VARIATION IN BIOMASS, CARBON STOCK AND CARBON SEQUESTRATION POTENTIAL OF SELECTED FORESTS OF MIZORAM

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Submitted

In partial fulfilment of the requirements of the Degree of Doctor of Philosophy in Forestry of Mizoram University, Aizawl

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CERTIFICATE

This is to certify that the thesis entitled “Variation in Biomass, Carbon Stock and Carbon Sequestration Potential of Selected Forests of Mizoram”submitted by Mr. Anudip Gogoi to the Department of Forestry, Mizoram University, Aizawl for the award of the degree of Doctor of Philosophy in Forestry embodies the record of original investigation carried out by him under mysupervision. I further certify that Mr. Anudip Gogoi has fulfilled all the criteria prescribed by UGC and the conditions laid down in the Ph.D. regulations of the MizoramUniversity. The thesis as whole nor any part of it has not been submitted earlier to any university or institute for the award of any degreeand the thesis presented is worthy of being considered for the award of the Ph.D Degree.

Date: 27/06/2022
Place: Aizawl

(Professor U. K. Sahoo)
Supervisor

DECLARATION

I, Mr. Anudip Gogoi, do hereby declare that the subject matter of the thesis entitled "Variation in Biomass, Carbon Stock and Carbon Sequestration Potential of Selected Forests of Mizoram" is the record of original work done by me under the supervision of Prof. U.K. Sahoo, Department of Forestry, Mizoram University. The thesis did not form the basis of the award of any previous degree to me or to the best of my knowledge to anybody else, and it has not been submitted by me for any research degree in any other University or Institute.

This thesis is being submitted to the Mizoram University for the degree of Doctor of Philosophy in Forestry.

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CHAPTER- 1

GENERAL INTRODUCTION

1.1 Global Climate Change and its Impact

Climate change is one of the greatest challenges that the global community is facing today. The perceptible rise in temperature in today's world brings in its wake huge catastrophic changes which can no longer be ignored. Climate change crisis is threatening the entire global population with water shortages, hunger and poverty; as a result the security of our planet is under questioned today. There are multiple causes which are responsible for shaping the earth's climate. Although, natural causes are considered as the reason for repeated temperature changes in the geological past, the present rise is mostly attributed to accelerated global temperature rise due to anthropogenic greenhouse gas emissions (Jan et al., 2017). Evidences from the past records indicate that the earth is currently going through an accelerated period of global warming(IPCC, 2007a).Increases in anthropogenic emissions of greenhouse gases and its effects are considered to be the major driving force behind the accelerated global warmingthat has taken place over the last century (IPCC, 2007a,b).The natural causes include variations in radiation emitted from the sun, the cyclical behaviour of the Earth's orbit and axis, changesin the gas composition of the atmosphere, volcanism, uplifting and wearing a way ofland surfaces, shifting distribution of landmasses and oceans caused by plate tectonics,and changes in the characteristics of the Earth's land surface etc. (McMullen and Jabbour,2009).

Increasing levels of greenhouse gas (GHG) emissions leading to rise in global temperature and climate change have become a major concern of all the stakeholders including policy makers which has sparked extensive research on potential climate change mitigation strategies and lead to many international discussions and negotiations. Thesmall incremental increases of global temperature were observed until the period of 1915-1970 before greater increases were recorded beyond this period following rapid increases of anthropogenic CO_2 (Alexiadis, 2007).Global GHGs emissions have risen at a rate of 1.5 per cent per year in the last decade (UNEP, 2019). Total GHGs emissions, including from land-use change, reached a record high of 55.3 $GtCO_2$ in 2018. The anthropogenic emissions of greenhouse gasses are discernibly impacting the global climate and it is predicted to grow stronger over the next 100 years (Barker et al., 2002). It is predicted that climate change caused by the greenhouse gas emissions will increase the mean global temperature by 1.0^{o}C to 3.5°C in the next fifty to hundred years (Rustad et al., 2001).The Intergovernmental Panel on Climate Change (IPCC, 1995, 2001) has projected the average temperature increment ranging up to 6.4^{o} C by 2100. Global average temperature reached 14.8^{o}Cin 2005 which was higher by 1^{o}C than values in 1955. According to a projection by the IPCC, the global mean temperature may increase from 1.1°C to 6.4°C by 2100, which is likely to affect storms and floods, and lead to a rise in sea level due to the thermal expansion of the oceans and the melting of ice sheets and glaciers (IPCC, 2007a).Therefore, a major step forwarded towards the global climate governance in the year 2015. The Paris Agreement, adopted by 195 countries at Conference of the Parties (COP) 21 sets out a global action plan to limit global warming to well below 2°C and pursuing efforts to limit it to 1.5°C. To put the world on the least-cost pathway to limiting global warming to below2˚C and 1.5°C, the emissions would need to be 25 % and 55 % lower than in 2018.

