution (Heip and Engels, 1974). Diversity Index is calculated by taking the number of each species, the proportion each species is of the total number of individuals, and sums the proportion times the natural log of the proportion for each species. Since this is a negative number, it is then taken the negative of the negative of this sum. The higher the number, the higher is the species diversity (Nolan and Collahan, 2006). The following equations were used for calculation of IVI and species richness index.

IVI = % relative density + % relative frequency + % relative dominance………….. (1)

$$\text{Then, relative density (RD)} = \frac{\text{Density of species A}}{\text{Total density of all species}} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(1.1)}$$

$$\text{Relative frequency (RF)} = \frac{\text{Frequency value for species A}}{\text{Total of all frequency values for all species}} \times 100 \quad \ldots\ldots\ldots \text{(1.2)}$$

``

$$\text{Relative dominance (RD)} = \frac{\text{Dominance for species A}}{\text{Total dominance of all species}} \times 100 \quad \ldots\ldots\ldots \text{(1.3)}$$

Shannon-Wiener Index $$H' = -\sum_{i=1}^{s} p_i \ln p_i \quad (2)$$

Where H' = index of species diversity

S = the number of species richness

p_i = the proportion of individuals of each species belonging to the i^{th} species of the total number of individuals

ln = natural log (base e = not the same of log)

Species diversity (SD) was estimated by using Shannon-Wiener index (Spellerberg and Fedor, 2003). Species diversity reflects the plentiful or less of different species in an area which has been related to the community or properties of the environment, spatial heterogeneity, stability, primary production, productivity, competition, predation, niche structure and evolution (Heip and Engels, 1974). Diversity Index is calculated by taking the number of each species, the proportion each species is of the total number of individuals, and sums the proportion times the natural log of the proportion for each species. Since this is a negative number, it is then taken the negative of the negative of this sum. The higher is the number, the higher is the species diversity (Nolan and Collahan, 2006).

There were two parts of tree biomass for estimating total carbon content: 1) aboveground such as stem, branch and leaf and 2) belowground biomass, i.e., root. The aboveground and belowground biomass of each forest ecosystems was calculated using allometric equations which are related to tree diameter and height. The allometric equations related with each forest ecosystem are shown table 3.1.

Table 3.1 Allometric equations for forest biomass estimation

Forest ecosystem	Allometric equations	References
Dry hill evergreen forest	$Ws = 0.0509 (D^2H)^{0.919}$ $Wb = 0.00893 (D^2H)^{0.977}$ $Wl = 0.0140 (D^2H)^{0.669}$ $Wr = 0.0313 (D^2H)^{0.805}$	Tsutsumi et al. (1983)
Dry mixed deciduous forest Deciduous dipterocarp forest	$Ws = 0.0396 (D^2H)^{0.9326}$ $Wb = 0.003487 (D^2H)^{1.027}$ $Wl = (28.0/Ws + Wb) + 0.025)^{-1}$ $Wr = 8.2 \times 10^{-2} (D^2)$	Ogawa et al. (1965)
Dry forest	$Ws = 0.5825 (D^{1.6178})$ $Wb = 0.0433 (D^{2.3929})$ $Wl = 0.0433 (D^{2.3929})$ $Wr = 0.0051 (D^{2.6680})$	Na'var (2009)

[D = diameter at breast height (cm), H = total height (m), Ws = stem biomass (kg), Wb = branch biomass (kg), Wl = leaf biomass (kg), Wr = root biomass (kg)]

The vegetation sample biomass of plants with dbh < 4.5 cm and height < 1.3 m as well as litter and grass in the study plots were dried at 80°C in a constant temperature oven for 48 hours or until the weight was stable. After drying, the percentage of moisture content was calculated by the following equations (Petsri et al., 2007).

$$\% \text{ Moisture} = \frac{(\text{Weight of fresh mass} - \text{Weight of dry mass}) \times 100}{\text{Weight of dry mass}} \quad \ldots\ldots\ldots\ldots (3)$$

$$\text{Dry Weight} = \frac{100 \times \text{Weight of fresh mass}}{\% \text{ Moisture} + 100} \quad \ldots\ldots\ldots\ldots (4)$$

All biomass values were converted into the total carbon stock using a carbon conversion factor 0.5, i.e., 50% of dry weight biomass (FORDA and JICA, 2005; IPCC, 1996).

C = DW × CF……………………………………………………………...................... (5)

Where C = carbon stock,

DW= dry weight of biomass,

CF = carbon fraction of dry matter

3.2.2 Soil Sample Analysis

Soil samples were collected and dried at between 95 - 105°C for 24 hours or until weight was stable and calculated for finding bulk density (D_b) (Panaadisai, 2011). Soil samples were prepared by air drying, mashing and sieving before they were analyzed. Table 3.2 shows the analyzed soil sample parameters and using methods.

Table 3.2 Analyzed Soil sample parameters and using methods

Soil parameters	**Methods**
Soil texture	Hydrometer method
Bulk density (D_b)	$D_b = \dfrac{\text{Dry mass (g)}}{\text{Total soil volume (cm}^3\text{)}}$
Soil moisture (% Pw)	$\%\text{by weight} = \dfrac{(\text{weight before dry} - \text{weight after dry}) \times 100}{\text{weight after dry}}$
Soil reaction (pH)	pH meter
Soil organic matter (SOM)	Walkley and Black method (1974)
% Organic carbon (% OC)	Combustion with C/N analyzer
Total nitrogen (N)	Distillation method (Kjeltec 8100 Distillation Unit)
Available phosphorus (P)	Spectrophotometer (Jasco V-630)
Available potassium (K)	AA combustion machine (Varian AA 240 FS – Fast Sequential Atomic Absorption Spectrometer)

3.3 Estimation of total carbon storage in Popa Mountain Park

Each forest carbon storage and soil carbon storage were multiplied with the area (ha) of each forest ecosystem in order to estimate the total carbon storage. Then total carbon storage was calculated by combination of total forest carbon storage and soil carbon storage in forest ecosystems of Popa Mountain Park. The following equations show the calculation for total carbon storage of Popa Mountain Park.

TC = TCF + TCS………………………………………………………………. (6)

Where TC = total carbon storage in forest ecosystems of Popa Mountain Park

TCF = FC x Area (ha)…………………………………………………………... (6.1)

Where TCF = total carbon storage in forest ecosystems

FC = carbon storage in each forest ecosystem

TCS = CS x Area (ha) ………………………………………………………….. (6.2)

Where TCS = total carbon storage in forest soil

CS = total soil carbon storage in each forest ecosystem

3.4 Statistical Analysis

Analysis of variance (one-way ANOVAs) was used in order to compare carbon concentration in tree biomass of the natural forest ecosystems. Duncan's multiple range tests was used for examining the ranking order of investigated parameters among the forest ecosystems. All statically analyzes were performed by using SPSS 15.0 for Windows.

CHAPTER IV
RESULTS AND DISCUSSIONS

4.1 Tree species composition and diversity in forest ecosystems of Popa Mountain Park

Species richness is simply the number of species present in an area (Nolan and Callahan, 2006). Different tree species of 28 families with 45 species were found in dry hill evergreen forest whereas 37 families with 77 species in dry mixed deciduous forest, 30 families with 63 species in deciduous dipterocarp forest and 18 families with 35 species in dry forest were recorded respectively. It was found that mixed deciduous forest contained the largest number of species and families among the forest ecosystems whereas there were the smallest numbers of families and species in dry forest ecosystem.

Some findings from other studies showed hill evergreen forest involved 52 species, mixed deciduous forest contained 32 species, and deciduous dipterocarp forest belonged to 28 species. These data obtained from one of the National Parks in Thailand called Khao Yai National Park by Panaadisai (2011). When comparing with this research, the species numbers in dry hill evergreen forest contained smaller numbers than Khao Yai National Park but for dry mixed deciduous forest and deciduous dipterocarp forest, the numbers of species that they possessed are higher than the previous research. Dry forest also possessed a high number of species when compared with other forest types though it did not have the comparable studies exactly. The reasons might be so variables in terms of species richness belonging due to different locations, different management systems, and different intensities of human disturbances and so on.

The species rich families for dry hill evergreen forest are found to be Euphorbiaceae, Combretaceae and Rutaceae which were represented by 5 species with 16.18% of the total species, 4 species with 8.38% of the total species, and 3 species with 5.49% of the total species. For dry mixed deciduous forest, Euphorbiaceae, Dipterocarpaceae and Fabaceae were observed as species rich families representing 5 species of 10.25%, 3 species of 9.63% and 4 species of 7.00% of the total species. In the case of deciduous dipterocarp forest, the species rich families were Dipterocarpaceae, Verbenaceae and Euphorbiaceae which possessed 3 species with 24.14%, 7 species with 11.80%, and 5 species with 7.00% of the total species. For dry forest, Combretaceae, Verbenaceae and Rubiaceae were investigated as species rich families representing 3 species of 25.06%, 3 species 17.22% and 7 species of 8.35% of the total species. The family Euphorbiaceae was found to be dispersion among the dry hill evergreen forest, dry mixed deciduous forest and deciduous diptercarp forest where they could grow adaptively.

The highest IV value in dry hill evergreen forest for trees with dbh ≥ 4.5 cm belonged to the species *Rapanea neriifolia* Mez. whereas *Pittosporum nepaulensis* (DC.) Rehd. & Wilson for dry mixed deciduous forest, *Shorea obtusa* Wall. ex Blume for deciduous dipterocarp forest and *Tectona hamiltoniana* Wall. for dry forest which values were 74.46, 41.47, 65.93 and 54.71 respectively. In the case of saplings and shrubs with dbh < 4.5 cm, it was observed the largest IV value species *Glycosmis pentaphylla* Correa with IV value 55.16, *Chionanthus ramiflorus* Roxb. with IV value 46.38, *Rhus paniculata* Wall. with IV value 40.35 and *Croton roxburghianus* N.P. Balakr. with IV value 35.94 for dry hill evergreen forest, dry mixed deciduous forest, deciduous dipterocarp forest and dry forest, respectively.

In terms of species diversity, Shannon-Weiner index H' showed 0.3 for trees dbh ≥ 4.5 cm and 0.1 for saplings and shrubs with dbh < 4.5 cm for dry hill evergreen forest whereas dry mixed deciduous forest (0.6 for trees with dbh ≥ 4.5 cm and 0.3 for saplings and shrubs with dbh < 4.5 cm), deciduous dipterocarp forest (0.5 for trees with dbh ≥ 4.5 cm and 0.3 for saplings and shrubs with dbh < 4.5 cm) and dry forest (0.4 for trees with dbh ≥ 4.5 cm and 0.1 for saplings and shrubs with dbh < 4.5 cm), respectively. Generally the diversity H' value is ranging between 0 – 4. The H' value which is near to 0 indicates low community complexity and the value of H' which is near to 4 indicates high community complexity (Source: http:// www.docstoc.com/docs/36333614/SHANNON-WIENER-DIVERSITY-INDEX). The results from the research showed the H' value for tree with dbh ≥ 4.5 cm of dry mixed deciduous forest and deciduous dipterocarp forest were near to 1 but for dry hill evergreen forest and dry forest were near to 0. The result highlighted dry hill evergreen forest and dry forest belonged to low species diversity while dry mixed deciduous forest and deciduous dipterocarp forest were neither low nor high species diversity. However, dry mixed deciduous forest possessed the highest species diversity when compared with other forest ecosystems. In terms of saplings and shrubs with dbh < 4.5 cm, *H'* value of all forest ecosystems showed low species diversity because their *H'* values were near to 0.Table 4.1, 4.2, 4.3 and 4.4 list the Shannon-Weiner index and the top ten species which belonged to the highest IV values for trees with dbh ≥ 4.5 cm and saplings and shrubs with dbh < 4.5 cm which were the most abundant, frequent and dominant in different forest ecosystems.

Table 4.1 Ten highest IV species of dry hill evergreen forest

Species	**Relative frequency (%)**	**Relative density (%)**	**Relative dominance (%)**	**IV**
Trees with dbh ≥ 4.5 cm				
Shannon-Weiner Index (*H'*) 0.3				
Rapanea neriifolia Mez.	11.26	36.05	27.15	74.46
Croton roxburghianus N.P. Balakr.	9.93	11.90	15.84	37.67
Pinus khasya Royle ex Parl.	5.30	4.42	13.52	23.24
Anogeissus acuminata Wall.	6.62	6.12	5.43	18.17
Pittosporum napaulensis (DC.) Rehder & Wilson	6.62	4.76	3.19	14.57
Flacourtia cataphracta Roxb.	4.64	3.40	5.96	13.99
Albizia chinensis (Osbeck) Merr.	3.97	2.38	3.38	9.73
Wendlandia tinctoria DC.	3.31	2.04	3.72	9.07
Diospyros mollis Griff.	3.97	2.72	1.82	8.51
Mallotus philippinensis (Lam.) Muell. Arg.	3.31	2.38	2.36	8.06
Others	41.06	23.81	17.63	82.50
Total	**100.00**	**100.00**	**100.00**	**300.00**

(cont.) from table 4.1

Saplings and shrubs dbh < 4.5 cm				
Shannon-Weiner Index (*H'*) 0.1				
Glycosmis pentaphylla Correa	16.28	19.23	19.65	55.16
Mallotus philippinensis (Lam.) Muell. Arg.	9.30	7.69	11.62	28.61
Smilax perfoliata Lour.	11.63	11.54	3.55	26.71
Sapium baccatum Roxb.	4.65	7.69	13.15	25.50
Murraya paniculata (L.) Jack	9.30	9.62	5.33	24.25
Laportea interrupta (L.) Chew	6.98	5.77	2.96	15.70
Grewia laevigata Vahl	2.33	3.85	9.21	15.38
Croton roxburghianus N.P. Balakr.	4.65	3.85	5.34	13.84
Debregesia longifolia Wedd.	2.33	3.85	7.50	13.67
Diospyros oleifolia Wight	2.33	1.92	5.24	9.49
Other species	30.23	25.00	16.45	71.69
Total	**100.00**	**100.00**	**100.00**	**300.00**

Table 4.2 Ten highest IV species of dry mixed deciduous forest

Species	**Relative frequency (%)**	**Relative density (%)**	**Relative dominance (%)**	**IV**
Trees with dbh ≥ 4.5 cm				
Shannon-Weiner Index (*H'*) 0.6				
Pittosporum nepaulensis (DC.) Rehder & Wilson	9.14	17.46	14.87	41.47
Shorea siamensis (Kurz) Miq.	5.14	5.59	11.40	22.13
Shorea obtusa Wall.	4.57	5.42	8.98	18.98
Dalbergia cultrata Grah.	2.86	4.92	6.33	14.11
Diospyros mollis Griff.	3.71	5.08	5.27	14.06
Engelhardtia spicata Blume	3.14	6.27	4.49	13.91
Schleichera oleosa (Lour.) Oken	4.00	3.22	3.51	10.73
Chionanthus ramiflora Roxb.	4.00	3.39	1.17	8.56
Dipterocarpus tuberculatus Roxb.	1.14	1.02	6.20	8.36
Protium serratum Engl.	3.14	2.71	2.49	8.34
Other species	59.14	44.92	35.28	139.34
Total	**100.00**	**100.00**	**100.00**	**300.00**

(cont.) from table 4.2

Saplings and shrubs with dbh < 4.5 cm				
Shannon-Weiner Index (*H'*) 0.3				
Chionanthus ramiflora Roxb.	10.34	18.57	17.46	46.38
Rhus paniculata Wall.	8.28	11.90	9.57	29.75
Vitex canescens Kurz	6.21	6.19	6.86	19.26
Antidesma ghesaembilla Gaertn.	6.90	5.24	7.09	19.23
Acacia nilotica (L.) Delile	6.21	4.76	3.32	14.29
Croton roxburghianus N.P. Balakr.	4.83	3.33	3.35	11.51
Indigofera lacei Craib	4.14	5.24	2.10	11.48
Jasminum angustifolium Vahl	3.45	2.86	3.45	9.75
Mallotus philippinensis (Lam.) Muell. Arg.	3.45	3.81	2.40	9.66
Protium serratum Engl.	3.45	2.38	3.55	9.38
Other species	42.76	35.71	40.84	119.31
Total	**100.00**	**100.00**	**100.00**	**300.00**

Table 4.3 Ten highest IV species of deciduous dipterocarp forest

Species	**Relative frequency (%)**	**Relative density (%)**	**Relative dominance (%)**	**IV**
Trees with dbh ≥ 4.5 cm				
Shannon-Weiner Index (*H'*) 0.5				
Shorea obtusa Wall.	12.46	19.71	33.77	65.93
Shorea siamensis (Kurz) Miq.	8.54	11.53	11.71	31.78
Diospyros burmanica Kurz	5.34	7.55	4.71	17.59
Premna pyramidata Wall.	6.05	4.82	4.85	15.72
Dipterocarpus tuberculatus Roxb.	1.42	2.52	11.55	15.49
Engelhardtia spicata Blume	4.27	5.24	5.76	15.27
Terminalia crenulata (Heyne) Roth	6.05	4.82	3.01	13.88
Pittosporum nepaulensis (DC.) Rehder & Wilson	4.98	4.61	3.38	12.97
Tectona grandis L. f.	3.56	3.77	2.90	10.23
Dalbergia oliveri Gamble	3.56	3.14	2.69	9.39
Other species	43.77	32.28	15.68	91.74
Total	**100.00**	**100.00**	**100.00**	**300.00**

(cont.) from table 4.3

Saplings and shrubs with dbh < 4.5 cm				
Shannon-Weiner Index (*H'*) 0.3				
Rhus paniculata Wall.	7.14	15.60	17.61	40.35
Chionanthus ramiflora Roxb.	5.36	14.00	15.21	34.56
Vitex canescens Kurz	5.95	8.40	11.18	25.53
Indigofera lacei Craib	6.55	5.60	1.75	13.90
Santalum album L.	4.17	4.00	5.11	13.28
Lagerstroemia speciosa (L.) Pers.	2.98	3.20	6.30	12.47
Phyllanthus albizzioides (Kurz) Hook. f.	4.17	3.20	4.20	11.57
Shorea siamensis (Kurz) Miq.	4.17	2.80	4.44	11.41
Flacourtia cataphracta Roxb.	2.98	2.80	3.97	9.75
Acacia nilotica (L.) Delile	4.76	3.20	1.36	9.32
Other species	51.79	37.20	28.87	117.86
Total	**100.00**	**100.00**	**100.00**	**300.00**

Table 4.4 Ten highest IV species of dry forest

Species	Relative frequency (%)	Relative density (%)	Relative dominance (%)	IV
Trees with dbh ≥ 4.5 cm				
Shannon-Weiner Index (*H'*) 0.4				
Tectona hamiltoniana Wall.	12.24	14.41	28.06	54.71
Terminalia crenulata (Heyne) Roth	13.06	20.46	10.19	43.71
Diospyros burmanica Kurz	11.43	13.26	13.80	38.49
Terminalia oliveri Brandis	6.53	4.61	6.45	17.59
Acacia leucophloea (Roxb.) Willd.	1.63	1.15	13.97	16.76
Dalbergia paniculata Roxb.	5.71	4.03	6.01	15.75
Morinda tinctoria Roxb.	6.12	5.76	2.75	14.64
Croton roxburghianus N.P. Balakr.	5.31	4.32	1.46	11.09
Rhus paniculata Wall.	3.67	4.32	1.19	9.19
Premna pyramidata Wall.	3.67	3.17	2.32	9.17
Other species	30.61	24.50	13.80	68.91
Total	**100.00**	**100.00**	**100.00**	**300.00**

(cont.) from table 4.4

Saplings and shrubs with dbh < 4.5 cm				
Shannon-Weiner Index (*H'*) 0.1				
Croton roxburghianus N.P. Balakr.	11.90	13.64	10.39	35.94
Terminalia oliveri Brandis	9.52	9.09	14.23	32.84
Hiptage benghalensis (L.) Kurz	9.52	9.09	10.34	28.95
Dalbergia paniculata Roxb.	7.14	9.09	11.89	28.13
Rhus paniculata Wall.	9.52	9.09	3.63	22.24
*Acacia catechu*Willd.	7.14	6.82	5.67	19.63
Terminalia crenulata (Heyne) Roth	7.14	6.82	5.59	19.55
Gardenia obtusifolia Roxb.	4.76	4.55	5.67	14.97
Grewia tiliifolia Vahl	4.76	4.55	4.03	13.34
Morinda tinctoria Roxb.	2.38	2.27	7.33	11.98
Other species	26.19	25.00	21.25	72.44
Total	**100.00**	**100.00**	**100.00**	**300.00**

A reversed J-shaped population structure was represented for all different forest ecosystems, i.e., increase in numbers of small diameter trees with decrease in numbers of large diameter trees. The number of individual in dbh size distribution of tree in all forest types decreased with the increase of dbh class. This result highlighted the secondary forest characteristic. According to classifying results, the number of trees with diameter size class 10 - 15 cm were abundant than other classes in dry hill evergreen forest. When looking to other forest ecosystems, dbh size class 4.5 - 10 cm was the most prominent. The highest dbh class which was around 40 - 60 cm were found in all forest types but were very few. The largest diameter size class 55 - 60 cm was investigated in dry hill evergreen and dry mixed deciduous forest. Figure 4.1, 4.2, 4.3, 4.4 and 4.5 show dbh size classes of forest ecosystems found in Popa Mountain Park.

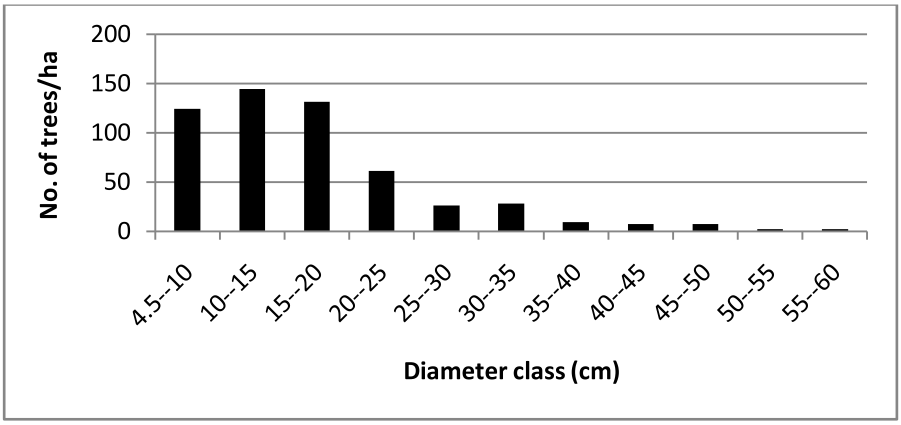


Fig. 4.1 Stand density in dry hill evergreen forest according to dbh

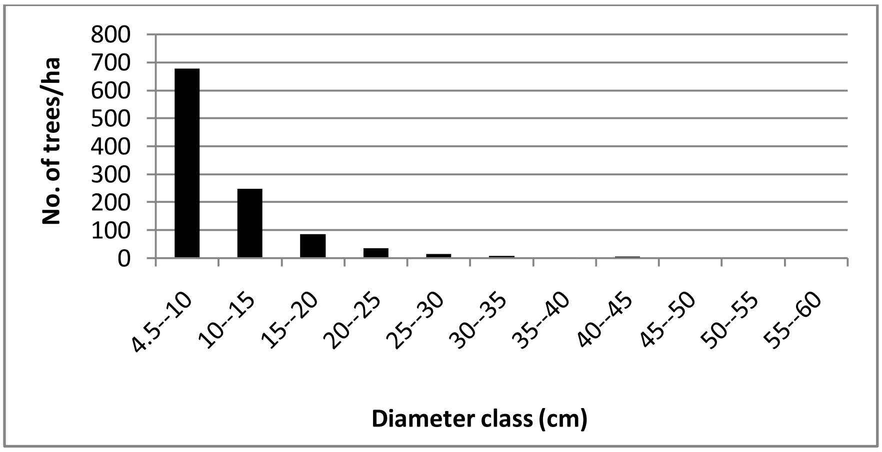


Fig. 4.2 Stand density in dry mixed deciduous forest according to dbh

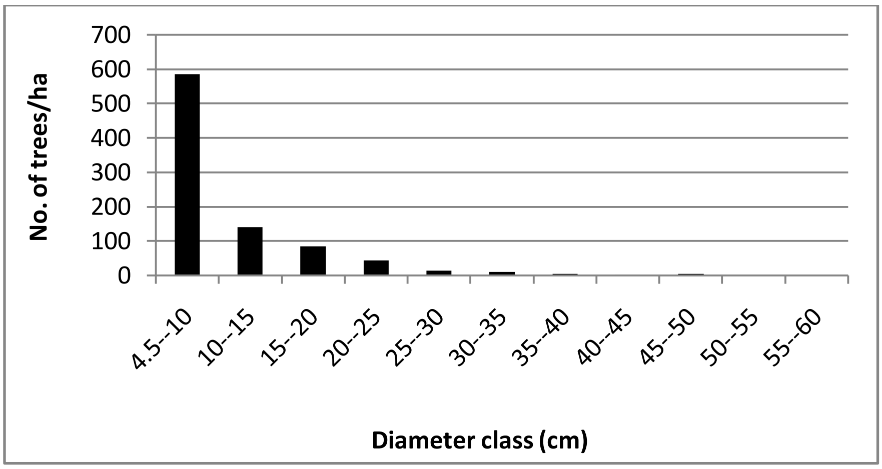


Fig. 4.3 Stand density in deciduous dipterocarp forest according to dbh

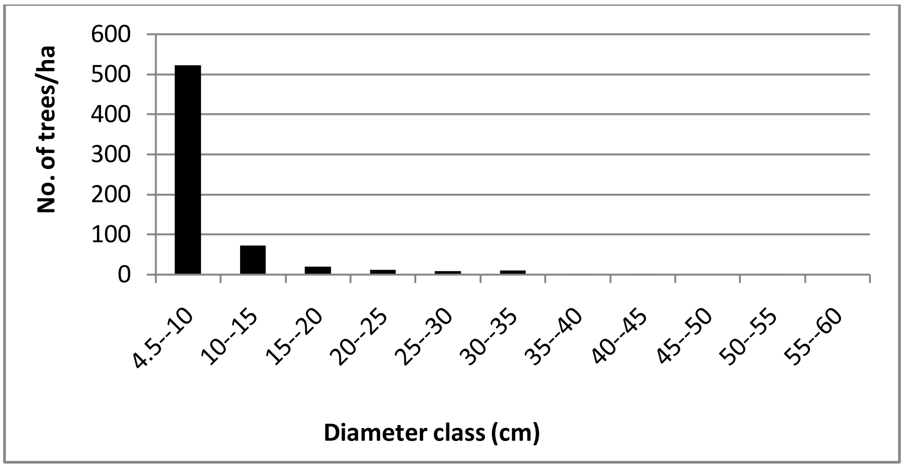


Fig. 4.4 Stand density in dry forest according to dbh

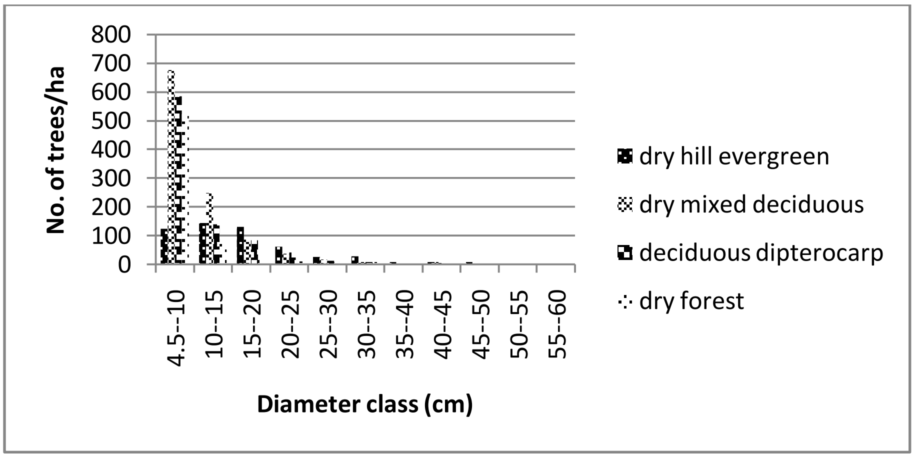


Fig. 4.5 Stand density in forest ecosystems according to dbh

According to the results, many standing trees did not reach the mature stage though there was much recruitment of younger trees. Furthermore, large diameter size classes of trees were found to be very less or rare. This might be due to over-collecting or exploitation of trees such as multiple uses for households near or outside the boundaries of the Park. Or it might be due to unfavorable conditions of microclimate such as growing under the shadow of the dominant trees that limited for the growth of smaller diameter size class trees to reach the mature one. However, all small diameter size class trees observed in forest ecosystems of Popa Mountain Park could be suggested they still belonged to a higher potential for substitution when the old or dominant ones died.

4.2 Carbon storage in forest ecosystems of Popa Mountain Park

Carbon storage in this research included the carbon stored in vegetation biomass and soil organic carbon in forest ecosystems of Popa Mountain Park.

4.2.1. Carbon storage in stems, branches, leaves and roots biomasses for trees with dbh ≥ 4.5 cm

Generally, biomass of the standing tree can be divided into 4 parts such as stems, branches, leaves and roots. Among the forest ecosystems, the research investigated dry hill evergreen forest possessed the largest value of carbon content in aboveground biomass of their vegetation parts followed by dry mixed deciduous forest, deciduous dipterocarp forest and dry forest, respectively. In dry hill evergreen forest, stem biomass of the forest ecosystem possessed 72.93±30.70 ton/ha whereas 42.08±21.24 ton/ha in dry mixed deciduous forest type, 30.99±24.18 ton/ha in deciduous dipterocarp forest, and 13.74±3.26 ton/ha in dry forest, respectively. In the case of branch biomass, dry hill evergreen belonged to the highest biomass concentration with 22.87±8.09 ton/ha when compared with other three forest ecosystems which were 8.35±4.53 ton/ha, 6.14±5.30 ton/ha and 8.77±3.61 ton/ha in dry mixed deciduous forest, deciduous dipterocarp forest and dry forest, respectively. For leaf biomass, dry hill evergreen possessed 2.09±0.54 ton/ha, dry mixed deciduous belonged to 1.49±0.70 ton/ha, deciduous dipterocarp forest was found to be 1.10±0.75 ton/ha and 8.77±3.61 ton/ha in dry forest ecosystem. For root biomass, hill evergreen forest contained 16.11±4.72 ton/ha where as 13.82±5.68 ton/ha, 11.13±5.54 ton/ha and 2.40±1.20 ton /ha in dry mixed deciduous forest, deciduous dipterocarp forest and dry forest. Total biomass from stems, branches, leaves and roots of dry hill evergreen forest was 114.00 ton/ha whereas 65.73 ton/ha in dry mixed deciduous forest, 49.68 ton/ha in deciduous dipterocarp forest and 33.67 ton/ha in dry forest, respectively.

As carbon content in their biomasses of each forest ecosystems, dry hill evergreen forest possessed 36.46±15.35 ton/ha, 11.44±4.05 ton/ha, 1.05±0.27 ton/ha and 8.05±2.36 ton/ha in stems, branches, leaves and roots, respectively. In dry mixed deciduous forest, their biomass belonged to carbon contents 21.04±10.62 ton/ha, 4.17±2.26 ton/ha, 0.75±0.35 ton/ha and 6.91±2.84 ton/ha in their stems, branches, leaves and roots. Deciduous dipterocarp forest maintained 15.50±12.10 ton/ha, 3.07±2.65 ton/ha, 0.55±0.37 ton/ha and 5.57±2.78 ton/ha whereas dry forest ecosystem stored carbon as 6.87±1.63 ton/ha, 4.38±1.81 ton/ha, 4.38±1.81 ton/ha and 1.20±0.60 ton/ha in their biomass of stems, branches, leaves and roots, respectively. In total, there were 57.00 ton/ha in dry hill evergreen forest, 32.87 ton/ha in dry mixed deciduous forest, 24.69 ton/ha in deciduous dipterocarp forest and 16.83 ton/ha in dry forest respectively in their standing tree biomasses. The total results highlighted dry hill evergreen forest belonged to the highest carbon content among the different forest ecosystems. Table 4.5 shows the comparison of carbon content for trees dbh ≥ 4.5 cm in different vegetation parts of forest ecosystems in Popa Mountain Park.

Table 4.5 Comparison of carbon content in different vegetation parts for trees with dbh ≥ 4.5 cm (ton/ha)

Vegetation Parts	Carbon content (ton/ha)			
	Dry hill evergreen	**Dry mixed deciduous**	**Deciduous dipterocarp**	**Dry forest**
Stems	36.46±15.35^{a}	21.04±10.61^{b}	15.50±12.10^{b}	6.87±1.63^{c}
Branches	11.44±4.05^{a}	4.17±2.26^{b}	3.07±2.65^{b}	4.38±1.81^{b}
Leaves	1.05±0.27^{b}	0.75±0.35^{b}	0.55±0.37^{b}	4.38±1.81^{a}
Roots	8.05±2.36^{b}	6.91±2.84^{b}	5.57±2.78^{b}	1.20±0.60^{a}
Total	**57.00**	**32.87**	**24.69**	**16.83**

Numbers are the total carbon with standard deviation (Mean±SD) in the parentheses. Different letters indicate significant difference among the forests according to Duncan's multiple range tests at 5% level of probability. The letters are the rank order from highest to lowest value (alphabetically). (For stems: $n = 24$, $df = 20$, $F = 7.48$, $p < 0.05$, for branches: $n = 24$, $df = 20$, $F = 11.05$, $p < 0.05$, for leaves: $n = 24$, $df = 20$, $F = 21.91$, $p < 0.05$, for roots: $n = 24$, $df = 20$, $F= 9.97$, $p < 0.05$)

The comparison of Duncan's multiple range tests showed carbon content in stems of dry hill evergreen forest and dry forest was significantly different among the forest ecosystems but the other two did not each other. For branches, dry hill evergreen forest was significantly different with deciduous dipterocarp forest ecosystems but other three forests did not differ significantly each other. In the case of carbon content in leaves, it was found dry forest was significantly higher than other forests. For root carbon, dry forest was significantly less than other there forest ecosystems.

4.2.2 Carbon storage in stems, branches, leaves and roots biomasses for saplings and shrubs with dbh < 4.5 cm

Among the forest ecosystems, the results showed dry forest possessed the highest biomass in terms of saplings and shrubs followed by deciduous dipterocarp forest, dry mixed deciduous forest and dry hill evergreen forest respectively. In dry hill evergreen forest, stem biomass of the saplings and shrubs possessed 0.11±0.13 ton/ha whereas 1.72±2.72 ton/ha in dry mixed deciduous forest, 1.36±1.24 ton/ha in deciduous dipterocarp forest, and 0.65±0.45 ton/ha in dry forest respectively. In the case of branch biomass, dry hill evergreen forest belonged to 0.02±0.03 ton/ha, 0.17±0.23 ton/ha in dry mixed deciduous forest, 0.13±0.12 ton/ha in deciduous dipterocarp forest and 0.10±0.07 ton/ha in dry forest. For leaves biomasses, dry hill evergreen forest possessed 0.05±0.06 ton/ha, dry mixed deciduous forest belonged to 0.48±0.53 ton/ha, deciduous dipterocarp forest contained 0.90±0.10 and dry forest consisted 0.02±0.01 ton/ha in dry hill evergreen forest ecosystem. In terms of root biomass, dry hill evergreen forest belonged to 0.05±0.06 ton/ha, dry mixed deciduous forest contained 0.48±0.53 ton/ha, deciduous dipterocarp forest included 0.90±0.10 ton/ha and dry forest contained 0.15±0.10 ton/ha, respectively. Total biomass from stems, branches, leaves and roots biomass of dry hill evergreen forest was 0.20 ton/ha whereas 2.40 ton/ha in dry mixed deciduous forest, 2.44 ton/ha in deciduous dipterocarp forest and 0.86 ton/ha in dry forest, respectively. Dry hill evergreen forest ecosystem found as the lowest biomass contained in saplings and shrubs compared with other forests.

As carbon content in their biomasses of each forest ecosystems, dry hill evergreen possessed 0.06±0.06 ton/ha, 0.01±0.01 ton/ha, 0.01±0.01 ton/ha and 0.03±0.03 ton/ha in stems, branches, leaves and roots, respectively. In dry mixed deciduous forest type, their biomass belonged to carbon content of 0.86±1.36 ton/ha, 0.08±0.12 ton/ha, 0.02±0.02 ton/ha and 0.24±0.27 ton/ha in their stems, branches, leaves and roots. Deciduous dipterocarp forest maintained 0.68±0.62 ton/ha, 0.07±0.06

ton/ha, 0.02±0.02 ton/ha and 0.45±0.55 ton/ha whereas dry forest ecosystem stored carbon as 0.33±0.23 ton/ha, 0.05±0.03 ton/ha,0.05±0.03 ton/ha and 0.01±0.01 ton/ha in their biomass of stems, branches, leaves and roots, respectively. In total, there were 0.11 ton/ha in dry hill evergreen forest, 1.20 ton/ha in dry mixed deciduous forest, 1.22 ton/ha in deciduous dipterocarp forest and 0.44 ton/ha in dry forest respectively in the biomasses of saplings and shrubs. Table 4.6 shows carbon content for saplings and shrubs with dbh < 4.5 cm in different vegetation parts of forest ecosystems in Popa Mountain Park.

Table 4.6 Total carbon content in different vegetation parts for saplings and shrubs with dbh < 4.5 cm (ton/ha)

Vegetation Parts	Carbon content (ton/ha)			
	Dry hill evergreen	**Dry mixed deciduous**	**Deciduous dipterocarp**	**Dry forest**
Stems	0.06±0.06	0.86±1.36	0.68±0.62	0.33 ±0.23
Branches	0.01±0.01	0.08±0.12	0.07±0.06	0.05±0.03
Leaves	0.01±0.01^{b}	0.02±0.02^{b}	0.02±0.02^{b}	0.05±0.03^{a}
Roots	0.03±0.03	0.24±0.27	0.45±0.55	0.01±0.01
Total	**0.11**	**1.20**	**1.22**	**0.44**

Numbers are the total carbon with standard deviation (Mean±SD) in the parentheses. Different letters indicate significant difference among the forests according to Duncan's multiple range tests at 5% level of probability. The letters are the rank order from highest to lowest value (alphabetically). (For stems: n=24, df= 20, F= 1.35, $p > 0.05$, for branches: n =24, df=20, F= 1.25, $p > 0.05$, for leaves: n= 24, df= 20, F= 4.05, $p < 0.05$, for roots: n=24, df= 20, F= 2.77, $p > 0.05$).

Duncan's multiple comparison range tests resulted carbon storage in leaves of saplings and shrubs were significantly different among the forest ecosystems but stems, branches and roots did not. The results highlighted dry mixed deciduous forest and deciduous dipterocarp forest belonged to the highest carbon content among the forest ecosystems while dry hill evergreen forest and dry forest contained less carbon content in their vegetation parts. The reason might be less gap opportunities that prevent carbon accumulation in the vegetation parts of dry hill evergreen forest and dry forest when compared with other forest ecosystems. Bhat and Murali (2005) stated the carbon accumulation of under-storey species of the forests respond positively to increase with light availability. That decides difference in carbon accumulation among the forests.

4.2.3 Carbon storage in litter, undergrowth and grass

In the regards of carbon content in forest litter, there were 2.29±0.64 ton/ha, 1.45±0.57 ton/ha, 0.81±0.51 ton/ha and 0.24±0.23 ton/ha in dry hill evergreen, dry mixed deciduous, deciduous dipterocap and dry forest, respectively. For carbon stored in undergrowth, there were 0.09±0.06 ton/ha, 0.13±0.10 ton/ha, 0.19±0.12 ton/ha and 0.12±0.10 ton/ha in dry hill evergreen, dry mixed deciduous, deciduous dipterocarp and dry forest, respectively. Grass biomass possessed 0.08±0.06 ton/ha in hill evergreen forest, 0.03±0.04 ton/ha in dry mixed deciduous forest, 0.07±0.10 ton/ha in deciduous dipterocarp forest and 0.07±0.01 in dry forest. This research found there were fewer amount of carbon stored in undergrowth of dry hill evergreen forest rather than other forest ecosystems. In terms of litter, it was detected the dry hill evergreen forest possessed the largest amount of carbon in litter fall compared with others. It can be assumed that litter fall on forest floor prevent sunlight directly to ground so that it might have less chance to grow pioneer species like shrubs, herbs and grass.

According to Duncan's multiple range tests, the carbon component in litter of dry hill evergreen forest and dry mixed deciduous forest were significantly different with other forest ecosystems whereas deciduous dipterocarp and dry forest did not differ each other. In the regards of carbon storage in undergrowth, the comparison showed deciduous dipterocarp forest was found the highest carbon in their undergrowth but all of the forests did not differ significantly at $p < 0.05$ level. In the case of carbon stored in grass biomass, the analysis expressed all forest ecosystems did not significantly different. Table 4.7 describes the Duncan's multiple range tests in the comparison of carbon content in litter, shrub, herb and grass in different forest types of Popa Mountain Park and figure 4.6 shows the carbon storage in vegetation of litter, undergrowth and grass in forest ecosystems.

Table 4.7 Comparison of carbon content in litter, undergrowth and grass (ton/ha)

Vegetation parameters	Carbon content (ton/ha)			
	Dry hill evergreen	**Dry mixed deciduous**	**Deciduous dipterocarp**	**Dry forest**
Litter	2.29±0.64[a]	1.45±0.57[b]	0.81±0.51[c]	0.24±0.23[c]
Undergrowth	0.09±0.06	0.13±0.10	0.19±0.12	0.12±0.10
Grass	0.08±0.06	0.03±0.04	0.07±0.10	0.07±0.01

Numbers are the means with standard deviation (Mean±SD) in the parentheses. Different letters indicate significant difference among the forests according to Duncan's multiple range tests at 5% level of probability. The letters are the rank order from highest to lowest value (alphabetically). (For litter: n=24, df= 20, F= 18.07, $p < 0.05$, for undergrowth: n =24, df=20, F= 1.26, $p > 0.05$, for grass: n= 24, df= 20, F= 0.79, $p > 0.05$)

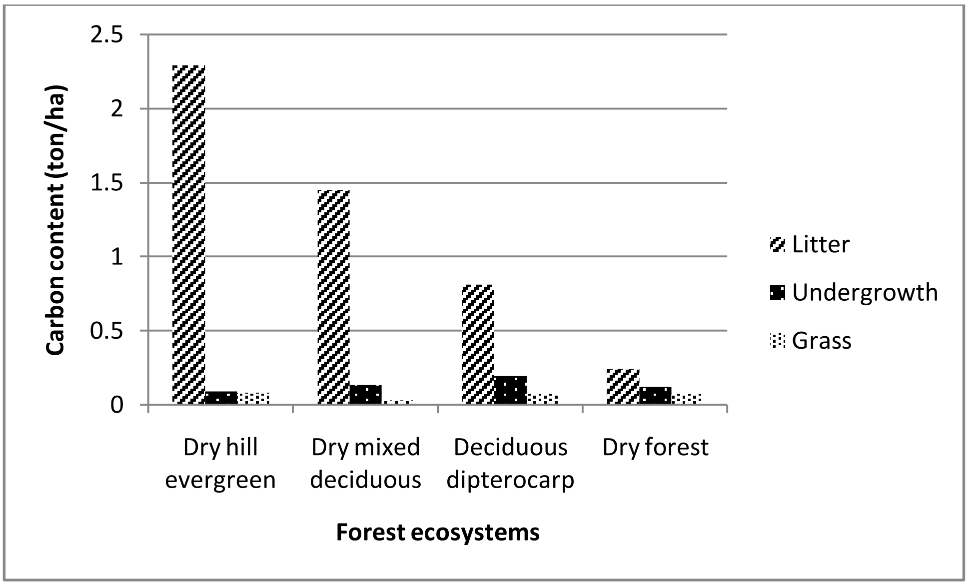


Fig 4.6 Carbon storage in litter, undergrowth and grass in forest ecosystems

4.2.4 Total carbon storage in vegetation biomass of forest ecosystems

When combining all carbon storage in trees with dbh ≥ 4.5 cm and saplings and shrubs with dbh < 4.5 cm, the results showed that dry hill evergreen contained 36.52 ton/ha, 11.45 ton/ha, 1.06 ton/ha and 8.08 ton/ha of carbon in their stems, branches, leaves and roots. Dry mixed deciduous forest included 21.90 ton/ha, 4.25 ton/ha, 0.77 ton/ha and 7.15 ton/ha in their stems, branches, leaves and roots biomasses. For deciduous dipterocarp forest, it belonged to 16.18 ton/ha, 3.14 ton/ha, 0.57 ton/ha and 6.02 ton/ha in their stems, branches, leaves and roots biomasses. Dry forest stored 7.20 ton/ha, 4.43 ton/ha, 4.43 ton/ha and 1.21 ton/ha in their stems, branches, leaves and roots biomasses. In total, dry hill evergreen forest contained 57.11 ton/ha whereas 34.07 ton/ha in dry mixed deciduous forest, 25.91 ton/ha in deciduous dipterocarp and 17.27 ton/ha in dry forest ecosystems, respectively. Table 4.8 shows the total carbon storage in trees with dbh ≥ 4.5 cm and saplings and shrubs with dbh < 4.5 cm of different forest ecosystems and figure 4.7 shows the total carbon storage in different vegetation parts of different forest ecosystems.