Global warming and climate change are closely related to amount of CO_2 in the air. Among the GHGs, carbon dioxide (CO_2) is the most dominant, accounting for nearly 77% of the global total CO_2 equivalent greenhouse gas emissions (IPCC, 2007a). In the present days, human activity has significantly altered the global carbon cycle as land use change and fossil fuel burning has increased the level of global GHG, most importantly, CO_2 in the atmosphere (Hamere et al., 2015).An unprecedented increase of 36% in CO_2 concentration was observed between 1750 and 2005 (IPCC,2007a). According to an estimate, atmospheric CO_2 concentration has increased from 280 ppm in the pre-industrial periods of today's over 400 ppm accounting for 60% of global warming (Pan et al., 2011). Fossil CO_2 emissions from energy use and industry, which dominate total GHG emissions, grew 2.0 per cent in 2018, reaching a record 37.5 $GtCO_2$ per year.

The increasing CO_2 concentration in the air can impact the natural systems as well as the biotic life in many ways. It can affect the earth's temperature, global climate pattern, soil moisture content, net carbon exchange, soil nutrition, solar radiation and air pollutants, ocean depth, floods, landslide, melting of glaciers, surface salinity and density etc. (Hirst, 1999).It can also affectthe survival of coral reef (Crabbe, 2008), ecosystems and biologic species both on land and in the oceans (Jan et al., 2017), spreads infectious diseases (Kurane, 2010); soil biota (Jucevica and Melecis, 2006): crop productivity (Tan and Shibasaki, 2003) as well as the rate of plant growth (Dhakhwa et al., 1997). Scientists have pointed out that the extinction of species over geological time is mainly due to climate change (Jan et al., 2017). Studies suggests that climate change can pushes mass migration of species from one place to another including humans (IPCC, 2014). Climate change and global warming also have vast adverse impacts on socio-economic developments. According to Mora (2017), almost three quarters of world's human population will be exposed to deadly climate conditions by 2100. Vector borne diseases, such as malaria, dengue and water borne diseases such as dysentery, typhoid are likely to re-emerge. This will not only increase the informal settlements, but would also lead to social conflicts, poverty and standard of life. However, the effect of climate change is more pronounced in the developing countries due to the large scale dependency on natural resources as well as due to the rapid development activities.

1.2 CO_2 Emission and Carbon Sequestration

Reducing the output of greenhouse gas emissions is the starting point for any mitigation program and it plays a critical role in implementing the carbon and climate commitments.There are number of remedial measures through which the amount of CO_2 in the air can be controlled. Some of these measures are short and medium term and some are long term. However, reduction in carbon emissions and promotion of carbon sinks in the biosphere through carbon sequestration are two key activities which can check the increasing level of CO_2 in the environment. The details of the remedial measures mostly discussed so far by the global scientific community are-replacement of coal by gas in power generation, use of clean energy such as hydro, wind and solar energy, removal of CO_2 from the atmosphere, increase in afforestation and reduction in deforestation, changing our lifestyle in terms of energy use, producing waste materials, unnecessary use of vehicle, eating less meat, geo-engineering for controlling the heat increment, spatial planning and infrastructure etc. Out of all these,nature-based solutions can make a large contribution and are currently the main option for CO_2 removal (UNFCCC climate action summit 2019). Forests and other terrestrial ecosystems, agriculture and food systems and marine and coastal ecosystems are the three main natural system for improving mitigation and adaptation to climate change.