Table 4.8 Total carbon storage in trees, saplings and shrubs in forest ecosystems (ton/ha)

Vegetation parameters	**Carbon content (ton/ha)**			
	Dry hill evergreen	**Dry mixed deciduous**	**Deciduous dipterocarp**	**Dry forest**
Trees with dbh ≥ 4.5 cm	57.00	32.87	24.69	16.83
Saplings and shrubs with dbh < 4.5 cm	0.11	1.20	1.22	0.44
Total	**57.11**	**34.07**	**25.91**	**17.27**

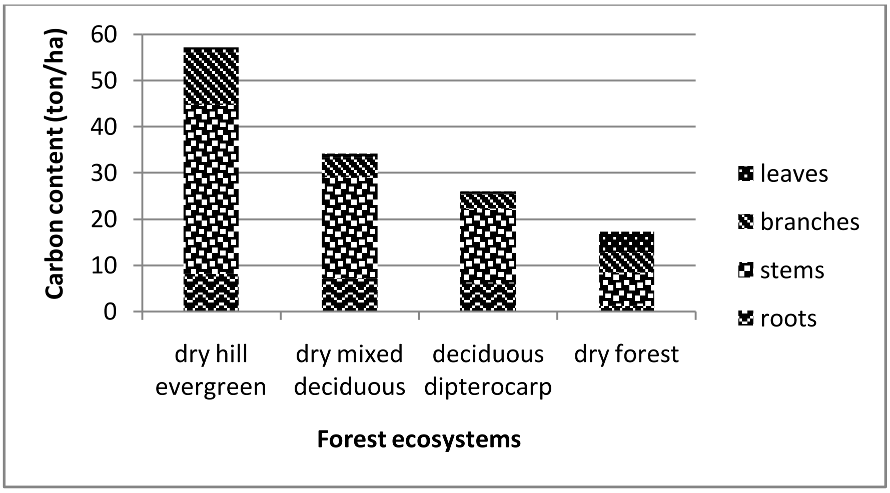


Fig. 4.7 Carbon storage in different vegetation parts of forest ecosystems

When combining all forest biomasses in trees, saplings and shrubs, litter, undergrowth and grass, the results obtained dry hill evergreen forest contained 59.57 ton/ha whereas dry mixed deciduous forest consisted of 35.68 ton/ha, deciduous dipterocarp forest belonged to 26.98 ton/ha and dry forest contained 17.70 ton/ha, respectively. Total carbon storage in all vegetations of forest ecosystems is shown in table 4.9.

Table 4.9 Total carbon storage in all vegetations of forest ecosystems (ton/ha)

Vegetation parameters	**Carbon content (ton/ha)**			
	Dry hill evergreen	**Dry mixed deciduous**	**Deciduous dipterocarp**	**Dry forest**
Trees with dbh ≥ 4.5 cm	57.00	32.87	24.69	16.83
Saplings and shrubs with dbh< 4.5 cm	0.11	1.20	1.22	0.44
Litter	2.29	1.45	0.81	0.24
Undergrowth	0.09	0.13	0.19	0.12
Grass	0.08	0.03	0.07	0.07
Total	**59.57**	**35.68**	**26.98**	**17.70**

4.2.5 Comparison of carbon content stored in forest ecosystems with other research findings

Aboveground carbon storage in all different forest ecosystems of this research showed less amount of carbon ton/ha compared with other studies. The comparison of aboveground carton storage with this research findings and previous research findings in different forest ecosystems are shown in Table 4.10.

Forest carbon content may vary in accord with land use, topography, forest types and so on. Aside from these, the net effect on changes in forest carbon depends on many factors. When forest practices alter the vegetation on a site, they alter the constant fluctuations of carbon storage and release CO_2 by changing biomass levels, vegetation growth patterns and soil structure and composition. Even afforestation and deforestation can have major impacts on carbon storage because often cuts of some vegetation for enhancement of desired tree growth from foresters cause CO_2 releasing from vegetation. Other factors such as forest management systems, nutrients and wild fire can also affect forest carbon change (Gorte, 2009).

Table 4.10 Comparison of aboveground carbon storage with other studies

Forest ecosystems	Carbon storage (ton/ha)		
	Current research findings	**Previous research findings**	**References for previous studies**
Stems, branches and leaves			
Dry hill evergreen	49.03	331.75	Senpaseuth et al. (2009)
		212.00	Panaadisai (2011)
Dry mixed deciduous	26.92	155.50	Ogawa et at. (1965)
		48.14	Terakunpisut et al. (2007)
		227.7	Oo (2009)
		42.42	Panaadisai (2011)
Deciduous dipterocarp	19.89	142.95	Senpaseuth et al. (2009)
		36.89	Panaadisai (2011)
Dry forest	16.06	112.19	Juwarkar et al. (2011)
Litter			
Dry hill evergreen	2.29	61.08	Pannadisai (2011)
Dry mixed deciduous	1.45	62.57	Pannadisai (2011)
		4.20	Oo (2009)
Deciduous dipterocarp	0.81	46.94	Pannadisai (2011)
Dry forest	0.24	-	-
Undergrowth			
Dry hill evergreen	0.09	-	-
Dry mixed deciduous	0.13	7.9	Oo (2009)
Deciduous dipterocarp	0.19	-	-
Dry forest	0.12	-	-
Grass			
Dry hill evergreen	0.08	-	-
Dry mixed deciduous	0.03	-	-
Deciduous dipterocarp	0.07	-	-
Dry forest	0.07	-	-

The carbon storage capacity of forest ecosystems in this research found less value when compared with other studies. However, forest ecosystems in Popa Mountain Park still have been possessing smaller diameter class of tree species which might have the great potential of carbon sequestration in their growth until they reach to climax stage. In the case of litter, undergrowth and grass, the amount of carbon content in this research was very less compared with other study. The reason might be due to the annual wild fires that burn litter, undergrowth as well as grass of the forests releasing CO_2 to the atmosphere so that the litter biomasses were resulting less carbon storage in their biomasses. Therefore, prevention of wild fire is also important for Popa Mountain Park.

4.3 Soil properties in forest ecosystems of Popa Mountain Park

Productive soils are the foundation of sustainable forest ecosystems. Generally, forest soils are impacted by fewer disturbances rather than agricultural soils resulting better preservation of A-horizons than agricultural soils. Disturbances of forest soils strongly related with land-use change, wildfire, drainage, timber harvest, nitrogen deposition and site preparation. These affect soil characteristics which in turn affect forest productivity and health (Perry and Amacher, 2007). The quality of forest soils is very important for the sustainability of forest ecosystem functions in addition to plant productivity. Specific functions and subsequent values supported by forest ecosystems are vary and depend on numerous soil physical, chemical, and biological properties and processes, which can differ across spatial and temporal scales (Schoenholtz et al., 2000).

The current research examined some soil properties including both physical and chemical properties in the study area of Popa Mountain Park. The results are discussed in the following.

4.3.1 Soil texture

Soil texture is an important soil physical characteristic that determines crop production and field management. The textural class of a soil is classified by the percentage of sand, silt, and clay. Four major textural classes are sands, silts, loams, and clays. A clay soil is a fine-textured soil and a sandy soil is a coarse textured soil. Soil texture influences on variables of soil properties such as drainage, water holding capacity, aeration, susceptibility to erosion, organic matter content, cation exchange capacity, pH and soil tilth, etc (Berry et al., 2007).

Soil texture drives the rate of water flows through a saturated soil. For example, water moves more freely through sandy soils than it does through clayey soils. Soil texture also determines how much water is available to the plant. For example, clay soils have a greater water holding capacity than sandy soils. Accordingly, well drained soils have good soil aeration resulting healthy root growth and thus a healthy crop. Soil texture also determines erodibility of a soil. For example, a soil with higher percentage of silt and clay particles has a greater risk for soil erosion than a sandy soil. Soil texture also impacts organic matter levels. For example, organic matter breaks down faster in sandy soils than in fine-textured soil because of the sufficient availability of oxygen for decomposition in the light-textured sandy soils. Soil texture also controls cation exchange capacity. For example, cation exchange capacity is increases with the percentage of clay and organic matter. As the same way, pH also depends on clay and organic matter content as well as soil tilth (Berry et al., 2007). Figure 4.8 is the triangle that determines soil texture according to the percentage of sand, silt and clay content.

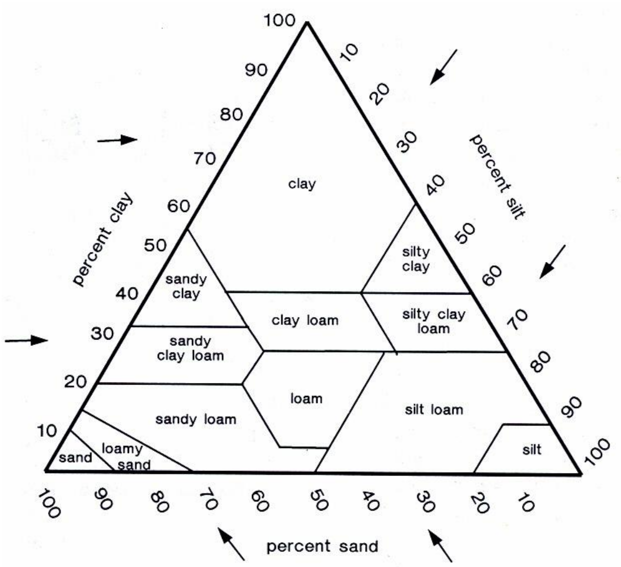


Fig. 4.8 Soil texture triangle (Source: Berry et al., 2007)

According to multiple comparison tests, the percentage of sand, silt, and clay results in 0 - 15 cm and 15 - 30 cm layers were variable in forest ecosystems. For sand content in forest ecosystems of the research showed that dry hill forest and dry forest differ significantly at 5% level with other forest ecosystems while dry mixed deciduous forest and deciduous dipterocarp forest did not differ significantly each others at both layers of soil. As the same results as in sand percentage, silt component of all forest ecosystems differ significantly at both soil layers but dry hill evergreen and dry forest as well as dry mixed deciduous forest and deciduous dipterocarp forest did not differ significantly each other at 5% level. In the case of clay percentage in soil in different forests, it showed different from the results of sand and silt. It only resulted dry hill evergreen forest was significantly different in clay component in 0 - 15 cm soil layer with other forest ecosystems whereas other three forest ecosystems did not differ significantly each other. In the regards of 15 - 30 cm depth, all forest ecosystems were significantly different each other expect dry mixed deciduous forest and deciduous dipterocarp forest. The results of sand, silt and clay percentages are shown in table 4.11.

Table 4.11 Comparison of sand, silt and clay component in forest ecosystems

Forest ecosystems	0-15 cm			15-30 cm		
	Sand%	Silt%	Clay%	Sand%	Silt%	Clay %
Dry hill evergreen	68.02±6.91[a]	12.62±5.4[b]	19.36±2.03[a]	64.69±11.19[a]	14.62±4.04[b]	20.70±4.55[c]
		Sandy Loam			Clay Loam	
Dry mixed deciduous	45.74±12.91[c]	23.69±9.00[a]	30.57±8.98[b]	32.19±14.86[c]	27.74±8.26[a]	40.07±10.94[a]
		Sandy Clay Loam			Clay	
Deciduous dipterocarp	40.35±16.33[c]	24.48±11.52[a]	35.17±11.69[b]	31.28±13.87[c]	23.96±5.78[a]	44.76±12.14[a]
		Clay Loam			Clay	
Dry forest	56.26±6.92[b]	13.65±4.43[b]	30.09±5.21[b]	56.24±7.79[b]	15.07±6.13[b]	28.68±5.86[b]
		Sandy Loam			Sandy Loam	

Numbers are the means with standard deviation (Mean±SD) in the parentheses. Different letters indicate significant difference among the forests according to Duncan's multiple range tests at 5% level of probability. The letters are the rank order from highest to lowest value (alphabetically). (sand for 0-15cm: $n= 72$, $df= 68$, $F= 20.34$, $p < 0.05$, sand for 15-30cm: $n= 72$, $df= 68$, $F= 34.53$, $p < 0.05$, silt for 0-15cm: $n= 72$, $df= 68$, $F= 10.98$, $p < 0.05$, silt for 15-30cm: $n= 72$, $df= 68$, $F= 16.32$, $p < 0.05$, clay for 0-15cm: $n= 72$, $df= 68$, $F= 12.98$, $p < 0.05$, clay for 15-30cm: $n= 72$, $df= 68$, $F=26.60$, $p < 0.05$)

According to the soil texture triangle, dry hill evergreen possessed sandy loam soil in upper layer of 0 - 15 cm and clay loam soil in 15 - 30 cm layer. For dry mixed deciduous forest, 0 - 15 cm soil layer belonged to sandy clay loam and clay soil in 15 - 30 cm whereas in deciduous dipterocarp forest, clay loam in 0 - 15 cm and clay in 15 - 30 cm, and in dry forest, both soil layers were sandy loam soil.

4.3.2 Soil bulk density

Bulk density indicates how much of soil compaction. It is calculated as the dry weight of soil divided by its volume. The volume involves the volume of soil particles and the volume of pores of soil particles, and it expresses in gram per cubic centimeter (g/cm^3). Soil texture, organic matter particles and their packing arrangement influence on bulk density. As a rule of thumb, most rocks have a bulk density of 2.65 g/cm^3. A medium texture soil with about 50 % pore space will have a bulk density of 1.33 g/cm^3. Generally, loose, porous soil rich in organic matter have lower bulk density. For example, sandy soil has relatively high bulk density than silt or clay soil. As the same way, finer textured soil such as silt and clay loams has lower bulk density compared with sandy soil because they have good structure with higher pore space while sandy soil has less pore space. Furthermore, bulk density increases with soil depth which has less pore space than surface layers. Therefore, high bulk density means low soil porosity and soil compaction. It may result poor movement of air and water restricting to root growth. Consequently, it impacts crop yield and reduces vegetative cover in terms of protection of soil erosion (Arshad et al., 1996). Jaiarree et al. (2011) also supported the available value of bulk density for natural forest soil which was 1.39 g/cm^3 for 0 - 17 cm soil depth. Table 4.12 shows the general relationship of root growth and bulk density based on soil texture.

Table 4.12 Relationship of root growth and bulk density based on soil texture

Soil Texture	**Ideal bulk densities for plant growth (g/cm^3)**	**Bulk densities that restrict root growth (g/cm^3)**
Sandy	< 1.60	>1.80
Silty	< 1.40	> 1.65
Clayey	< 1.10	> 1.47

(Source: Arshad et al., 1996)

In the research, the results showed dry hill evergreen forest belonged to the least mean value of bulk density which were 0.76 g/cm^3 in 0 - 15 cm layer whereas 0.79 g/cm^3 in 15 - 30 cm depth. In dry mixed deciduous forest, the mean bulk density of upper soil layer was 1.12 g/cm^3 and 1.18 g/cm^3 in lower layer. At the same time, 1.37 g/cm^3 and 1.47 g/cm^3 in 0 - 15 cm soil depth whereas 1.21 g/cm^3 and 1.41 g/cm^3

in 15 - 30 cm soil depth of deciduous dipterocarp forest and dry forest respectively. Table 4.13 shows the results of Duncan's multiple comparison tests for bulk density in forest ecosystems.

Table 4.13 Comparison of bulk density in forest ecosystems

Soil layers	**Bulk density**			
	Dry hill evergreen	**Dry mixed deciduous**	**Deciduous dipterocarp**	**Dry forest**
0-15 cm	$0.76{\pm}0.20^{b}$	$1.12{\pm}0.12^{c}$	$1.37{\pm}0.24^{a}$	$1.47{\pm}0.20^{a}$
15-30 cm	$0.79{\pm}0.22^{c}$	$1.18{\pm}0.17^{b}$	$1.21{\pm}0.27^{b}$	$1.41{\pm}0.16^{a}$

Numbers are the means with standard deviation (Mean±SD) in the parentheses. Different letters indicate significant difference among the forests according to Duncan's multiple range tests at 5% level of probability. The letters are the rank order from highest to lowest value (alphabetically). (n=72, df= 68, F= 47.25, $p < 0.05$ for 0-15 cm and n=72, df= 68, F= 27.30, $p < 0.05$ for 15-30 cm)

The results said the bulk density for 0 - 15 cm depth of dry hill evergreen forest was significantly different at 5% level with other forest ecosystems while dry mixed deciduous forest, deciduous dipterocarp and dry forest did not significantly difference each other. For 15 - 30 cm depth of soil bulk density, all forest ecosystems but dry mixed deciduous forest and deciduous dipterocarp forest did not show significantly difference at 5% level.

Comparing with the findings of Arshad et al. (1996), the current research findings were nearly around the ideal bulk densities for plant growth. Confidently, it could be concluded that dry hill evergreen forest might have high organic matter which bulk density showed very low compared with the bulk densities of other forest ecosystems. For this research, soil bulk density was ranging from 0.76 g/cm^3 to 1.47 g/cm^3 in 0 - 15 cm layer of four focusing forests. Figure 4.9 shows mean value of soil bulk density in 0 - 15 cm and 15 - 30 cm depth of forest ecosystems.

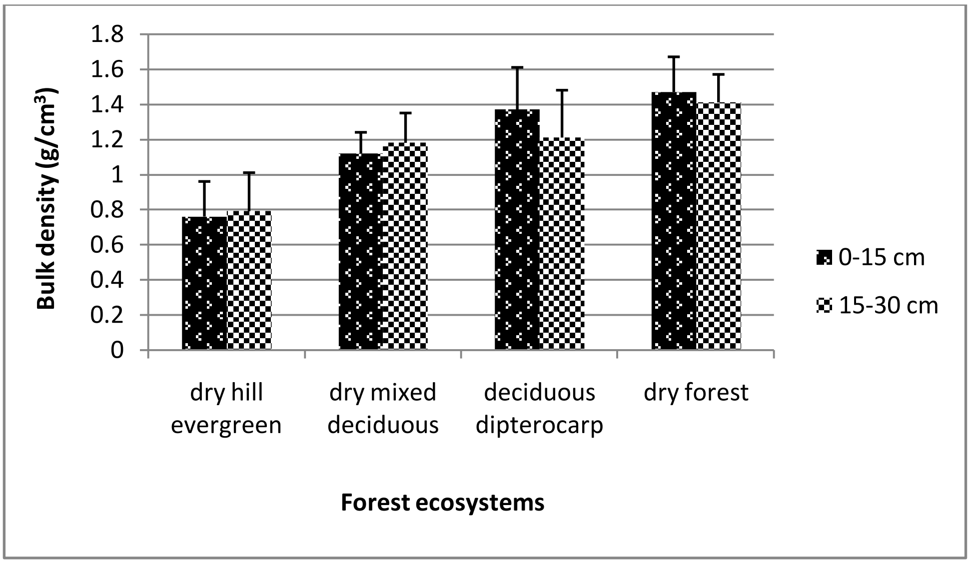


Fig. 4.9 Soil bulk densities in forest ecosystems

4.3.3 Percentage of soil moisture

Soil moisture is water contained in soil which held in soil pore. Soil moisture is a small proportion which is only 0.15% of the liquid freshwater on the earth. Soil moisture strongly influences the interactions between the land surface and the atmosphere which in turn influences climate and weather. It is also a major component of the soil related to plant growth. If there is an adequate amount of soil moisture content, plants can readily absorb soil water for their growth since soil water dissolves salts and makes up the soil solution which is important as a medium for supply of nutrients for plant growth (Shaxson and Barber, 2003). Soil water serve as a solvent and carrier of food nutrients for plant growth, determine yield of crop, acts as a nutrient itself, regulates soil temperature, essential for soil forming processes and weathering, metabolic activities of micro-organisms, chemical and biological activities of soil as well as for photosynthesis. IPCC (2007c) also supported the moisture condition of soil influences the evapotranspiration mechanisms and the emission and absorption of gases. Soil moisture is a small proportion which is only 0.15% of the liquid freshwater on the earth. It also impacts a variety of process related to plant growth as well as a range of soil processes. Soil moisture may vary in accord with the degree of local climate change as well as soil characteristics (Western et al., 2002). Figure 4.10 is the soil moisture range chart which is almost cited in Ploeg et al. (2009).

According to figure 4.10, it describes wilting point, irrigation start point and field capacity in different soil types.

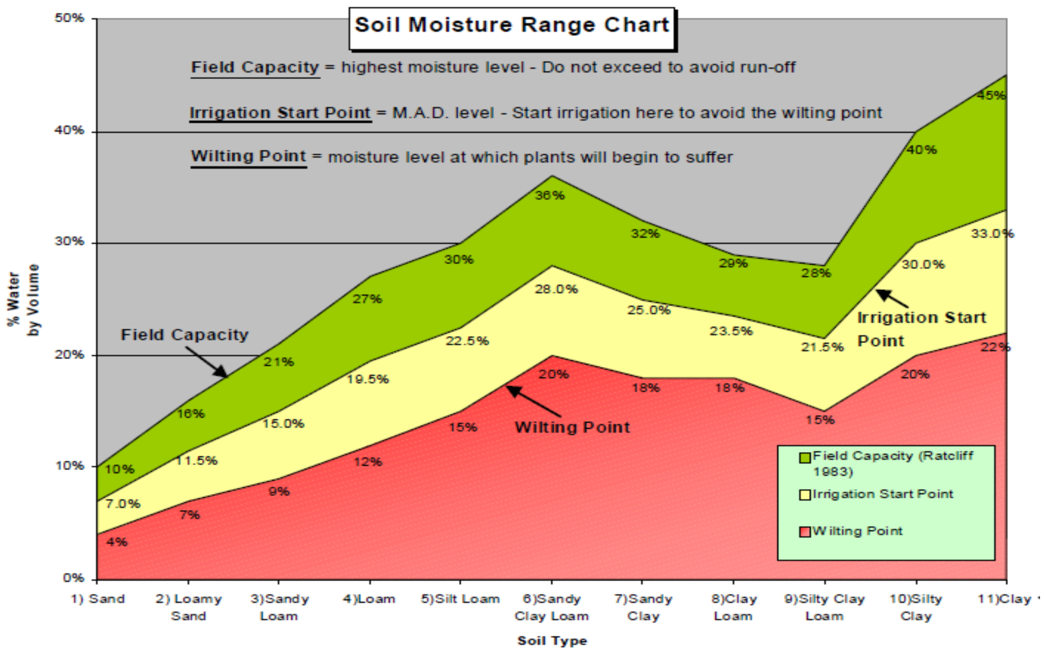


Fig 4.10 Soil moisture range chart

(Source:ftp://ftp.dynamax.com/turf_irrigation/Soil%20Moisture%20Range%20Chart.pdf)

Regarding to the research findings, soil moisture content was variable in the layers 0 - 15cm and 15 - 30 cm of different forest ecosystems. The average soil moisture in dry hill evergreen forest found 65.68% in 0 - 15 cm layer and 56.78% in sub soil layer of 15 - 30 cm. In dry mixed deciduous forest, there were 37.83% of average soil moisture in 0 - 15 cm depth and 32.72% in 15 - 30 cm depth. For deciduous dipterocarp forest, it showed 28.29% of average soil moisture content in the upper layer and 31.78% in the subsoil layer. In dry forest, 19.22% of average soil moisture content represented as 0 - 15 cm depth and 20.06% for 15 - 30 cm depth. Table 4.14 and figure 4.11 explain the difference of soil moisture content in different forest ecosystems according to Duncan's multiple range tests.

Table 4.14 Comparison of soil moisture in forest ecosystems

Soil layers	Soil moisture%			
	Dry hill evergreen	Dry mixed deciduous	Deciduous dipterocarp	Dry forest
0-15 cm	65.68±20.01[a]	37.83±6.25[b]	28.29±7.58[c]	19.22±6.09[d]
15-30 cm	56.78±19.12[a]	32.72±4.02[b]	31.78±6.84[b]	20.06±8.32[c]

Numbers are the means with standard deviation (Mean±SD) in the parentheses. Different letters indicate significant difference among the forests according to Duncan's multiple range tests at 5% level of probability. The letters are the rank order from highest to lowest value (alphabetically). (n=72, df= 68, F= 54.51, $p < 0.05$ for 0-15 cm and n=72, df= 68, F= 34.37, $p < 0.05$ for 15-30 cm)

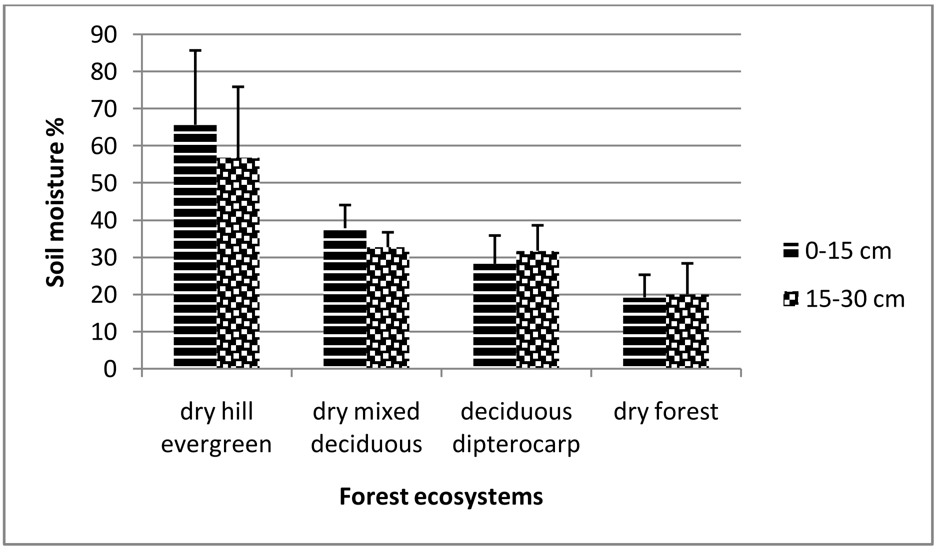


Fig. 4.11 Comparison of soil moisture in forest ecosystems

According to the comparison test, percentage of soil moisture content of dry hill evergreen and dry mixed deciduous showed higher values in 0 - 15 cm depth than the subsoil layer 15 - 30 cm depth except with deciduous dipterocarp forest and dry forest which showed a little less value of soil moisture % in 15 - 30 cm layer than 0 - 15 cm layer. For soil moisture % of 0 - 15 cm layer, all forest ecosystems in the research were significantly difference at 5% level but for 15 - 30 cm depth, all forest ecosystems received significantly different values while dry mixed deciduous and deciduous dipterocarp did not differ each other significantly.

According to soil moisture chart cited in Ploeg et al. (2009), soil moisture content % in both soil layers of all forests belonged to field capacity point which is the highest moisture level for plant growth and over wilting point.

4.3.4 Soil pH

pH is the measure of acidity. It is also the measure of the potential of hydrogen ions. The higher the concentration of hydrogen ions, the lower the pH of the soil. The level of acidity or alkalinity is measured on a scale of 1 to 14 with 7 being neutral. The availability of plant nutrient varies in accord with soil pH (Miller and Hills, 2000). Soil pH influences the nutrient availability to plants. Some nutrients are only available at a certain level of pH. For example, acid soils can cause deficiencies of phosphorus, calcium, magnesium and molybdenum, as well as toxic levels of manganese and aluminium. Alkaline soils may result deficiencies in iron, manganese, boron, copper and zinc. Most plants prefer neutral soil but some prefer other pH levels. In terms of resistance for plant against pests and diseases, only strong and health plants which get adequate water, nutrition and sunlight will build up a natural resistance. Therefore, soil pH is one of the important soil properties for well plant growth (Hoffmann, 2010). Jaiarree et al. (2011) supported soil pH for natural forest which was ranging from 6.0 to 7.2 for 0-30 cm soil layer in the previous research. Figure 4.12 shows nutrient availability and soil pH. According to soil pH, the narrow bands represent less availability of nutrients whereas the widest are the most availability of nutrients.

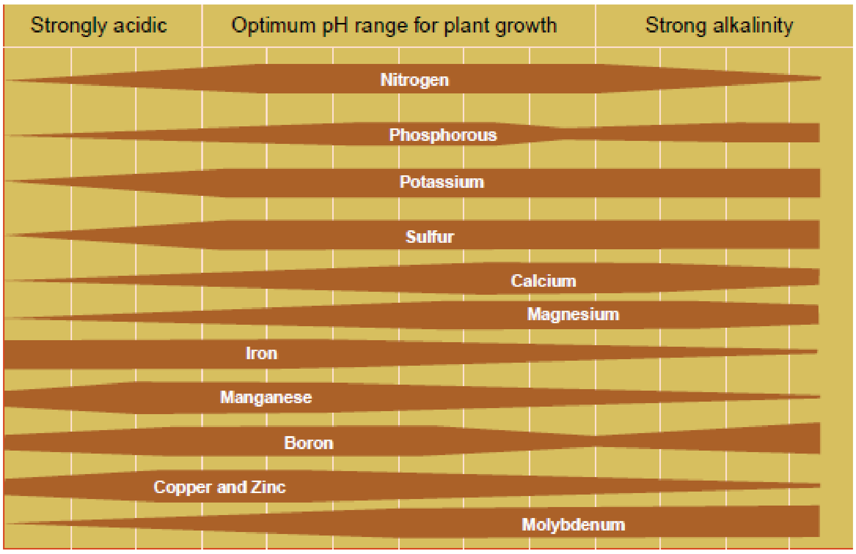


Fig. 4.12 Nutrients availability with pH (source: Miller and Hills, 2000)

According to the research, dry hill evergreen forest contained average pH about 6.67 in 0 - 15 cm depth whereas 6.42 in subsoil layer of 15 - 30 cm depth. In dry mixed deciduous forest, it was found 6.63 of soil pH in upper layer and 6.44 in subsoil layer. In the case of deciduous dipterocarp forest, pH was 6.57 in 0 - 15 cm depth and 6.53 in 15 - 30 cm depth. For dry forest, the upper layer was found pH 7.36 whereas 7.58 in subsoil layer. Table 4.15 and figure 4.13 exhibit the difference of soil pH in forest ecosystems according to Duncan's multiple range tests.

Table 4.15 Comparison of soil pH in forest ecosystems

Soil layers	**Soil pH**			
	Dry hill evergreen	**Dry mixed deciduous**	**Deciduous dipterocarp**	**Dry forest**
0-15 cm	6.67±0.55[b]	6.63±0.27[b]	6.57±0.56[b]	7.36±0.76[a]
15-30 cm	6.42±0.50[b]	6.44±0.25[b]	6.53±0.57[b]	7.58±0.72[a]

Numbers are the means with standard deviation (Mean±SD) in the parentheses. Different letters indicate significant difference among the forests according to Duncan's multiple range tests at 5% level of probability. The letters are the rank order from highest to lowest value (alphabetically). ($n=72$, $df= 68$, $F= 7.84$, $p < 0.05$ for 0-15 cm and $n=72$, $df = 68$, $F= 19.23$, $p < 0.05$ for 15-30 cm)

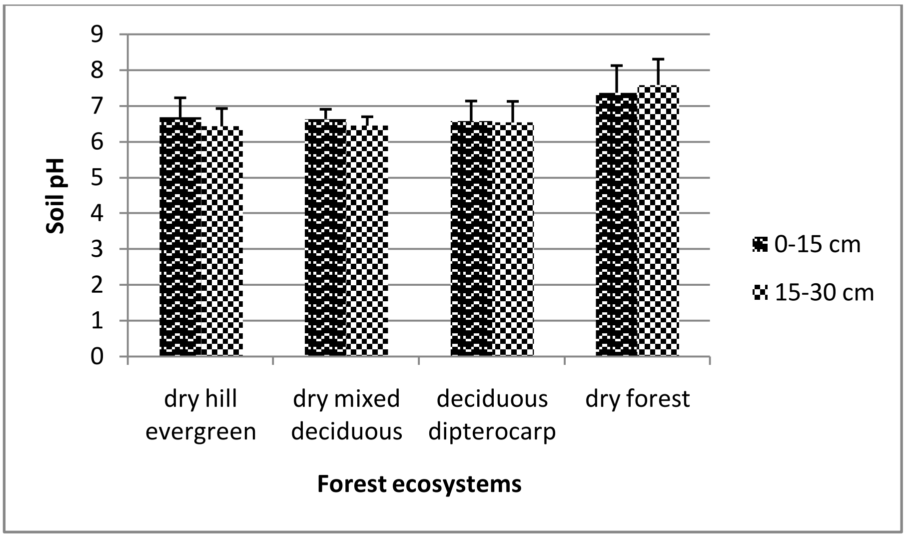


Fig. 4.13 Soil pH in forest ecosystems

According to Duncan's multiple range tests, pH values of nearly all forest types were not different significantly while dry hill evergreen forest and dry forest were significantly different at 5% level. Regarding to figure 4.16, soil pH found in different forest types of Popa Mountain Park were said to be optimum pH range for plant growth. All values showed neither strong acid nor strong alkali. Therefore, soil pH for all focused forest ecosystems in the research was in good condition for the establishment of plant growth.

4.3.5 Soil organic matter

Healthy soil is very important for plant growth. Plants obtain nutrient form two natural sources: organic matter and minerals (Bot and Benites, 2005). Organic matter consists of any plant or animal material that goes to the soil by decomposition process. Organic matter is made up of different components such as plant residues and living microbial biomass, detritus as active soil organic matter and humus as stable soil organic matter. The living microbial biomass involves the microorganisms which provide decomposition of plant residues and detritus (Fenton et al., 2008). Most soil contains 2 - 10% of organic matter. Soil organic matter is very essential for nutrient exchanges that maintain sustainable production purposes. Soil organic matter contributes to soil productivity in many different ways. Soil organic matter content is a function of organic matter inputs and litter decomposition. It is also related to moisture, temperature and aeration as well as physical and chemical properties of the soils (Bot and Benites, 2005).

In the regards of the results, all mean values of soil organic matter% in 0 - 15 cm soil depth showed higher than 15 - 30 cm soil depth. The mean value of soil organic matter in 0 - 15 cm layer contained 19.78%, 4.81%, 2.88% and 1.87% while in 15 - 30 cm layer involved 15.92%, 2.81%, 1.80% and 1.42% in dry hill evergreen forest, dry mixed deciduous forest, deciduous dipterocarp forest and dry forest respectively. The comparison of the mean values of soil organic matter% in both soil layers of forest ecosystems are shown in table 4.16 and figure 4.14.

Table 4.16 Comparison of soil organic matter in forest ecosystems

Soil layers	Soil organic matter%			
	Dry hill evergreen	**Dry mixed deciduous**	**Deciduous dipterocarp**	**Dry forest**
0-15 cm	19.78 ± 8.55^{a}	4.81 ± 1.33^{b}	2.88 ± 1.07^{cd}	1.87 ± 0.82^{cd}
15-30 cm	15.92 ± 7.81^{a}	2.81 ± 1.03^{b}	1.80 ± 0.62^{b}	1.42 ± 0.93^{b}

Numbers are the means with standard deviation (Mean±SD) in the parentheses. Different letters indicate significant difference among the forests according to Duncan's multiple range tests at 5% level of probability. The letters are the rank order from highest to lowest value (alphabetically). (n=72, df= 68, F= 66.01, $p < 0.05$ for 0-15 cm and n=72, df= 68, F= 55.38, $p < 0.05$ for 15-30 cm)

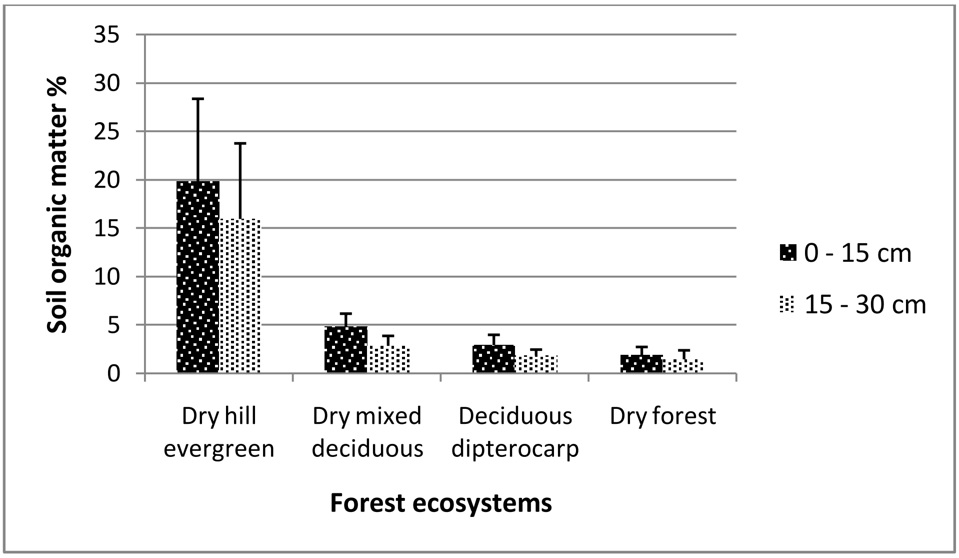


Fig 4.14 Soil organic matter in forest ecosystems

Duncan's multiple comparison tests resulted the mean value of soil organic matter in both layers of soil of dry hill evergreen forest was different significantly with other forest types while deciduous dipterocarp and dry forest were not differ significantly at 5% level in 0 - 15 cm depth and dry mixed deciduous, deciduous dipterocarp and dry forests did not differ significantly at 15 - 30 cm level. According to the results, dry hill evergreen forest belonged to the highest forest growth potential as it contained the highest soil organic matter when compared with others.

4.3.6 Total nitrogen

The atmosphere contains about 78% nitrogen gas (N_2). However, most plants cannot use atmospheric N_2. Atmospheric N_2 must be converted by means of biological fixation (i.e., nitrogen fixing bacteria takes N_2 from atmosphere and fix it in a form that plant can use) or chemical fixation (i.e., ammonia NH_3 by combination of atmospheric N_2 with hydrogen H_2). Most of nitrogen in the soil is unavailable organic form. This form of nitrogen is converted to available form by means of soil bacteria. It is influenced by environmental factors such as temperature, rainfall, and soil oxygen levels. In this situation, the amount of organic matter takes a role for increasing soil nitrogen levels as a natural source (Bundy, 1998).

The total nitrogen content of surface mineral soils normally ranges between 0.05% and 0.2%. It can be varied in accord with various soil forming processes. In most cases, less than 5% of total nitrogen is available to plants in the form as nitrate N (NO_3) and ammonium N (NH_4). Nitrogen is the most important plant nutrient which is essential component of chlorophyll, enzymes, proteins, etc. Nitrogen stimulates root growth and crop development (Hofman and Cleemput, 2004). Luo and Zhou (2006) also supported that high nitrogen content is generally associated with high growth rates. It was found by Jaiarree et al. (2011) that total nitrogen for natural forest in the previous research was ranging 0.8% to 3.9% for 0 - 30 cm depth.

According to the results, all 0 - 15 cm soil layers of forest ecosystems found to be the higher total nitrogen than the 15 - 30 cm soil layers. Dry hill evergreen forest consisted of the highest amount of total nitrogen in both soil layers compared with others. Dry hill evergreen forest possessed 3.76% of total nitrogen in upper soil layer whereas 3.45% of total nitrogen in subsoil layer. As the same way, 1.56%, 0.86% and 0.85% in 0 - 15 cm layers of soil while 0.95%, 0.74% and 0.70% of total nitrogen in 15 - 30 cm layers of dry mixed deciduous forest, deciduous dipterocarp forest and dry forest respectively. The results are as shown in Table 4.17 and figure 4.15.

Table 4.17 Comparison of total nitrogen in forest ecosystems

Soil layers	**Total nitrogen %**			
	Dry hill evergreen	**Dry mixed deciduous**	**Deciduous dipterocarp**	**Dry forest**
0-15 cm	3.77±1.51[a]	1.56±0.69[b]	0.87±0.43[c]	0.85±0.36[c]
15-30 cm	3.45±1.73[a]	0.95±0.31[b]	0.74±0.60[b]	0.70±0.32[b]

Numbers are the means with standard deviation (Mean±SD) in the parentheses. Different letters indicate significant difference among the forests according to Duncan's multiple range tests at 5% level of probability. The letters are the rank order from highest to lowest value (alphabetically). (n= 72, df= 68, F= 44.51, $p < 0.05$ for 0-15 cm and n= 72, df= 68, $p < 0.05$, F= 36.12 for 15-30 cm)

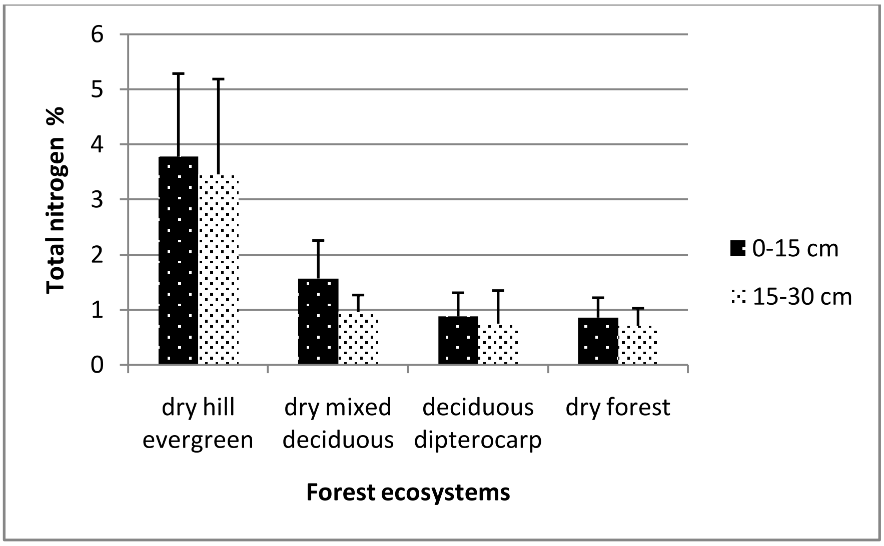


Fig 4.15 Total nitrogen in forest ecosystems

The multiple comparison tests outputted that the mean value of total nitrogen in 0 - 15 cm layer of all forest were significantly different at 5% level of probability but deciduous dipterocarp forest and dry forest did not differ significantly in containing total nitrogen in their soils. In the case of 15 - 30 cm soil layer, only dry hill evergreen differed significantly with other forest ecosystems while the other three did not.

4.3.7Available phosphorus

Phosphorus is a naturally occurring element in the environment that can be found in all living organisms as well as in water and soils. Phosphorus is one of the essential nutrients for plant growth. An adequate supply of phosphorus is required for optimum growth and reproduction. Once inside the plant root, phosphorus may be stored in the root or transported to the upper portions of the plants. If there is limited phosphorus, it affects the expansion of leaves and leaf surface area as well as the number of leaves. Phosphorus deficiency also reduces root growth leading to fewer roots mass to reach water and nutrients. Other effects of phosphorus deficiency on plant growth include delayed maturity, reduced quality of forage, fruit, vegetable and grain corps as well as decreased disease resistance (John and William, 1999).It was evaluated by Jaiarree et al. (2011) in the previous research for available phosphorus found in natural forest was ranging from 9.70 ppm to 32.91 ppm. The following table 4.18 shows phosphorus levels by Marx et al. (1996).

Table 4.18 Available phosphorus levels

Level	**Available Phosphorus (ppm)**
Low	< 20
Medium	20-40
High	40-100
Excessive	>100

(Source: Marx et al., 1996)

According to the results, hill evergreen forest belonged to the mean value of P of 123.79 ppm in 0 - 15 cm depth and 108.84 ppm in 15 - 30 cm depth while dry mixed deciduous forest contained 28.31 ppm in upper soil layer and 12.45 ppm in subsoil layer, deciduous dipterocarp forest involved 45.81 ppm in upper layer and

56.48 ppm in sub layer, and dry forest possessed 35.12 ppm in upper layer and 29.22 ppm in subsoil layer respectively. The multiple comparison tests result is shown in table 4.19 and figure 4.16.

Table 4.19 Comparison of available phosphorus in forest ecosystems

Soil layers	**Available phosphorus (ppm)**			
	Dry hill evergreen	**Dry mixed deciduous**	**Deciduous dipterocarp**	**Dry forest**
0-15 cm	123.00±139.24[a]	28.31±41.52[b]	45.81±54.85[b]	35.12±27.59[b]
15-30 cm	108.84±172.62[a]	12.45±17.59[c]	56.48±85.96[abc]	29.23±26.81[b]

Numbers are the means with standard deviation (Mean±SD) in the parentheses. Different letters indicate significant difference among the forests according to Duncan's multiple range tests at 5% level of probability. The letters are the rank order from highest to lowest value (alphabetically). (n=72, df= 68, F= 5.67, p < 0.05 for 0-15 cm and n=72, df= 68, F= 3.35, p < 0.05 for 15-30 cm)

The comparison tests expressed the mean value of available phosphorus for 0-15 cm layer of dry hill evergreen forest was significantly different at 5% level of the probability when compared with others. For the lower 15-30 cm depth, the mean values of available phosphorus in all forest ecosystems were significantly different at 5% level in each mean values of phosphorus except for which deciduous dipterocarp forest did not differ significantly with others.