There are numbers of definition available on CO_2 sequestration. The United Nations Framework Convention on Climate Change (UNFCCC) defines carbon sequestration as the process of removing carbon from the atmosphere and depositing it in a reservoir. In short, it refers to the transfer of atmospheric CO_2 and its secure storage in long lived pools.

1.3 Role of Forestry Sector in CO_2 Mitigation

Forests are the largest long lived carbon pool in any terrestrial ecosystem and play a vital role in alleviating CO_2 emission. CO_2 from the atmosphere is taken up by vegetation and stored as plant biomass. Biomass from forestry can contribute 12-74 EJ/yr to energy consumption, with a mitigation potential roughly equal to 0.4-4.4 GtCO2/yr depending on the assumption whether biomass replaces coal or gas in power plants (medium agreement, medium evidence).Therefore, quantifying biomass and carbon sequestration in forest ecosystem has a significant concern for the purpose of the improvement of global carbon accounting and environmental services.Forest represents the largest, most complex and self-regenerating of all natural resources. However, structure and function of forest ecosystems are changing drastically due to several anthropogenic activities. Studies suggest that forestry sector is the most cost-effective mitigation options which includeafforestation, sustainable forest management, agroforestry and reducing deforestation. Deforestation is the single most important source, which alone responsible for the loss of 7.3 million $ha^{-1}yr^{-1}$ forest areas between 2000 and 2005 (IPCC, 2007b).

Various bottom-up regional studies suggests that forestry sector has the economic potential to mitigate CO_2 emissions at costs up to 100 US$/ tCO_2-eq to contribute 1.3-4.2 $GtCO_2$-eq/yr (average 2.7 $GtCO_2$-eq/yr) in 2030. About 50% can be achieved at a cost under 20 US$/$tCO_2$-eq (around 1.6 $GtCO_2$/yr) with large differences between regions. The global top-down models predict far higher mitigation potentials of 13.8 $GtCO_2$-eq/yr in 2030 at carbon prices less than or equal to 100 US$/$tCO_2$-eq. However, regional studies tend to use more detailed data and a wider range of mitigation options are reviewed, thus, these studies may more accurately reflect regional circumstances and constraints than simpler, more aggregate global models (IPCC, 2007b).

1.4 SCOPE OF THE STUDY

North-East India’s forests contribute a significant part of the country’s total carbon stock.A GIS based assessment on technically suitable forest lands describe that Peninsular Malaysia and the Eastern and North Eastern part of India have the highest suitable lands for carbon sequestration among all the countries in tropical Asia (Iverson et al., 1993). At the same time, Assam (vulnerability index=0.72) and Mizoram (vulnerability index=0.71) are considered to be the most vulnerable state to climate change among the twelve Indian Himalayan States (DST, 2018).

Although many studies have been done on carbon sequestration in forestry sector, the influence of environmental factors on forest carbon stocks has not been properly addressed (Gubena and Soromessa, 2016). Temperature, rainfall and altitude are the three major environmental factors which affects the carbon allocation pattern in the different forest compartments. Therefore, it is very important to adopt such an approach which combines these three driving factors of environment viz., temperature, rainfall and altitude under the same umbrella. There has been relatively limited research on the link between vegetation activity and rainfall in high precipitation belts of the world, for example the eastern extension of Himalaya (Prasad et al., 2007; Saikia, 2009). Moreover, numerous simulation models were developed to predict carbon stock for future climatic conditions that often include temperature and precipitation as an independent variable. Models such as RothC, CENTURY and CarboSOIL have been successfully used to determine future carbon pool. However, an in-depth study of the independent variable is still needed to precisely estimate future carbon stocks. However, these variables are still not well explored in the Indian scenario particularly, in the North-East India.