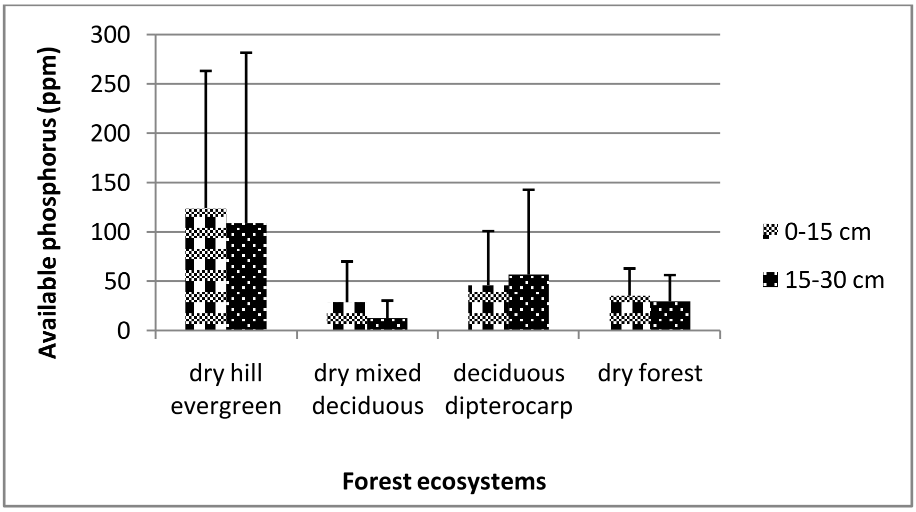


Fig. 4.16 Available phosphorus in forest ecosystems

When compared with available phosphorus levels according to Marx et al. (1996) and Jaiarree et al. (2011), the phosphorus contents in dry hill evergreen forest at both soil layers were in excessive levels which were more than 100 ppm. In dry mixed deciduous forest, the phosphorus contents contained in both soil layers were at medium which phosphorus values were between 20 - 40 ppm. For deciduous dipterocarp forest, the phosphorus involvement in its soil layers of 0 - 15 cm and 15 - 30 cm were said to be high because of their values coincided between 40 - 100 ppm while the available of phosphorus in dry forest consisted were at medium levels. According to Marx et al. (1996), none of the forest ecosystems in Popa Mountain Park were found as lower levels of phosphorus or phosphorus deficiency. The research was found the standard deviation for some forest ecosystems were too high. The fact is due to too varying of the soil phosphorus even in the same forest type. There was a claim by Hairston and Grigal (1991) that soil properties can vary even in the same topography, landscape or within single mapping units.

4.3.8 Available potassium

Potassium is absorbed by plants in larger amounts than any other mineral element except nitrogen. In soils, only small amount of potassium is available for plants. One of the significant functions of potassium is in the construction of cuticle layer. Soil potassium exists in three forms such as unavailable, slowly available and readily available. The unavailable form is found in un-weathered or slightly weathered minerals which accounts for 90% - 98% of total potassium in soil. The presence of slowly available potassium is depending on soil type and equilibrium of the soil which accounts for 1% - 10% of soil potassium. Readily available potassium is a combination of water soluble and exchangeable potassium which accounts for 0.1% - 2% depending on soil type. Potassium influences on photosynthesis, plays a role in water retention and uptake of the plants. Therefore, a plant with adequate potassium can stand longer periods of low moisture. The symptom of potassium deficiency is the wilting of plants in prolonged dry weather (A & L Canada Laboratories Inc, 2002). According to Jaiarree et al. (2011), the available potassium in natural was ranging from 28.89 ppm to 153.40 ppm in 0 - 30 cm soil layer. The available phosphorus levels are shown in Table 4.20.

Table 4.20 Available potassium levels

Level	Available Potassium (ppm)
Low	<150
Medium	150-250
High	250-800
Excessive	>800

(Source: Marx et al., 1996)

According to the results, dry hill evergreen forest possessed the mean values of available potassium of 28.52 ppm and 37.11 ppm in 0 - 15 cm soil depth and 15 - 30 cm soil depth. In dry mixed deciduous forest, it contained 537.87 ppm in upper soil layer and 659.27 ppm in lower soil layer. In the case of deciduous dipterocarp forest, 0 - 15 cm of soil layer consisted 315.83 ppm and 15 - 30 cm soil depth belonged to 388.24 ppm whereas 115.01 ppm and 95.70 ppm in both soil layers of dry forest. Table 4.21 and figure 4.17 highlight the comparison results of available potassium contents in forest ecosystems.

Table 4.21 Comparison of available potassium in forest ecosystems

Soil layers	Available potassium (ppm)			
	Dry hill evergreen	Dry mixed deciduous	Deciduous dipterocarp	Dry forest
0-15 cm	28.52±18.90[c]	537.87±222.17[a]	315.83±158.14[b]	115.01±38.38[c]
15-30 cm	37.11±67.08[c]	659.27±315.90[a]	388.24±197.42[b]	95.78±39.94[c]

Numbers are the means with standard deviation (Mean±SD) in the parentheses. Different letters indicate significant difference among the forests according to Duncan's multiple range tests at 5% level of probability. The letters are the rank order from highest to lowest value (alphabetically). (n=72, df= 68, F= 48.66, $p < 0.05$ for 0-15 cm and n=72, df= 68, F= 41.02, $p < 0.05$ for 15-30 cm)

In the regards of Duncan's multiple comparison tests, all forests ecosystems were different each other. However, only dry mixed deciduous forest and deciduous dipterocarp forest differed significantly each other while dry hill evergreen and dry forest did not.

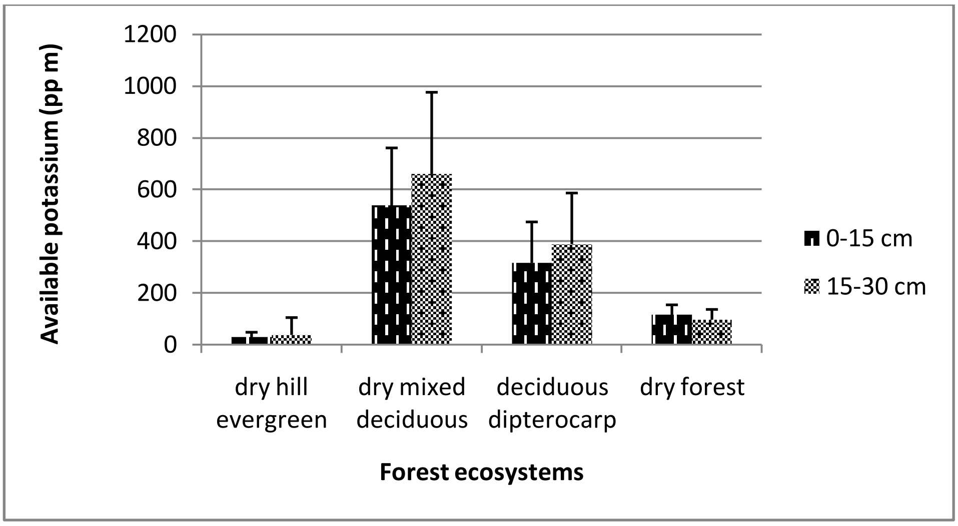


Fig. 4.17 Available potassium in forest ecosystems

When comparing with Marx et al. (1996), the content of available potassium in dry hill evergreen forest and dry forest were very low which only contained the available potassium less than 150 ppm. But for dry mixed deciduous forest, the content of available potassium in soil layers seem to be high because the forest contained K values between 250 - 800 ppm. The available potassium content that belonged to deciduous dipterocarp forest was also high but the amount was less than dry mixed deciduous forest. In addition, dry forest was under the shadow of potential risks for plant growth rather than dry hill evergreen forest when prolonged drought event was come. The fact is dry hill evergreen forest stayed at high altitude and wetter than dry forest staying. When comparing with Jaiarree et al. (2011), the results from this study are coincided with the results of the previous study for 0 - 15 cm level but for 15 - 30 cm level, the current results are higher than the previous study.

4.3.9 Soil organic carbon

Soil organic carbon is composed of a plant debris and decomposition intermediates and microorganism (Post and Kwon, 1999). Actually, soil carbon exists in two principle forms: organic and inorganic form. In general, soil organic carbon content increases with precipitation with optimum levels in humid and cold climates. Principally, Soil organic carbon is stored in the soil organic matter. Soil organic carbon storage varies within regions and biomes (Marks et al., 2009).Soil organic carbon storage is driven by the balance of carbon inputs from plant production and outputs through decomposition. In humid climates, both production and decomposition increase with temperature. Soil texture also affects soil organic carbon; for example, soil organic carbon is positively associated with mean annual precipitation and clay content, and they are negatively related with mean annual temperature and variation of soil type and vegetation types (Jobbagy and Jackson, 2000). Therefore, soil with higher clay content tends to have higher soil organic carbon than other soil with low clay content under similar land use and climate conditions. The content of soil organic carbon in soil can range from less than 1% in sandy soil to almost 100% in wetland soil (Milne and Heimsath, 2009). Jaiarree et al. (2011) found soil organic in natural forest was ranging from 7.30% to 38.30% for 0 - 30 cm soil layer.

According to the results, dry hill evergreen forest belonged to the highest organic carbon content when compared with other forest types whereas the dry forest was the smallest values of organic carbon % in soil. The dry hill evergreen forest contained 11.6% in 0 - 15 cm and 9.04% in 15 - 30 cm depth of soil layers followed by dry mixed deciduous forest with 2.87% and 1.67%, deciduous dipterocarp forest with 1.77% and 1.19%, 1.02% and 0.70% in 0 - 15 cm and 15 - 30 cm, respectively. The multiple comparison tests are shown in table 4.22 and figure 4.18.

Table 4.22 Comparison of soil organic carbon in forest ecosystems

Soil layers	Soil organic carbon%			
	Dry hill evergreen	**Dry mixed deciduous**	**Deciduous dipterocarp**	**Dry forest**
0-15 cm	11.47±4.96^{a}	2.74±0.77^{b}	1.67±0.62^{b}	1.00±0.48^{bc}
15-30 cm	9.23±4.53^{a}	1.63±0.60^{b}	1.04±0.36^{b}	0.82±0.54^{b}

Numbers are the means with standard deviation (Mean±SD) in the parentheses. Different letters indicate significant difference among the forests according to Duncan's multiple range tests at 5% level of probability. The letters are the rank order from highest to lowest value (alphabetically). (n=72, df= 68, F= 66.01, $p < 0.05$ for 0-15 cm and n=72, df= 68, F= 55.38, $p < 0.05$ for 15-30 cm)

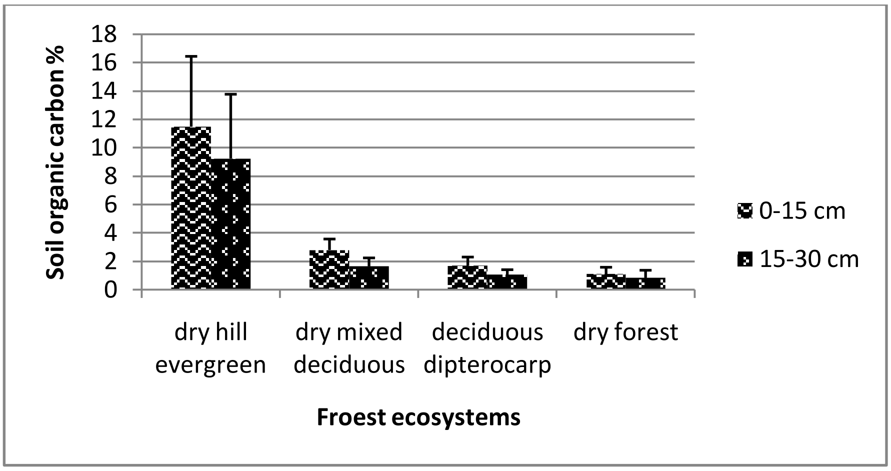


Fig. 4.18 Soil organic carbon in forest ecosystems

In accord with Duncan's multiple range tests, the soil organic carbon of dry hill evergreen forest was significantly difference with other forest types while dry mixed deciduous forest, deciduous dipterocarp forest and dry forest did not different each other in terms of 0 - 15 cm soil layer. For 15 - 30 cm depth, it was the same case as in 0-15 cm depth, i.e., dry hill evergreen forest differed significantly in possessing soil organic carbon content while other forests did not. When compared with the results from Jaiarree et al. (2011), soil organic carbon values in current research were less than the previous.

4.3.10 Soil carbon storage

Soil organic carbon is the carbon stored in soil organic matter. Organic carbon enters the soil through the decomposition of plant and animal residues, root exudates, living and dead microorganisms, and soil biota. Soil organic carbon is the main source of energy for soil microorganisms. Soil organic carbon deficiency results reduced microbial biomass, activity, and nutrient mineralization due to a shortage of energy sources. Consequently, scarce soil organic carbon results in less diversity in soil biota with a risk of the food chain equilibrium disturbing causing disturbance in the soil environment (Edwards et al., 1999). There was an estimated soil carbon stock by Jaiarree et al. (2011) that soil carbon stock ranges 18.65 ton/ha to 60.38 ton/ha in natural forest soil. Panaadisai (2011) also investigated total soil organic carbon stock at 0 - 30 cm layer in hill evergreen forest was 125. 25 ton/ha, mixed deciduous forest possessed 88.43 ton/ha, deciduous dipterocarp forest belonged to 66.89 ton/ha respectively.

According to the results of the research, dry hill evergreen forest belonged to 119.01 ton/ha in 0 - 15 cm soil depth and 96.33 ton/ha in 15 - 30 cm depth whereas in dry mixed deciduous forest, it contained 47.78 ton/ha and 28.50 ton/ha, in deciduous dipterocarp forest, it consisted 35.32 ton/ha and 20.99 ton/ha, in dry forest, it involved 21.67 ton/ha and 14.45 ton/ha in their soil levels of 0 - 15 cm and 15 - 30 cm depth. When combining the results of 0 - 15 cm and 15 - 30 cm, the total result of 0-30 cm of soil layer stored 215.34 ton/ha in dry hill evergreen forest, 76.28 ton/ha in dry mixed deciduous forest, 56.31 ton/ha in deciduous dipterocarp forest and 36.12 ton/ha in dry forest, respectively. Table 4.23 and figure 4.19 show the comparison of soil carbon storage in forest ecosystems.

Table 4.23 Comparison of soil carbon storage (ton/ha) in forest ecosystems

Soil layers	**Soil carbon storage (ton/ha)**			
	Dry hill evergreen	**Dry mixed deciduous**	**Deciduous dipterocarp**	**Dry forest**
0-15 cm	119.01 ± 34.72^{a}	47.78 ± 13.55^{b}	35.32 ± 11.27^{b}	21.67 ± 9.16^{c}
15-30 cm	96.33 ± 35.48^{a}	28.50 ± 12.92^{b}	20.99 ± 10.01^{bc}	14.45 ± 9.86^{bc}
Total (0-30 cm)	**215.34**	**76.28**	**56.31**	**36.12**

Numbers are the means with standard deviation (Mean±SD) in the parentheses. Different letters indicate significant difference among the forests according to Duncan's multiple range tests at 5% level of probability. The letters are the rank order from highest to lowest value (alphabetically). ($n = 72$, $df = 68$, $F = 84.67$, $p < 0.05$ for 0-15 cm and $n=72$, $df = 68$, $F=63.88$, $p < 0.05$ for 15-30 cm)

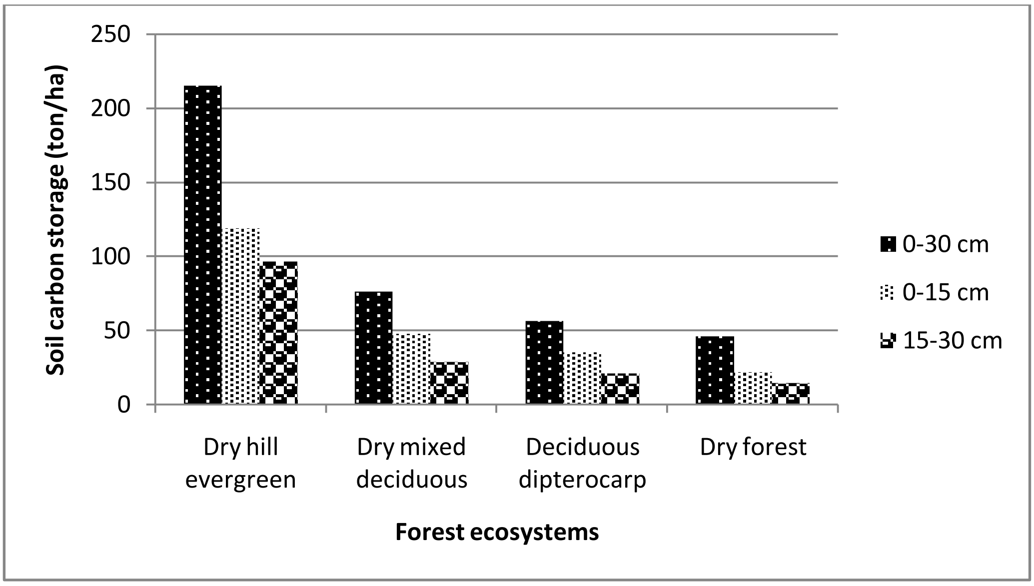


Fig. 4.19 Soil carbon storage in forest ecosystems

According to Duncan's multiple range tests, soil total organic carbon in dry hill evergreen forest in soil layers was significantly different with other soil carbon storage in other forest ecosystems while dry mixed deciduous forest and deciduous dipterocarp forest did not differ significantly in 0 - 15 cm of soil layer and also for 15 - 30 cm soil layer, deciduous dipterocarp forest and dry forest did not significantly differ each other. When compared with other studies, soil carbon stock in the forests of Popa Mountain Park is higher than the results from Jaiarree et al. (2011) but less than from the results of Panaadisai (2011). The comparison of soil carbon storage in this study and other research are shown in table 4.24.

Table 4.24 Comparison of soil carbon storage with other studies

Forest ecosystems	Soil carbon storage (ton/ha)		
	Current research findings	**Previous research findings**	**References for previous studies**
Dry hill evergreen	215.34	125.25	Panaadisai (2011)
Dry mixed deciduous	76.28	88.43	Panaadisai (2011)
Deciduous dipterocarp	56.31	66.89	Panaadisai (2011)
Dry forest	36.12	-	-
Natural forest	-	18.65 – 60.38	Jaiarree et al. (2011)

4.3.11 C/N ratio

Carbon and nitrogen are crucial for plants to drive the routine and fundamental cellular activities. Therefore, maintaining the appropriate balance or ratio of carbon and nitrogen nutrient is essential. Physiological and biochemical studies highlighted that when plants occur nitrogen deficiency, the photosynthetic output was negatively affected. That can only be recovered if nitrogen is provided back to the soil. As the same way, increasing carbon will also promote nitrogen uptake and assimilation. C/N ratio is an indicator of compost stability and N availability. If C/N ratio is high, it will take for a long time to decompose the biomass. On the other hand, if C/N ratio is low, the biomass will decompose faster than before (Zheng, 2009).

According to the result, C/N ratio of dry hill evergreen showed the highest when compared with other forest types which were 3.19 for 0 - 15 cm soil layer and 2.78 for 15 - 30 cm soil layer. In dry mixed deciduous forest, it described 2.20 and 1.33 while others were 2.95 and 2.07, 1.26 and 1.07 in deciduous dipterocarp forest and dry forest. Table 4.25 and figure 4.20 show C/N ratio of forest ecosystems.

Table 4.25 Comparison of C/N ratio in forest ecosystems

Soil layers	C/N ratio			
	Dry hill evergreen	**Dry mixed deciduous**	**Deciduous dipterocarp**	**Dry forest**
0-15 cm	3.14±1.02[a]	2.20±1.33[abc]	2.95±2.90[b]	1.26±0.69[c]
15-30 cm	2.78±0.99[a]	1.78±0.58[b]	2.07±1.30[b]	1.07±0.71[c]

Numbers are the means with standard deviation (Mean±SD) in the parentheses. Different letters indicate significant difference among the forests according to Duncan's multiple range tests at 5% level of probability. The letters are the rank order from highest to lowest value (alphabetically). ($n = 72$, $df = 68$, $F = 4.65$, $p < 0.05$ for 0-15 cm and $n = 72$, $df = 68$, $F = 10.31$, $p < 0.05$ for 15-30 cm)

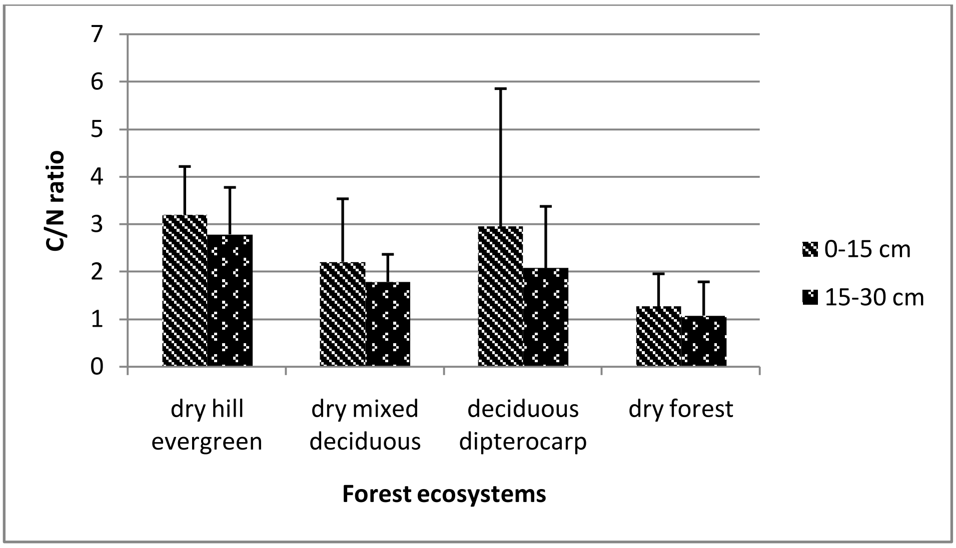


Fig. 4.20 C/N ratio in forest ecosystems

According to Duncan's multiple comparison tests, C/N ratio of all forest types were significantly different each other but dry mixed deciduous forest did not differ with other forest types. It can be concluded that the decomposition rate of biomass will be faster as the C/N ratio for all forest ecosystems were low.

4.4 Estimation of Total carbon storage in forest ecosystems of Popa Mountain Park

When estimating total carbon storage in forest biomasses (stems, branches, leaves, roots) and soil organic carbon storage in four forest ecosystems, the total result showed 232,732.20 ton of carbon was stored in forest biomasses and 507,741.10 ton of carbon was stored in soil organic carbon. Final result was calculated that total aboveground and belowground carbon storage (i.e., forest biomasses and soil organic carbon) was 740,473.30 ton of carbon when combining all forest ecosystems of dry hill evergreen forest, dry mixed deciduous forest, deciduous dipterocarp forest and dry forest of Popa Mountain Park. Table 4.25 shows total carbon storage in forest ecosystems of Popa Mountain Park.

Table 4.26 Total carbon storage in forest ecosystems of Popa Mountain Park

Forest ecosystems	**Carbon storage (ton)**		**Total carbon storage (ton)**
	Forest carbon storage	**Soil carbon storage**	
Dry hill evergreen	10,841.74	39,191.88	50,033.62
Dry mixed deciduous	150,569.60	321,901.60	472,471.20
Deciduous dipterocarp	23,796.36	49,665.42	73,461.78
Dry forest	47,524.50	96,982.20	144,506.70
Total carbon storage (ton)	**232,732.20**	**507,741.10**	**740,473.30**

CHAPTER V
CONCLUSIONS AND RECOMMENDATIONS

This study found that dry mixed deciduous forest contained the hightest in species richness among the forest ecosystems of Popa Mountain Park. When looking to detailed species which possessed the highest species richness, the species of Euphorbiaceae family is found to be an adapted species which are observed among dry hill evergreen, dry mixed deciduous and deciduous dipterocarp forest. One important species which is very rare to find in other forest ecosystems call *Tectona hamiltoniana* Wall. is found as the highest IV value species in dry forest. It is a characterized species for dry forest ecosystem in central dry zone of Myanmar. In the regards of diameter class, dbh size class of all forest ecosystems are examined as reversed J-shaped. That highlighted the forests are suggested to be second growth or third growth forests. The dbh size class with 40 - 60 cm size is investigated in all forest ecosystems but very few. The dbh size class with 55 - 60 cm is observed only in dry hill evergreen and dry mixed deciduous forest types.

In terms of carbon storage capacity in forest biomass, dry hill evergreen forest stored the highest carbon content. Among the forest ecosystems, stem is the main vegetation part that stored the highest amount of carbon in its biomass compared with other vegetation parts. This study suggested that the tallest height with the largest dbh size class tree stored the highest carbon content in their biomasses. The highest carbon storage in litter fall is found in dry mixed deciduous forest. In terms of undergrowth carbon storage, dry forest was the lowest among forest ecosystems. Carbon storage of grass in almost all forest ecosystems is relatively low.

In terms of soil carbon, the forest with the highest organic matter is observed as the highest organic carbon storage forest as organic matter and organic carbon are positively related each other. According to the results, dry hill evergreen forest stored the highest total organic carbon in their soil layers. This study also assessed the upper soil layer of 0 - 15 cm depth contained more organic matter as well as organic carbon than the soil depth of 15 - 30 cm.

In addition, the largest carbon content was found in dry hill evergreen forest with 59.57 ton/ha followed by dry mixed deciduous forest with 35.68 ton/ha, deciduous dipterocarp forest with 26.98 ton/ha and dry forest with 17.70 ton/ha respectively. All mean values of soil organic carbon (SOC %) showed higher in soil depth of 0 - 15 cm above 15 - 30 cm. The total soil organic carbon of 0 - 30 cm contained 215.34 ton/ha in dry hill evergreen forest, 76.28 ton/ha in dry mixed deciduous forest, 56.31 ton/ha in deciduous dipterocarp forest and 36.12 ton/ha in dry forest, respectively. This research assessed soil organic carbon storage as being nearly two times more than forest carbon storage. The possible reason for lower forest carbon storage is due to disturbances from human activities because there is still found some commercial plantations of crops and fruits by clearing existing forest areas. This is an avoidable manner if it would like to protect the existing forest area as well as forest carbon storage and soil properties. Establishment of forest plantations should be conducted in the disturbed forest areas in order to improve forest carbon storage. On the other hand, the possible reason for higher total soil organic carbon storage than forest carbon storage is that Popa Mountain Park is actually an old volcanic area which has already erupted for many thousands years ago. However, the volcanic ash might be still remained in the soil of the Popa Mountain Park by combining with the parent materials. So that is why the soil organic carbon is higher than the forest carbon. Since the soil of Popa Mountain Park is andosols soil, it was suggested by Imaya et al. (2010) that among the soil in the world, the carbon stock is larger in volcanic ash soil such as andosols. Furthermore, volcanic ash deposition can accumulate on flat or gentle slopes where the soil stays stably over long periods. Finally, the study found the current total carbon storage is 740,473.30 ton in both aboveground and belowground of focused forest ecosystems.

Forest ecosystems in Popa Mountain Park have a great potential for future carbon storage as it belonged to the higher numbers of smaller dbh size class standing trees. The carbon content of vegetation parts will be increased as they grow until they reach the climax stage. The fact is the smaller dbh size class trees will absorb the atmospheric CO_2 through photosynthesis process and store carbon in their biomasses along with their growth. In addition, in order to maintain the carbon storage in forest ecosystems of Popa Mountain Park sustainably, fire protection is one of the important factors to account for considering so that it could not only be well protected from losing of forest biomass which are essential for carbon storage but also improved for soil nutrients and organic carbon through forest biomass decomposition. Well management system as well as Park protecting Laws and regulations are required in order to maintain the forest carbon storage from avoiding unfavorable activities from human beings. Actually, this protected area with different forest ecosystems has a high potential for carbon storage. It is not only a carbon sink for a nation but also an oasis for the central dry zone of Myanmar.

In conclusion, this study could be provided a basic data of carbon storage capacity in forest ecosystems as well as in protected areas of Myanmar. This could also be led for the enhancement of forest restoration program towards sustainable forest management in Myanmar.

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APPENDIX

Fig. A.1 Dry hill evergreen forest ecosystem of Popa Mountain Park, Myanmar

Fig. A.2 Dry mixed deciduous forest ecosystem of Popa Mountain Park, Myanmar

Fig. A.3 Deciduous dipterocarp forest ecosystem of Popa Mountain Park, Myanmar

Fig. A.4 Dry forest ecosystem of Popa Mountain Park, Myanmar

Table A.1 Lists of the species found in dry hill evergreen forest

No	Local name	Family name	Species name
	Species with dbh ≥ 4.5 cm		
1	Thetyin-gyi	Euphorbiaceae	*Croton roxburghianus* N.P. Balakr.
2	Na-ywe	Flacourtiaceae	*Flacourtia cataphracta* Roxb.
3	Thade	Burseraceae	*Protium serratum* Engl.
4	Thawshaut	Rutaceae	*Glycosmis pentaphylla* Correa
5	Phetsut	Rosaceae	*Eriobotrya bengalensis* (Roxb.) Hook. f.
6	Ondon	Lauraceae	*Litsea salicifolia* (Nees) Hook. f.
7	Thidin	Euphorbiaceae	*Mallotus philippinensis* (Lam.) Muell. Arg.
8	Panga	Combretaceae	*Terminalia chebula* Retz.
9	Yon	Combretaceae	*Anogeissus acuminata* Wall.
10	Zaungbalwe	Lythraceae	*Lagerstroemia villosa* Wall. ex Kurz
11	Sagawa	Magnoliaceae	*Michelia champaca* L.
12	Tanpe	Combretaceae	*Terminalia tripteroides* Craib
13	Phetwunphyu	Tiliaceae	*Berrya mollis* Wall. ex Kurz
14	Lethokegyi	Apocynaceae	*Holarrhena pubescens* Wall. ex G. Don
15	Bonmeza	Mimosaceae	*Albizia chinensis* (Osbeck) Merr.
16	Thabye	Myrtaceae	*Eugenia* sp
17	Kyetthet	Combretaceae	*Combretum apetalum* Wall.
18	Yemane	Verbenaceae	*Gmelina arborea* Roxb.
19	Tayaw	Tiliaceae	*Grewia tiliifolia* Vahl
20	Thawkyetsa	Oleaceae	*Chionanthus ramiflora* Roxb.
21	Thinyu	Pinaceae	*Pinus khasya* Royle ex Parl.
22	Mani awwga	Myrsinaceae	*Rapanea neriifolia* Mez.
23	Linlun	Euphorbiaceae	*Sapium baccatum* Roxb.
24	Thitni	Rubiaceae	*Wendlandia tinctoria* DC.
25	Mayanin	Pittosporaceae	*Pittosporum napaulensis* (DC.) Rehder & Wilson
26	Thindwenyo	Ebenaceae	*Diospyros mollis* Griff.
27	Linyaw	Dilleniaceae	*Dillenia parviflora* Griff.
28	Ziphyu	Euphorbiaceae	*Emblica officinalis* Gaertn.

(cont.) from table A.1

29	Taung zalatni	Apocynaceae	*Kopsia fruticosa* A. DC.
30	Phetsut pho	Urticaceae	*Laportea interrupta* (L.) Chew
31	Thitgyoke	Ebenaceae	*Diospyros oleifolia* Wight
32	Sulein	Asteraceae	*Echinops echinatus* Roxb.
33	Kywelabyin	Sabiaceae	*Sabia paniculata* Edgew. ex Hook. f. & Thomson
34	Didu	Bombacaceae	*Bombax insigne* Wall.
35	Yin-dike	Fabaceae	*Dalbergia cultrata* Grah.
36	Seitchee	Euphorbiaceae	*Bridelia retusa* (L.) A. Juss.
37	Kwe tayaw	Tiliaceae	*Grewia laevigata* Vahl
38	Cherry	Rosaceae	*Prunus cerasoides* D. Don
39	Tawyuzana	Rutaceae	*Murraya paniculata* (L.) Jack
	Species with dbh < 4.5 cm		
1	Thetyingyi	Euphorbiaceae	*Croton roxburghianus* N.P. Balakr.
2	Naywe	Flacourtiaceae	*Flacourtia cataphracta* Roxb.
3	Thadi	Burseraceae	*Protium serratum* Engl.
4	Thawshaut	Rutaceae	*Glycosmis pentaphylla* Correa
5	Phetsut	Rosaceae	*Eriobotrya bengalensis* (Roxb.) Hook. f.
6	Thidin	Euphorbiaceae	*Mallotus philippinensis* (Lam.) Muell. Arg.
7	Tamagagyi	Verbenaceae	*Symphorema involucratum* Roxb.
8	Yon	Combretaceae	*Anogeissus acuminata* Wall.
9	Seinabaw	Smilacaceae	*Smilax perfoliata* Lour.
10	Tawkyetsa	Oleaceae	*Chionanthus ramiflora* Roxb.
11	Linlun	Euphorbiaceae	*Sapium baccatum* Roxb.
12	Yetakwa	Urticaceae	*Debregeasia longifolia* Wedd.
13	Mayanin	Pittosporaceae	*Pittosporum napaulensis* (DC.) Rehder & Wilson
14	Phetsut pho	Urticaceae	*Laportea interrupta* (L.) Chew
15	Thitgyoke	Ebenaceae	*Diospyros oleifolia* Wight
16	Kunlein	Agavaceae	*Cordyline fruticosa* (L.) A. Chev.

(cont.) from table A.1

17	Kyetlesan	Verbenaceae	*Virtex* sp
18	Kwetayaw	Tiliaceae	*Grewia laevigata* Vahl
19	Shintmatetgyi	Rutaceae	*Toddalia asiatica* (L.) Lam.
20	Tawyuzana	Rutaceae	*Murraya paniculata* (L.) Jack

Table A.2 Lists of the species found in dry mixed deciduous forest

No	Local name	Family name	Species name
	Species with dbh ≥ 4.5 cm		
1	Zimani	Malpighiaceae	*Hiptage candicans* Hook. f.
2	Mayanin	Pittosporaceae	*Pittosporum napaulensis* (DC.) Rehder & Wilson
3	Ingyin	Dipterocarpaceae	*Shorea siamensis* (Kurz) Miq.
4	In	Dipterocarpaceae	*Dipterocarpus tuberculatus* Roxb.
5	Te	Ebenaceae	*Diospyros burmanica* Kurz
6	Gyokhamet	Meliaceae	*Walsura trichostemon* Miq.
7	Thitswele	Juglandaceae	*Engelhardtia spicata* Blume
8	Thadi	Burseraceae	*Protium serratum* Engl.
9	Kyunkhautnwe	Verbenaceae	*Vitex limonifolia* Wall.
10	Kinpalin	Euphorbiaceae	*Antidesma ghesaembilla* Gaertn.
11	Ondon	Lauraceae	*Litsea salicifolia* (Nees) Hook. f.
12	Tawkyetsa	Oleaceae	*Chionanthus ramiflora* Roxb.
13	Phalan	Caesalpiniaceae	*Bauhinia racemosa* Lam.
14	Kyetyo	Verbenaceae	*Vitex canescens* Kurz
15	Pyinma	Lythraceae	*Lagerstroemia speciosa* (L.) Pers.
16	Thande	Bignoniaceae	*Stereospermum neuranthum* Kurz
17	Gyo	Sapindaceae	*Schleichera oleosa* (Lour.) Oken
18	Thetyingyi	Euphorbiaceae	*Croton roxburghianus* N.P. Balakr.
19	Sae eikemwe	Lythraceae	*Lagerstroemia macrocarpa* Kurz
20	Thaukgyant	Combretaceae	*Terminalia crenulata* (Heyne) Roth
21	Tawtanakha	Olacaceae	*Anacolosa griffithii* Mast.

(cont.) from table A.2

22	Ziphyu	Euphorbiaceae	*Emblica officinalis* Gaertn.
23	Thitya	Dipterocarpaceae	*Shorea obtusa* Wall.
24	Phetsut	Rosaceae	*Eriobotrya bengalensis* (Roxb.) Hook. f.
25	Swedaw	Caesalpiniaceae	*Bauhinia variegata* L.
26	Khaung	Anacardiaceae	*Rhus paniculata* Wall.
27	Suyit	Mimosaceae	*Acacia nilotica* (L.) Delile
28	Tamalan	Fabaceae	*Dalbergia oliveri* Gamble
29	Kyettet	Combretaceae	*Combretum apetalum* Wall.
30	Lunbo	Anacardiaceae	*Buchanania lanzan* Spreng.
31	Kyun	Lamiaceae	*Tectona grandis* L. f.
32	Zaungbalwe	Lythraceae	*Lagerstroemia villosa* Wall. ex Kurz
33	Yingat	Rubiaceae	*Gardenia obtusifolia* Roxb.
34	Panga	Combretaceae	*Terminalia chebula* Retz.
35	Kyunbo	Verbenaceae	*Premna pyramidata* Wall.
36	Thindwenyo	Ebenaceae	*Diospyros mollis* Griff.
37	Zi talaing	Rhamnaceae	*Ziziphus rugosa* Lam.
38	Thidin	Euphorbiaceae	*Mallotus philippinensis* (Lam.) Muell. Arg.
39	Thayet	Anacardiaceae	*Mangifera indica* L.
40	Yindaike	Fabaceae	*Dalbergia cultrata* Grah.
41	Tmagagyi	Verbenaceae	*Symphorema involucratum* Roxb.
42	Kyaungshaletto	Araliaceae	*Heteropanax fragrans* (Roxb. ex DC.) Seem.
43	Yinma	Meliaceae	*Chukrasia velutina* Roem.
44	Lettokegyi	Apocynaceae	*Holarrhena pubescens* Wall. ex G. Don
45	Tayaw	Tiliaceae	*Grewia tiliifolia* Vahl
46	Naywe	Flacourtiaceae	*Flacourtia cataphracta* Roxb.
47	Shone	Ulmaceae	*Ulmus lancifolia* Roxb.
48	Yon	Combretaceae	*Anogeissus acuminata* Wall.
49	Banbwe	Lecythidaceae	*Careya arborea* Roxb.
50	Kyetlesan	Verbenaceae	*Virtex* sp

(cont.) from table A.2

51	Taw sabai	Oleaceae	*Jasminum angustifolium* Vahl
52	Taminsaphyu	Rubiaceae	*Gardenia sessiliflora* Wall.
53	Won u	Fabaceae	*Millettia extensa* Benth.
54	Ngu shwe	Caesalpiniaceae	*Cassia fistula* L.
55	Thitseint	Combretaceae	*Terminalia bellerica* Roxb.
56	Thitgyoke	Ebenaceae	*Diospyros oleifolia* Wight
57	Shitsha	Euphorbiaceae	*Phyllanthus albizzioides* (Kurz) Hook. f.
58	Yemane	Verbenaceae	*Gmelina arborea* Roxb.
59	Phetthan	Bignoniaceae	*Heterophragma adenophylla* (Wall.) Seem. ex Benth. & Hook.
60	Phetwunphyu	Tiliaceae	*Berrya mollis* Wall. ex Kurz
61	Taung zalatni	Apocynaceae	*Kopsia fruticosa* A. DC.
62	Bonmeza	Mimosaceae	*Albizia chinensis* (Osbeck) Merr.
63	Malwa	Bignoniaceae	*Markhamia stipulata* (Wall.) Seem. ex K. Schum.
64	Pyinkado	Mimosaceae	*Xylia xylocarpa* (Roxb.) Taub.
65	Tawkhan	Apocynaceae	*Carissa spinarum* A. DC.
66	Sandagu	Santalaceae	*Santalum album* L.
67	Kha aung	Moraceae	*Ficus hispida* L. f.
68	Tin	Malvaceae	*Fioria vitifolia* (L.) Mattei
69	Khabaunggyi	Loganiaceae	*Strychnos potatorum* L. f.
70	Thin win	Fabaceae	*Millettia pendula* Benth.
	Species with dbh < 4.5 cm		
1	Mayanin	Pittosporaceae	*Pittosporum napaulensis* (DC.) Rehder & Wilson
2	Ingyin	Dipterocarpaceae	*Shorea siamensis* (Kurz) Miq.
3	Thit swele	Juglandaceae	*Engelhardtia spicata* Blume
4	Thadi	Burseraceae	*Protium serratum* Engl.
5	Kinpalin	Euphorbiaceae	*Antidesma ghesaembilla* Gaertn.
6	Ondon	Lauraceae	*Litsea salicifolia* (Nees) Hook. f.
7	Tawkyetsa	Oleaceae	*Chionanthus ramiflora* Roxb.

(cont.) from table A.2

8	Palan	Caesalpiniaceae	*Bauhinia racemosa* Lam.
9	Kyetyo	Verbenaceae	*Vitex canescens* Kurz
10	Pyinma	Lythraceae	*Lagerstroemia speciosa* (L.) Pers.
11	Tawyuzana	Rutaceae	*Murraya paniculata* (L.) Jack
12	Thande	Bignoniaceae	*Stereospermum neuranthum* Kurz
13	Gyo	Sapindaceae	*Schleichera oleosa* (Lour.) Oken
14	Thetyingyi	Euphorbiaceae	*Croton roxburghianus* N.P. Balakr.
15	Sae eikemwe	Lythraceae	*Lagerstroemia macrocarpa* Kurz
16	Tawtanakha	Olacaceae	*Anacolosa griffithii* Mast.
17	Ziphyu	Euphorbiaceae	*Emblica officinalis* Gaertn.
18	Thitya	Dipterocarpaceae	*Shorea obtusa* Wall.
19	Phetsut	Rosaceae	*Eriobotrya bengalensis* (Roxb.) Hook. f.
20	Swedaw	Caesalpiniaceae	*Bauhinia variegata* L.
21	Khaung	Anacardiaceae	*Rhus paniculata* Wall.
22	Suyit	Mimosaceae	*Acacia nilotica* (L.) Delile
23	Tamalan	Fabaceae	*Dalbergia oliveri* Gamble
24	Kyetet	Combretaceae	*Combretum apetalum* Wall.
25	Myingaungnayaung	Celastraceae	*Celastrus paniculatus* Willd.
26	Zaungbalwe	Lythraceae	*Lagerstroemia villosa* Wall. ex Kurz
27	Thindwenyo	Ebenaceae	*Diospyros mollis* Griff.
28	Thidin	Euphorbiaceae	*Mallotus philippinensis* (Lam.) Muell. Arg.
29	Tamagagyi	Verbenaceae	*Symphorema involucratum* Roxb.
30	Kyaungshaletto	Araliaceae	*Heteropanax fragrans* (Roxb. ex DC.) Seem.
31	Tayaw	Tiliaceae	*Grewia tiliifolia* Vahl
32	Naywe	Flacourtiaceae	*Flacourtia cataphracta* Roxb.
33	Kwe tayaw	Tiliaceae	*Grewia laevigata* Vahl
34	Kyetlesan	Verbenaceae	*Virtex* sp
35	Taw sabai	Oleaceae	*Jasminum angustifolium* Vahl
36	Taminsaphyu	Rubiaceae	*Gardenia sessiliflora* Wall.

(cont.) from table A.2

37	Seinabaw	Smilacaceae	*Smilax perfoliata* Lour.
38	Shitsha	Euphorbiaceae	*Phyllanthus albizzioides* (Kurz) Hook. f.
39	Tame	Fabaceae	*Indigofera lacei* Craib
40	Yemagyi	Acanthaceae	*Strobilanthes phyllostachyus* Kurz
41	Phetthan	Bignoniaceae	*Heterophragma adenophylla* (Wall.) Seem. ex Benth. & Hook.
42	Taung zalatni	Apocynaceae	*Kopsia fruticosa* A. DC.
43	Yinbya	Verbenaceae	*Clerodendrum serratum* Spreng.
44	Tawkhan	Apocynaceae	*Carissa spinarum* A. DC.
45	Te	Ebenaceae	*Diospyros burmanica* Kurz

Table A.3 Lists of the species found in deciduous dipterocarp forest

No	Local name	Family name	Species name
	Species with dbh ≥ 4.5 cm		
1	Thaukkyant	Combretaceae	*Terminalia crenulata* (Heyne) Roth
2	Seikchee	Euphorbiaceae	*Bridelia retusa* (L.) A. Juss.
3	Te	Ebenaceae	*Diospyros burmanica* Kurz
4	Ingyin	Dipterocarpaceae	*Shorea siamensis* (Kurz) Miq.
5	Zimani	Malpighiaceae	*Hiptage candicans* Hook. f.
6	Leikpyataung	Caesalpiniaceae	*Bauhinia diphylla* Buch.-Ham.
7	Tamalan	Fabaceae	*Dalbergia oliveri* Gamble
8	Tawkhan	Apocynaceae	*Carissa spinarum* A. DC.
9	Tamisaphyu	Rubiaceae	*Gardenia sessiliflora* Wall.
10	Tawkyetsa	Oleaceae	*Chionanthus ramiflora* Roxb.
11	Thitya	Dipterocarpaceae	*Shorea obtusa* Wall.
12	Nabe	Anacardiaceae	*Lannea coromandelica* (Houtt.) Merr.
13	Phetthan	Bignoniaceae	*Heterophragma adenophylla* (Wall.) Seem. ex Benth. & Hook.
14	Tayaw	Tiliaceae	*Grewia tiliifolia* Vahl

(cont.) from table A.3

15	Nibase	Rubiaceae	*Morinda tinctoria* Roxb.
16	Shitsha	Euphorbiaceae	*Phyllanthus albizzioides* (Kurz) Hook. f.
17	Thetyingyin	Euphorbiaceae	*Croton roxburghianus* N.P. Balakr.
18	Panga	Combretaceae	*Terminalia chebula* Retz.
19	Naywe	Flacourtiaceae	*Flacourtia cataphracta* Roxb.
20	Khaung	Anacardiaceae	*Rhus paniculata* Wall.
21	Ziphyu	Euphorbiaceae	*Emblica officinalis* Gaertn.
22	Lunbo	Anacardiaceae	*Buchanania lanzan* Spreng.
23	Khabaunggyi	Loganiaceae	*Strychnos potatorum* L. f.
24	Kyunbo	Verbenaceae	*Premna pyramidata* Wall.
25	Pyinma	Lythraceae	*Lagerstroemia speciosa* (L.) Pers.
26	Sandagu	Santalaceae	*Santalum album* L.
27	Mayanin	Pittosporaceae	*Pittosporum napaulensis* (DC.) Rehder & Wilson
28	Kinpalin	Euphorbiaceae	*Antidesma ghesaembilla* Gaertn.
29	Shinpagu	Olacaceae	*Olax psittacorum* (Willd.) Vahl
30	Pyingado	Mimosaceae	*Xylia xylocarpa* (Roxb.) Taub.
31	Thadi	Burseraceae	*Protium serratum* Engl.
32	In	Dipterocarpaceae	*Dipterocarpus tuberculatus* Roxb.
33	Thaungthangyi	Verbenaceae	*Premna integrifolia* L.
34	Kyun	Lamiaceae	*Tectona grandis* L. f.
35	Thitswele	Juglandaceae	*Engelhardtia spicata* Blume
36	Kyaungshaletto	Araliaceae	*Heteropanax fragrans* (Roxb. ex DC.) Seem.
37	Myingaungnayaung	Celastraceae	*Celastrus paniculatus* Willd.
38	Gyo	Sapindaceae	*Schleichera oleosa* (Lour.) Oken
39	Khutan	Rubiaceae	*Hymenodictyon orixense* (Roxb.) Mabb.
40	Kyunkhaungnwe	Verbenaceae	*Vitex limonifolia* Wall.
41	Yinma	Meliaceae	*Chukrasia velutina* Roem.

(cont.) from table A.3

42	Kyetlesan	Verbenaceae	*Virtex* sp
43	Tawtanakha	Olacaceae	*Anacolosa griffithii* Mast.
44	Kyetyo	Verbenaceae	*Vitex canescens* Kurz
45	Kyettet	Combretaceae	*Combretum apetalum* Wall.
46	Yingat	Rubiaceae	*Gardenia obtusifolia* Roxb.
47	Zi talaing	Rhamnaceae	*Ziziphus rugosa* Lam.
48	Yemane	Verbenaceae	*Gmelina arborea* Roxb.
49	Ngusat	Cesalpiniaceae	*Cassia renigera* Wall. ex Benth
	Species with dbh < 4.5 cm		
1	Thaukkyant	Combretaceae	*Terminalia crenulata* (Heyne) Roth
2	Seikchee	Euphorbiaceae	*Bridelia retusa* (L.) A. Juss.
3	Te	Ebenaceae	*Diospyros burmanica* Kurz
4	Ingyin	Dipterocarpaceae	*Shorea siamensis* (Kurz) Miq.
5	Tamalan	Fabaceae	*Dalbergia oliveri* Gamble
6	Tawkhan	Apocynaceae	*Carissa spinarum* A. DC.
7	Taminsaphyu	Rubiaceae	*Gardenia sessiliflora* Wall.
8	Kwe tayaw	Tiliaceae	*Grewia laevigata* Vahl
9	Tawkyetsa	Oleaceae	*Chionanthus ramiflora* Roxb.
10	Thitya	Dipterocarpaceae	*Shorea obtusa* Wall.
11	Tayaw	Tiliaceae	*Grewia tiliifolia* Vahl
12	Shitsha	Euphorbiaceae	*Phyllanthus albizzioides* (Kurz) Hook. f.
13	Thetyingyi	Euphorbiaceae	*Croton roxburghianus* N.P. Balakr.
14	Naywe	Flacourtiaceae	*Flacourtia cataphracta* Roxb.
15	Khaung	Anacardiaceae	*Rhus paniculata* Wall.
16	Ziphyu	Euphorbiaceae	*Emblica officinalis* Gaertn.
17	Lunbo	Anacardiaceae	*Buchanania lanzan* Spreng.

(cont.) from table A.3

18	Pyinma	Lythraceae	*Lagerstroemia speciosa* (L.) Pers.
19	Sandagu	Santalaceae	*Santalum album* L.
20	Mayanin	Pittosporaceae	*Pittosporum napaulensis* (DC.) Rehder & Wilson
21	Shinpagu	Olacaceae	*Olax psittacorum* (Willd.) Vahl
22	Kinpalin	Euphorbiaceae	*Antidesma ghesaembilla* Gaertn.
23	Pyinkado	Mimosaceae	*Xylia xylocarpa* (Roxb.) Taub.
24	Thadi	Burseraceae	*Protium serratum* Engl.
25	In	Dipterocarpaceae	*Dipterocarpus tuberculatus* Roxb.
26	Taungtangyi	Verbenaceae	*Premna integrifolia* L.
27	Won u	Fabaceae	*Millettia extensa* Benth.
28	Thitswele	Juglandaceae	*Engelhardtia spicata* Blume
29	Tamagagyi	Verbenaceae	*Symphorema involucratum* Roxb.
30	Suyit	Mimosaceae	*Acacia nilotica* (L.) Delile
31	Phetwunphyu	Tiliaceae	*Berrya mollis* Wall. ex Kurz
32	Myingaungnayaung	Celastraceae	*Celastrus paniculatus* Willd.
33	Kyunkhautnwe	Verbenaceae	*Vitex limonifolia* Wall.
34	Yinma	Meliaceae	*Chukrasia velutina* Roem.
35	Kyetlesan	Verbenaceae	*Virtex* sp
36	Tawtanakha	Olacaceae	*Anacolosa griffithii* Mast.
37	Kyetyo	Verbenaceae	*Vitex canescens* Kurz
38	Tame	Fabaceae	*Indigofera lacei* Craib
39	Thayet cho	Spotaceae	*Xantolis tomentosa* Raf.
40	Phetsut	Rosaceae	*Eriobotrya bengalensis* (Roxb.) Hook. f.
41	Mahagalantin	Thymelaeceae	*Linostoma decandrum* Wall.
42	Yingat	Rubiaceae	*Gardenia obtusifolia* Roxb.
43	Thitgyoke	Ebenaceae	*Diospyros oleifolia* Wight
44	Taw sabai	Oleaceae	*Jasminum angustifolium* Vahl

(cont.) from table A.3

45	Sae kamin	Fabaceae	*Desmodium gyrans* DC.
46	Swedaw	Caesalpiniaceae	*Bauhinia variegata* L.

Table A.4 Lists of the species found in dry forest

No	Local name	Family name	Species name
	Species with dbh ≥ 4.5 cm		
1	Dahat	Verbenaceae	*Tectona hamiltoniana* Wall.
2	Thaukkyant	Combretaceae	*Terminalia crenulata* (Heyne) Roth
3	Te	Ebenaceae	*Diospyros burmanica* Kurz
4	Nabe	Anacardiaceae	*Lannea coromandelica* (Houtt.) Merr.
5	Naywe	Flacourtiaceae	*Flacourtia cataphracta* Roxb.
6	Yingat	Rubiaceae	*Gardenia obtusifolia* Roxb.
7	Thetyingyi	Euphorbiaceae	*Croton roxburghianus* N.P. Balakr.
8	Taminsaphyu	Rubiaceae	*Gardenia sessiliflora* Wall.
9	Lettokegyi	Apocynaceae	*Holarrhena pubescens* Wall. ex G. Don
10	Tayaw	Tiliaceae	*Grewia tiliifolia* Vahl
11	Ingyin	Dipterocarpaceae	*Shorea siamensis* (Kurz) Miq.
12	Shitsha	Euphorbiaceae	*Phyllanthus albizzioides* (Kurz) Hook. f.
13	Kyettet	Combretaceae	*Combretum apetalum* Wall.
14	Tabutgyi	Annonaceae	*Miliusa velutina* Hook. f. & Thomson
15	Ziphyu	Euphorbiaceae	*Emblica officinalis* Gaertn.
16	Nebase	Rubiaceae	*Morinda tinctoria* Roxb.
17	Lunbo	Anacardiaceae	*Buchanania lanzan* Spreng.
18	Khaung	Anacardiaceae	*Rhus paniculata* Wall.
19	Zaungchan	Santalaceae	*Osyris wightiana* Wall.
20	Zimani	Malpighiaceae	*Hiptage candicans* Hook. f.
21	Kyunbo	Verbenaceae	*Premna pyramidata* Wall.

(cont.) from table A.4

22	Than	Combretaceae	*Terminalia oliveri* Brandis
23	Sha	Mimosaceae	*Acacia catechu* Willd.
24	Bein new	Malpighiaceae	*Hiptage benghalensis* (L.) Kurz
25	Tabauk	Fabaceae	*Dalbergia paniculata* Roxb.
26	Taw sabai	Oleaceae	*Jasminum angustifolium* Vahl
27	Pyinkado	Mimosaceae	*Xylia xylocarpa* (Roxb.) Taub.
28	Thitya	Dipterocarpaceae	*Shorea obtusa* Wall.
29	Thayet cho	Spotaceae	*Xantolis tomentosa* Raf.
30	Kyetlesan	Verbenaceae	*Vitex* sp
31	Tawkyetsa	Oleaceae	*Chionanthus ramiflora* Roxb.
32	Thanaung	Mimosaceae	*Acacia leucophloea* (Roxb.) Willd.
	Species with dbh < 4.5 cm		
1	Thaukkyant	Combretaceae	*Terminalia crenulata* (Heyne) Roth
2	Naywe	Flacourtiaceae	*Flacourtia cataphracta* Roxb.
3	Yingat	Rubiaceae	*Gardenia obtusifolia* Roxb.
4	Thetyingyi	Euphorbiaceae	*Croton roxburghianus* N.P. Balakr.
5	Taminsaphyu	Rubiaceae	*Gardenia sessiliflora* Wall.
6	Lettokegyi	Apocynaceae	*Holarrhena pubescens* Wall. ex G. Don
7	Tayaw	Tiliaceae	*Grewia tiliifolia* Vahl
8	Ingyin	Dipterocarpaceae	*Shorea siamensis* (Kurz) Miq.
9	Kyettet	Combretaceae	*Combretum apetalum* Wall.
10	Nebase	Rubiaceae	*Morinda tinctoria* Roxb.
11	Leikpyataung	Caesalpiniaceae	*Bauhinia diphylla* Buch.-Ham.
12	Khaung	Anacardiaceae	*Rhus paniculata* Wall.
13	Zimani	Malpighiaceae	*Hiptage candicans* Hook. f.
14	Than	Combretaceae	*Terminalia oliveri* Brandis

(cont.) from table A.4

15	Sha	Mimosaceae	*Acacia catechu* Willd.
16	Beinwe	Malpighiaceae	*Hiptage benghalensis* (L.) Kurz
17	Tabauk	Fabaceae	*Dalbergia paniculata* Roxb.
18	Taw sabai	Oleaceae	*Jasminum angustifolium* Vahl
19	Pyinkado	Mimosaceae	*Xylia xylocarpa* (Roxb.) Taub.
20	Tame	Fabaceae	*Indigofera lacei* Craib
21	Khaungthan	Apocynaceae	*Aganosma marginata* (Roxb.) G. Don

Table A.5 Lists of relative frequency, relative density, relative dominance and important value index (IV) of the species found in dry hill evergreen forest ecosystem of Popa Mountain Park, Myanmar

No	Local name	Species name	Relative frequency (%)	Relative density (%)	Relative dominance (%)	IV
	Species with dbh ≥ 4.5 cm					
1	Maniawga	*Rapanea neriifolia* Mez.	11.26	36.05	27.15	74.46
2	Thetyingyi	*Croton roxburghianus* N.P. Balakr.	9.93	11.90	15.84	37.67
3	Tinyu	*Pinus khasya* Royle ex Parl.	5.30	4.42	13.52	23.24
4	Yon	*Anogeissus acuminata* Wall.	6.62	6.12	5.43	18.17
5	Mayanin	*Pittosporum napaulensis* (DC.) Rehder & Wilson	6.62	4.76	3.19	14.57
6	Naywe	*Flacourtia cataphracta* Roxb.	4.64	3.40	5.96	13.99
7	Bonmeza	*Albizia chinensis* (Osbeck) Merr.	3.97	2.38	3.38	9.73
8	Thitni	*Wendlandia tinctoria* DC.	3.31	2.04	3.72	9.07
9	Thindwenyo	*Diospyros mollis* Griff.	3.97	2.72	1.82	8.51
10	Thidin	*Mallotus philippinensis* (Lam.) Muell. Arg.	3.31	2.38	2.36	8.06
11	Thabye	*Eugenia* sp	3.97	2.38	1.31	7.66
12	Lettokegyi	*Holarrhena pubescens* Wall. ex G. Don	3.31	2.38	1.57	7.27
13	Phetsut	*Eriobotrya bengalensis* (Roxb.) Hook. f.	3.97	2.04	0.83	6.84
14	Phetwunphyu	*Berrya mollis* Wall. ex Kurz	1.99	1.70	2.89	6.58
15	Kyetet	*Combretum apetalum* Wall.	3.31	2.04	0.33	5.69
16	Linyaw	*Dillenia parviflora* Griff.	2.65	1.36	0.74	4.75
17	Linlun	*Sapium baccatum* Roxb.	1.99	0.68	1.43	4.10
18	Thitgyoke	*Diospyros oleifolia* Wight	1.32	0.68	1.73	3.73
19	Cherry	*Prunus cerasoides* D. Don	1.99	1.02	0.60	3.61
20	Ondon	*Litsea salicifolia* (Nees) Hook. f.	1.32	1.02	1.04	3.38
21	Thanpe	*Terminalia tripteroides* Craib	1.32	1.02	0.99	3.34
22	Phetsut pho	*Laportea interrupta* (L.) Chew	1.99	1.02	0.26	3.26
23	Taung zalatni	*Kopsia fruticosa* A. DC.	1.32	1.02	0.10	2.45
24	Sulein	*Echinops echinatus* Roxb.	0.66	0.34	0.94	1.94
25	Seikchee	*Bridelia retusa* (L.) A. Juss.	0.66	0.34	0.67	1.67
26	Panga	*Terminalia chebula* Retz.	0.66	0.34	0.48	1.49
27	Yemane	*Gmelina arborea* Roxb.	0.66	0.34	0.40	1.41
28	Tawkyetsa	*Chionanthus ramiflora* Roxb.	0.66	0.34	0.25	1.25
29	Tayaw	*Grewia tiliifolia* Vahl	0.66	0.34	0.21	1.21
30	Kywelabyin	*Sabia paniculata* Edgew. ex Hook. f. & Thomson	0.66	0.34	0.21	1.21
31	Sagawa	*Michelia champaca* L.	0.66	0.34	0.18	1.18
32	Ziphyu	*Emblica officinalis* Gaertn.	0.66	0.34	0.16	1.16
33	Yindaike	*Dalbergia cultrata* Grah.	0.66	0.34	0.11	1.11
34	Tawshout	*Glycosmis pentaphylla* Correa	0.66	0.34	0.06	1.06
35	Didu	*Bombax insigne* Wall.	0.66	0.34	0.04	1.05

(cont.) from table A.5

36	Zaungbalwe	*Lagerstroemia villosa* Wall. ex Kurz	0.66	0.34	0.04	1.04
37	Thade	*Protium serratum* Engl.	0.66	0.34	0.03	1.04
38	Tawyuzana	*Murraya paniculata* (L.) Jack	0.66	0.34	0.02	1.03
39	Kwetayaw	*Grewia laevigata* Vahl	0.66	0.34	0.02	1.02
	Species with dbh < 4.5 cm					
1	Tawshaut	*Glycosmis pentaphylla* Correa	16.28	19.23	19.65	55.16
2	Thidin	*Mallotus philippinensis* (Lam.) Muell. Arg.	9.30	7.69	11.62	28.61
3	Seinabaw	*Smilax perfoliata* Lour.	11.63	11.54	3.55	26.71
4	Linlun	*Sapium baccatum* Roxb.	4.65	7.69	13.15	25.50
5	Tawyuzana	*Murraya paniculata* (L.) Jack	9.30	9.62	5.33	24.25
6	Phetsut pho	*Laportea interrupta* (L.) Chew	6.98	5.77	2.96	15.70
7	Kwe tayaw	*Grewia laevigata* Vahl	2.33	3.85	9.21	15.38
8	Thetyingyi	*Croton roxburghianus* N.P. Balakr.	4.65	3.85	5.34	13.84
9	Yetakwa	*Debregeasia longifolia* Wedd.	2.33	3.85	7.50	13.67
10	Thitgyoke	*Diospyros oleifolia* Wight	2.33	1.92	5.24	9.49
11	Naywe	*Flacourtia cataphracta* Roxb.	4.65	3.85	0.78	9.28
12	Tamagagyi	*Symphorema involucratum* Roxb.	4.65	3.85	0.56	9.06
13	Kunlein	*Cordyline fruticosa* (L.) A. Chev.	2.33	1.92	4.61	8.85
14	Shitmatet	*Toddalia asiatica* (L.) Lam.	4.65	3.85	0.04	8.54
15	Thadi	*Protium serratum* Engl.	2.33	1.92	3.20	7.45
16	Kyetlesan	*Virtex* sp	2.33	1.92	2.71	6.96
17	Phetsut	*Eriobotrya bengalensis* (Roxb.) Hook. f.	2.33	1.92	2.26	6.51
18	Yon	*Anogeissus acuminata* Wall.	2.33	1.92	2.26	6.51
19	Tawkyetsa	*Chionanthus ramiflora* Roxb.	2.33	1.92	0.02	4.27
20	Mayanin	*Pittosporum napaulensis* (DC.) Rehder & Wilson	2.33	1.92	0.02	4.27

Table A.6 Lists of relative frequency, relative density, relative dominance and important value index (IV) of the species found in dry mixed deciduous forest ecosystem of Popa Mountain Park, Myanmar

No	Local name	Species name	Relative frequency (%)	Relative density (%)	Relative dominance (%)	IV
	Species with dbh ≥ 4.5 cm					
1	Mayanin	*Pittosporum napaulensis* (DC.) Rehder & Wilson	9.14	17.46	14.87	41.47
2	Ingyin	*Shorea siamensis* (Kurz) Miq.	5.14	5.59	11.40	22.13
3	Thitya	*Shorea obtusa* Wall.	4.57	5.42	8.98	18.98
4	Yindaike	*Dalbergia cultrata* Grah.	2.86	4.92	6.33	14.11
5	Thindwenyo	*Diospyros mollis* Griff.	3.71	5.08	5.27	14.06
6	Thitswele	*Engelhardtia spicata* Blume	3.14	6.27	4.49	13.91
7	Gyo	*Schleichera oleosa* (Lour.) Oken	4.00	3.22	3.51	10.73
8	Tawkyetsa	*Chionanthus ramiflora* Roxb.	4.00	3.39	1.17	8.56
9	In	*Dipterocarpus tuberculatus* Roxb.	1.14	1.02	6.20	8.36
10	Thadi	*Protium serratum* Engl.	3.14	2.71	2.49	8.34
11	Zimani	*Hiptage candicans* Hook. f.	2.86	3.05	1.87	7.78
12	Phalan	*Bauhinia racemosa* Lam.	2.86	2.71	2.04	7.61
13	Thetyingyi	*Croton roxburghianus* N.P. Balakr.	3.43	3.05	1.13	7.60
14	Kyetet	*Combretum apetalum* Wall.	2.29	2.20	1.34	5.83
15	Thidin	*Mallotus philippinensis* (Lam.) Muell. Arg.	1.71	2.37	1.60	5.69
16	Thitgyoke	*Diospyros oleifolia* Wight	1.71	1.69	1.93	5.34
17	Ziphyu	*Emblica officinalis* Gaertn.	2.00	1.86	1.32	5.18
18	Ondon	*Litsea salicifolia* (Nees) Hook. f.	1.43	1.02	2.66	5.11
19	Tamalan	*Dalbergia oliveri* Gamble	2.00	1.53	1.01	4.54
20	Kyaungshaletto	*Heteropanax fragrans* (Roxb. ex DC.) Seem.	2.00	1.19	1.31	4.49
21	Naywe	*Flacourtia cataphracta* Roxb.	2.29	1.36	0.78	4.42
22	Phetsut	*Eriobotrya bengalensis* (Roxb.) Hook. f.	1.71	1.36	0.61	3.68
23	Yon	*Anogeissus acuminata* Wall.	1.43	0.85	1.17	3.45
24	Thayet	*Mangifera indica* L.	0.57	0.34	2.31	3.22
25	Thande	*Stereospermum neuranthum* Kurz	1.14	0.85	1.15	3.14
26	Thaukkyant	*Terminalia crenulata* (Heyne) Roth	1.71	1.02	0.36	3.09

(cont.) from table A.6

27	Bonmeza	*Albizia chinensis* (Osbeck) Merr.	0.86	0.68	1.42	2.95
28	Lunbo	*Buchanania lanzan* Spreng.	1.43	0.85	0.65	2.93
29	Te	*Diospyros burmanica* Kurz	1.43	1.19	0.31	2.93
30	Shone	*Ulmus lancifolia* Roxb.	0.57	0.51	1.60	2.68
31	Tawtanakha	*Anacolosa griffithii* Mast.	1.14	0.85	0.42	2.41
33	Kyunbo	*Premna pyramidata* Wall.	1.14	0.68	0.38	2.20
34	Tamagagyi	*Symphorema involucratum* Roxb.	1.14	0.68	0.22	2.05
35	Suyit	*Acacia nilotica* (L.) Delile	1.14	0.68	0.16	1.98
36	Banbwe	*Careya arborea* Roxb.	0.86	0.51	0.52	1.89
37	Thitseint	*Terminalia bellerica* Roxb.	0.57	0.34	0.94	1.85
38	Khaung	*Rhus paniculata* Wall.	0.86	0.68	0.25	1.79
39	Kyunkhautnwe	*Vitex limonifolia* Wall.	0.86	0.51	0.38	1.75
40	Tamainsaphyu	*Gardenia sessiliflora* Wall.	0.86	0.51	0.25	1.62
41	Pyinkado	*Xylia xylocarpa* (Roxb.) Taub.	0.86	0.51	0.21	1.58
42	Tayaw	*Grewia tiliifolia* Vahl	0.57	0.51	0.49	1.57
43	Shitsha	*Phyllanthus albizzioides* (Kurz) Hook. f.	0.86	0.51	0.13	1.49
44	Malwa	*Markhamia stipulata* (Wall.) Seem. ex K. Schum.	0.86	0.51	0.12	1.49
45	Thinwin	*Millettia pendula* Benth.	0.57	0.34	0.54	1.45
46	Kyetyo	*Vitex canescens* Kurz	0.57	0.68	0.11	1.36
47	Ngu shwe	*Cassia fistula* L.	0.57	0.51	0.26	1.34
48	Panga	*Terminalia chebula* Retz.	0.57	0.34	0.42	1.33
49	Zaungbalwe	*Lagerstroemia villosa* Wall. ex Kurz	0.57	0.51	0.22	1.30
50	Zi talaing	*Ziziphus rugosa* Lam.	0.57	0.34	0.17	1.08
51	Phetwunphyu	*Berrya mollis* Wall. ex Kurz	0.57	0.34	0.16	1.07
52	Kyun	*Tectona grandis* L. f.	0.57	0.34	0.13	1.04
53	Tawkhan	*Carissa spinarum* A. DC.	0.57	0.34	0.10	1.01
54	Taung zalatni	*Kopsia fruticosa* A. DC.	0.57	0.34	0.06	0.97
55	Kyetlasan	*Virtex* sp	0.57	0.34	0.05	0.96
56	Kinpalin	*Antidesma ghesaembilla* Gaertn.	0.57	0.34	0.02	0.93
57	Khabaungyi	*Strychnos potatorum* L. f.	0.29	0.17	0.40	0.85
58	Yemane	*Gmelina arborea* Roxb.	0.29	0.17	0.36	0.81
59	Swedaw	*Bauhinia variegata* L.	0.29	0.17	0.11	0.57
60	Gyokhamet	*Walsura trichostemon* Miq.	0.29	0.17	0.09	0.54
61	Kha aung	*Ficus hispida* L. f.	0.29	0.17	0.09	0.54
62	Wun u	*Millettia extensa* Benth.	0.29	0.17	0.07	0.53
63	Yinma	*Chukrasia velutina* Roem.	0.29	0.17	0.06	0.52
64	Sae eikemwe	*Lagerstroemia macrocarpa* Kurz	0.29	0.17	0.05	0.51
65	Yingat	*Gardenia obtusifolia* Roxb.	0.29	0.17	0.05	0.51
66	Lettokegyi	*Holarrhena pubescens* Wall. ex G. Don	0.29	0.17	0.05	0.51
67	Tin	*Fioria vitifolia* (L.) Mattei	0.29	0.17	0.05	0.50
68	Sandagu	*Santalum album* L.	0.29	0.17	0.04	0.50
69	Pyinma	*Lagerstroemia speciosa* (L.) Pers.	0.29	0.17	0.04	0.49
70	Taw sabai	*Jasminum angustifolium* Vahl	0.29	0.17	0.03	0.48
	Species with dbh < 4.5 cm					
1	Tawkyetsa	*Chionanthus ramiflora* Roxb.	10.34	18.57	17.46	46.38
2	Khaung	*Rhus paniculata* Wall.	8.28	11.90	9.57	29.75
3	Kyetyo	*Vitex canescens* Kurz	6.21	6.19	6.86	19.26
4	Kinpalin	*Antidesma ghesaembilla* Gaertn.	6.90	5.24	7.09	19.23
5	Suyit	*Acacia nilotica* (L.) Delile	6.21	4.76	3.32	14.29
6	Thetyingyi	*Croton roxburghianus* N.P. Balakr.	4.83	3.33	3.35	11.51
7	Tame	*Indigofera lacei* Craib	4.14	5.24	2.10	11.48
8	Taw sabai	*Jasminum angustifolium* Vahl	3.45	2.86	3.45	9.75
9	Thidin	*Mallotus philippinensis* (Lam.) Muell. Arg.	3.45	3.81	2.40	9.66
10	Thadi	*Protium serratum* Engl.	3.45	2.38	3.55	9.38
11	Ziphyu	*Emblica officinalis* Gaertn.	2.07	2.86	4.35	9.28
12	Mayanin	*Pittosporum napaulensis* (DC.) Rehder & Wilson	3.45	3.33	2.41	9.19
13	Thitya	*Shorea obtusa* Wall.	2.76	1.43	2.55	6.74
14	Tamalan	*Dalbergia oliveri* Gamble	2.76	1.90	1.57	6.24
15	Thitswele	*Engelhardtia spicata* Blume	2.07	1.43	2.49	5.99
16	Naywe	*Flacourtia cataphracta* Roxb.	2.07	1.90	1.89	5.86
17	Shitsha	*Phyllanthus albizzioides* (Kurz) Hook. f.	1.38	1.90	2.32	5.60
18	Phetsut	*Eriobotrya bengalensis* (Roxb.) Hook. f.	2.07	1.90	1.21	5.19
19	Kyaungshaletto	*Heteropanax fragrans* (Roxb. ex DC.) Seem.	2.07	1.43	1.66	5.16
20	Phalan	*Bauhinia racemosa* Lam.	1.38	0.95	1.73	4.06
21	Tawtanakha	*Anacolosa griffithii* Mast.	1.38	0.95	1.44	3.77
22	Gyo	*Schleichera oleosa* (Lour.) Oken	1.38	0.95	1.32	3.65

(cont.) from table A.6

23	Ingyin	*Shorea siamensis* (Kurz) Miq.	1.38	0.95	1.28	3.61
24	Taminsaphyu	*Gardenia sessiliflora* Wall.	0.69	0.95	1.83	3.48
25	Pyinma	*Lagerstroemia speciosa* (L.) Pers.	1.38	0.95	1.12	3.45
26	Swedaw	*Bauhinia variegata* L.	0.69	1.43	1.32	3.43
27	Tawkhan	*Carissa spinarum* A. DC.	1.38	0.95	0.57	2.90
28	Tayaw	*Grewia tiliifolia* Vahl	0.69	0.48	1.60	2.76
29	Myingaungnay aung	*Celastrus paniculatus* Willd.	0.69	0.48	1.38	2.55
30	Sae eikemwe	*Lagerstroemia macrocarpa* Kurz	0.69	0.48	1.12	2.28
31	Yemagyi	*Strobilanthes phyllostachyus* Kurz	0.69	1.43	0.05	2.17
32	Thindwenyo	*Diospyros mollis* Griff.	0.69	0.48	0.88	2.05
33	Te	*Diospyros burmanica* Kurz	0.69	0.48	0.88	2.05
34	Ondon	*Litsea salicifolia* (Nees) Hook. f.	0.69	0.48	0.78	1.94
35	Kyetlesan	*Virtex* sp	0.69	0.48	0.58	1.75
36	Kyetet	*Combretum apetalum* Wall.	0.69	0.48	0.54	1.71
37	Zaungbalwe	*Lagerstroemia villosa* Wall. ex Kurz	0.69	0.48	0.54	1.71
38	Seinabaw	*Smilax perfoliata* Lour.	0.69	0.48	0.54	1.71
39	Thande	*Stereospermum neuranthum* Kurz	0.69	0.48	0.46	1.62
40	Yinbya	*Clerodendrum serratum* Spreng.	0.69	0.48	0.35	1.51
41	Kwe tayaw	*Grewia laevigata* Vahl	0.69	0.48	0.03	1.20
42	Tamagagyi	*Symphorema involucratum* Roxb.	0.69	0.48	0.02	1.19
43	Tawyuzana	*Murraya paniculata* (L.) Jack	0.69	0.48	0.01	1.18
44	Phettan	*Heterophragma adenophylla* (Wall.) Seem. ex Benth. & Hook.	0.69	0.48	0.01	1.18
45	Taung zalatni	*Kopsia fruticosa* A. DC.	0.69	0.48	0.01	1.17

Table A.7 Lists of relative frequency, relative density, relative dominance and important value index (IV) of the species found in deciduous dipterocarp forest ecosystem of Popa Mountain Park, Myanmar

No	Local name	Species name	Relative frequency (%)	Relative density (%)	Relative dominance (%)	IV
	Species with dbh ≥ 4.5 cm					
1	Thitya	*Shorea obtusa* Wall.	12.46	19.71	33.77	65.93
2	Ingyin	*Shorea siamensis* (Kurz) Miq.	8.54	11.53	11.71	31.78
3	Te	*Diospyros burmanica* Kurz	5.34	7.55	4.71	17.59
4	Kyunbo	*Premna pyramidata* Wall.	6.05	4.82	4.85	15.72
5	In	*Dipterocarpus tuberculatus* Roxb.	1.42	2.52	11.55	15.49
6	Thitswele	*Engelhardtia spicata* Blume	4.27	5.24	5.76	15.27
7	Thaukkyant	*Terminalia crenulata* (Heyne) Roth	6.05	4.82	3.01	13.88
8	Mayanin	*Pittosporum napaulensis* (DC.) Rehder & Wilson	4.98	4.61	3.38	12.97
9	Kyun	*Tectona grandis* L. f.	3.56	3.77	2.90	10.23
10	Tamalan	*Dalbergia oliveri* Gamble	3.56	3.14	2.69	9.39
11	Pyinkado	*Xylia xylocarpa* (Roxb.) Taub.	3.56	2.31	1.03	6.89
12	Tawkyetsa	*Chionanthus ramiflora* Roxb.	2.85	2.52	1.23	6.59
13	Pyinma	*Lagerstroemia speciosa* (L.) Pers.	1.78	2.73	0.85	5.35
14	Kyetlesan	*Virtex* sp	2.14	1.68	1.18	4.99
15	Kabaungyi	*Strychnos potatorum* L. f.	2.14	1.47	0.88	4.49
16	Seikchee	*Bridelia retusa* (L.) A. Juss.	2.14	1.26	0.92	4.31
17	Thetyingyi	*Croton roxburghianus* N.P. Balakr.	1.78	1.68	0.65	4.11
18	Taminsaphyu	*Gardenia sessiliflora* Wall.	2.14	1.47	0.45	4.05
19	Panga	*Terminalia chebula* Retz.	1.42	0.84	1.12	3.38
20	Kyunkautnwe	*Vitex limonifolia* Wall.	1.78	1.05	0.37	3.19
21	Phettan	*Heterophragma adenophylla* (Wall.) Seem. ex Benth. & Hook.	1.42	1.05	0.54	3.01
22	Lunbo	*Buchanania lanzan* Spreng.	1.42	0.84	0.68	2.94
23	Shitsha	*Phyllanthus albizzioides* (Kurz) Hook. f.	1.42	0.84	0.32	2.58
24	Kinpalin	*Antidesma ghesaembilla* Gaertn.	1.42	0.84	0.29	2.55
25	Thadi	*Protium serratum* Engl.	1.07	0.63	0.83	2.52
26	Naywe	*Flacourtia cataphracta* Roxb.	1.42	0.84	0.22	2.48
27	Leikpyataung	*Bauhinia diphylla* Buch.-Ham.	0.36	1.26	0.66	2.27
28	Tawkhan	*Carissa spinarum* A. DC.	1.07	0.84	0.20	2.10
29	Tayaw	*Grewia tiliifolia* Vahl	1.07	0.84	0.16	2.06

(cont.) from table A.7

30	Nabe	*Lannea coromandelica* (Houtt.) Merr.	1.07	0.63	0.22	1.92
31	Khaung	*Rhus paniculata* Wall.	1.07	0.63	0.21	1.90
32	Zimani	*Hiptage candicans* Hook. f.	1.07	0.63	0.20	1.89
33	Kyaungshaletto	*Heteropanax fragrans* (Roxb. ex DC.) Seem.	0.71	0.63	0.25	1.59
34	Taungtangyi	*Premna integrifolia* L.	0.71	0.42	0.34	1.47
35	Gyo	*Schleichera oleosa* (Lour.) Oken	0.71	0.42	0.30	1.43
36	Nibase	*Morinda tinctoria* Roxb.	0.71	0.42	0.13	1.26
37	Kyetyo	*Vitex canescens* Kurz	0.71	0.42	0.08	1.21
38	Zi talaing	*Ziziphus rugosa* Lam.	0.71	0.42	0.07	1.20
39	Kyetet	*Combretum apetalum* Wall.	0.36	0.63	0.14	1.12
40	Khuthan	*Hymenodictyon orixense* (Roxb.) Mabb.	0.36	0.21	0.26	0.83
41	Yemane	*Gmelina arborea* Roxb.	0.36	0.21	0.23	0.79
42	Yingat	*Gardenia obtusifolia* Roxb.	0.36	0.21	0.23	0.79
43	Ngusat	*Cassia renigera* Wall. ex Benth	0.36	0.21	0.16	0.73
44	Shinpagu	*Olax psittacorum* (Willd.) Vahl	0.36	0.21	0.09	0.65
45	Yinma	*Chukrasia velutina* Roem.	0.36	0.21	0.07	0.63
46	Myingaungnayaung	*Celastrus paniculatus* Willd.	0.36	0.21	0.05	0.61
47	Tawtanakha	*Anacolosa griffithii* Mast.	0.36	0.21	0.05	0.61
48	Ziphyu	*Emblica officinalis* Gaertn.	0.36	0.21	0.03	0.60
49	Sandagu	*Santalum album* L.	0.36	0.21	0.03	0.60
	Species with dbh < 4.5 cm					
1	Kaung	*Rhus paniculata* Wall.	7.14	15.60	17.61	40.35
2	Tawkyetsa	*Chionanthus ramiflora* Roxb.	5.36	14.00	15.21	34.56
3	Kyetyo	*Vitex canescens* Kurz	5.95	8.40	11.18	25.53
4	Tame	*Indigofera lacei* Craib	6.55	5.60	1.75	13.90
5	Sandagu	*Santalum album* L.	4.17	4.00	5.11	13.28
6	Pyinma	*Lagerstroemia speciosa* (L.) Pers.	2.98	3.20	6.30	12.47
7	Shitsha	*Phyllanthus albizzioides* (Kurz) Hook. f.	4.17	3.20	4.20	11.57
8	Ingyin	*Shorea siamensis* (Kurz) Miq.	4.17	2.80	4.44	11.41
9	Naywe	*Flacourtia cataphracta* Roxb.	2.98	2.80	3.97	9.75
10	Suyit	*Acacia nilotica* (L.) Delile	4.76	3.20	1.36	9.32
11	Thaukkyant	*Terminalia crenulata* (Heyne) Roth	3.57	2.40	2.36	8.33
12	Pyinkado	*Xylia xylocarpa* (Roxb.) Taub.	2.98	2.00	2.53	7.51
13	Tayaw	*Grewia tiliifolia* Vahl	3.57	2.40	1.50	7.47
14	Thitya	*Shorea obtusa* Wall.	2.38	2.00	2.80	7.18
15	Ziphyu	*Emblica officinalis* Gaertn.	2.98	2.00	1.88	6.85
16	Thetyingyi	*Croton roxburghianus* N.P. Balakr.	2.38	2.80	1.14	6.32
17	Kinpalin	*Antidesma ghesaembilla* Gaertn.	2.98	2.40	0.01	5.38
18	Tawkhan	*Carissa spinarum* A. DC.	1.79	1.20	1.91	4.89
19	Taw sabai	*Jasminum angustifolium* Vahl	1.79	1.20	1.91	4.89
20	Te	*Diospyros burmanica* Kurz	2.38	1.60	0.61	4.60
21	Mayanin	*Pittosporum napaulensis* (DC.) Rehder & Wilson	1.19	1.60	0.95	3.74
22	Tamalan	*Dalbergia oliveri* Gamble	1.79	1.20	0.60	3.59
23	Wun u	*Millettia extensa* Benth.	1.79	1.20	0.53	3.51
24	Myingaungnayaung	*Celastrus paniculatus* Willd.	1.79	0.80	0.59	3.18
25	Kwe tayaw	*Grewia laevigata* Vahl	1.79	1.20	0.17	3.16
26	Yingat	*Gardenia obtusifolia* Roxb.	1.19	0.80	1.07	3.06
27	In	*Dipterocarpus tuberculatus* Roxb.	1.19	0.80	1.06	3.05
28	Kyunkhautnwe	*Vitex limonifolia* Wall.	1.19	0.80	1.05	3.04
29	Seikchee	*Bridelia retusa* (L.) A. Juss.	1.19	0.80	0.85	2.85
30	Thayet cho	*Xantolis tomentosa* Raf.	1.19	0.80	0.85	2.85
31	Tamagagyi	*Symphorema involucratum* Roxb.	1.19	0.80	0.01	2.00
32	Swedaw	*Bauhinia variegata* L.	1.19	0.80	0.01	2.00
33	Lunbo	*Buchanania lanzan* Spreng.	0.60	0.40	0.81	1.80
34	Tawtanakha	*Anacolosa griffithii* Mast.	0.60	0.40	0.81	1.80
35	Shinpagu	*Olax psittacorum* (Willd.) Vahl	0.60	0.40	0.75	1.75
36	Taminsaphyu	*Gardenia sessiliflora* Wall.	0.60	0.40	0.59	1.59
37	Thitgyoke	*Diospyros oleifolia* Wight	0.60	0.40	0.59	1.59
38	Phetsut	*Eriobotrya bengalensis* (Roxb.) Hook. f.	0.60	0.40	0.41	1.41
39	Taungtangyi	*Premna integrifolia* L.	0.60	0.40	0.26	1.26
40	Yinma	*Chukrasia velutina* Roem.	0.60	0.40	0.15	1.14
41	Kyetlesan	*Virtex* sp	0.60	0.40	0.07	1.06
42	Mahagalantin	*Linostoma decandrum* Wall.	0.60	0.40	0.01	1.01
43	Thadi	*Protium serratum* Engl.	0.60	0.40	0.01	1.00
44	Thitswele	*Engelhardtia spicata* Blume	0.60	0.40	0.01	1.00
45	Phetwunphyu	*Berrya mollis* Wall. ex Kurz	0.60	0.40	0.01	1.00
46	Sae kamin	*Desmodium gyrans* DC.	0.60	0.40	0.00	1.00

Table A.8 Lists of relative frequency, relative density, relative dominance and important value index (IV) of the species found in dry forest ecosystem of Popa Mountain Park, Myanmar

No	Local name	Species name	Relative frequency (%)	Relative density (%)	Relative dominance (%)	IV
	Species with dbh ≥ 4.5 cm					
1	Dahat	*Tectona hamiltoniana* Wall.	12.24	14.41	28.06	54.71
2	Thaukkyant	*Terminalia crenulata* (Heyne) Roth	13.06	20.46	10.19	43.71
3	Te	*Diospyros burmanica* Kurz	11.43	13.26	13.80	38.49
4	Than	*Terminalia oliveri* Brandis	6.53	4.61	6.45	17.59
5	Thanaung	*Acacia leucophloea* (Roxb.) Willd.	1.63	1.15	13.97	16.76
6	Tabauk	*Dalbergia paniculata* Roxb.	5.71	4.03	6.01	15.75
7	Nibase	*Morinda tinctoria* Roxb.	6.12	5.76	2.75	14.64
8	Thetyingyi	*Croton roxburghianus* N.P. Balakr.	5.31	4.32	1.46	11.09
9	Khaung	*Rhus paniculata* Wall.	3.67	4.32	1.19	9.19
10	Kyunbo	*Premna pyramidata* Wall.	3.67	3.17	2.32	9.17
11	Lettokegyi	*Holarrhena pubescens* Wall. ex G. Don	2.86	3.17	0.82	6.84
12	Kyetlesan	*Vitex* sp	2.86	2.02	1.91	6.78
13	Pyinkado	*Xylia xylocarpa* (Roxb.) Taub.	2.86	2.02	0.76	5.63
14	Nabe	*Lannea coromandelica* (Houtt.) Merr.	1.22	1.15	3.08	5.46
15	Tayaw	*Grewia tiliifolia* Vahl	2.45	1.73	0.73	4.90
16	Yingat	*Gardenia obtusifolia* Roxb.	2.04	1.73	0.50	4.27
17	Beinwe	*Hiptage benghalensis* (L.) Kurz	2.04	1.44	0.48	3.96
18	Naywe	*Flacourtia cataphracta* Roxb.	2.04	1.44	0.42	3.91
19	Thayet cho	*Xantolis tomentosa* Raf.	1.22	0.86	0.94	3.03
20	Kyetet	*Combretum apetalum* Wall.	1.22	1.15	0.30	2.68
21	Lunbo	*Buchanania lanzan* Spreng.	1.22	0.86	0.50	2.59
22	Tabutgyi	*Miliusa velutina* Hook. f. & Thomson	1.22	0.86	0.50	2.59
23	Ingyin	*Shorea siamensis* (Kurz) Miq.	1.22	0.86	0.46	2.55
24	Sha	*Acacia catechu* Willd.	1.22	0.86	0.38	2.47
25	Zimani	*Hiptage candicans* Hook. f.	0.82	0.58	0.30	1.70
26	Ziphyu	*Emblica officinalis* Gaertn.	0.82	0.58	0.26	1.65
27	Zaungchan	*Osyris wightiana* Wall.	0.41	0.86	0.36	1.64
28	Taminsaphyu	*Gardenia sessiliflora* Wall.	0.82	0.58	0.21	1.60
29	Taw sabai	*Jasminum angustifolium* Vahl	0.82	0.58	0.14	1.53
30	Thitya	*Shorea obtusa* Wall.	0.41	0.58	0.17	1.16
31	Tawkyetsa	*Chionanthus ramiflora* Roxb.	0.41	0.29	0.42	1.12
32	Shitsha	*Phyllanthus albizzioides* (Kurz) Hook. f.	0.41	0.29	0.16	0.86
	Species with dbh < 4.5 cm					
1	Thetyingyi	*Croton roxburghianus* N.P. Balakr.	11.90	13.64	10.39	35.94
2	Than	*Terminalia oliveri* Brandis	9.52	9.09	14.23	32.84
3	Beinwe	*Hiptage benghalensis* (L.) Kurz	9.52	9.09	10.34	28.95
4	Tabaut	*Dalbergia paniculata* Roxb.	7.14	9.09	11.89	28.13
5	Khaung	*Rhus paniculata* Wall.	9.52	9.09	3.63	22.24
6	Sha	*Acacia catechu* Willd.	7.14	6.82	5.67	19.63
7	Thaukkyant	*Terminalia crenulata* (Heyne) Roth	7.14	6.82	5.59	19.55
8	Yingat	*Gardenia obtusifolia* Roxb.	4.76	4.55	5.67	14.97
9	Tayaw	*Grewia tiliifolia* Vahl	4.76	4.55	4.03	13.34
10	Nibase	*Morinda tinctoria* Roxb.	2.38	2.27	7.33	11.98
11	Pyinkado	*Xylia xylocarpa* (Roxb.) Taub.	2.38	2.27	5.65	10.30
12	Naywe	*Flacourtia cataphracta* Roxb.	2.38	2.27	3.92	8.58
13	Zimani	*Hiptage candicans* Hook. f.	2.38	2.27	3.92	8.58
14	Taminsaphyu	*Gardenia sessiliflora* Wall.	2.38	2.27	1.92	6.58
15	Lettokegyi	*Holarrhena pubescens* Wall. ex G. Don	2.38	2.27	1.92	6.58
16	Tame	*Indigofera lacei* Craib	2.38	2.27	1.74	6.40
17	Khaungtan	*Aganosma marginata* (Roxb.) G. Don	2.38	2.27	0.74	5.39
18	Ingyin	*Shorea siamensis* (Kurz) Miq.	2.38	2.27	0.63	5.28
19	Taw sabai	*Jasminum angustifolium* Vahl	2.38	2.27	0.63	5.28
20	Kyetet	*Combretum apetalum* Wall.	2.38	2.27	0.16	4.81
21	Leikpyataung	*Bauhinia diphylla* Buch.-Ham.	2.38	2.27	0.02	4.67

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