Numerous studies have been carried out to estimate carbon storage patterns in the forests of North East India particularly in the forests of the Barak and Brahmaputra valleys (Nath et al., 2017; Gogoi et al., 2021). However, comprehensive studies to understand the plant biodiversity, carbon stock, and sequestration potential of the North East Indian forests and its relation to the environmental factors are limited. The varied topographical differences in the hilly state of Mizoram provide scope for understanding the effect of environmental driving factors and soil nutrients on plant diversity and ecosystem carbon stock of the different forest types in this region.Besides large variation in the environmental and topographical conditions, Mizoram has the highest forest cover (84.53 %) among all the Indian states in terms of percentage to the total geographical area (ISFR, 2021). However, it is not clear that whether or not forest cover increases carbon storage as compared to those Indian states which are having the highest forest cover.Additionally, forest degradation due to the age old practice of jhum cultivation is another major constrain towards the sustainable management of forest resources in the state. It is therefore very important to identify the potential forest areas in terms of plant diversity and carbon sequestration for prioritizing it for future management strategies. Thus, a proper study to understand the plant diversity and carbon sequestration potential of major forest types of Mizoram and its relation to environmental factors and soil nutrients is ofprime importance.

1.5 GENERAL OBJECTIVES

1. To investigate plant diversity, composition and vegetation structure of the study area.
2. To assess the variation in soil organic carbon stock and its influencing factors in selected forest types.
3. To estimate the variation in biomass, total carbon stock and carbon sequestration potential of the selected forest types.
4. To correlate the effect of environmental factors and soil nutrients on plant diversity and carbon storage pattern in the selected forest types.

CHAPTER-2

REVIEW OF LITERATURE

2.1 Relationship between Species Diversity and Carbon Storage

It has been found that plant diversity have a strong positive impact on ecosystem functioning and services (Cardinale et al., 2012, Eisenhauer at al., 2019). A series of plant biodiversity-ecosystem functioning (BEF) studies, distributed across different ecosystem types and experimental durations, have emerged since the mid1990s to explore the causal relationship between plant diversity and ecosystem functioning (Schulze and Mooney, 1994; Eisenhauer et al., 2016). These studies have mostly concentrated to find out the relationship between biodiversity and ecosystem carbon storage, including both above- and belowground carbon storage (Lange et al., 2015; Chen et al., 2018; Chen and Chen, 2019). Although many of these studies have found empirical evidence for the positive relationships between plant diversity and plant productivity as well as soil carbon stocks (Lange et al., 2015; Liu et al., 2018; Yang et al., 2019), there is still much uncertainty about the relationship between plant diversity and ecosystem carbon storage. For example, it is still unclear whether plant biomass and soil carbon storage respond consistently to plant species richness and whether plant diversity–ecosystem carbon storage relationships are consistent across multiple ecosystem types; and how plant diversity–ecosystem carbon storage relationships change with experimental duration. All of these uncertainties call for a quantitative and comprehensive synthesis based on these BEF studies, which is critical to determine ecosystem functioning that is susceptible to changes in plant diversity. Plant biomass, including above and belowground biomass, represents an important ecosystem carbon pool. Large numbers of studies have found that plant diversity has a positive effect on plant productivity, which is attributed to the major mechanisms of interactions among plant species and environmental filters, such as competition reduction, niche complementarity, selection effects, and biotic and abiotic facilitation under high plant diversity (Fornara and Tilman, 2009, Cowles et al., 2016; Huang et al., 2018). In addition, much attention has been focused on whether both above- and belowground biomass increase with plant diversity, and how the allocation of above- and belowground biomass changes with plant diversity (Li et al., 2019). Given that plant growth is distinct among biomes and regulated by climate conditions, the environmental modulators, such as ecosystem types (i.e. forest, grassland and wetland etc.) and climate conditions (such as aridity), can affect the relationship between plant diversity and plant biomass production (Eisenhauer et al., 2019). The stress gradient hypothesis suggests that competitive interactions may be more pronounced under very beneficial environmental conditions, while facilitative interactions and complementarity may dominate in harsh environmental conditions (Wright, 2017). However, evidence from BEF experiments is mixed (Craven et al., 2016), and some studies suggest that biodiversity effects increase under high resource supply (Wright, 2015). Resulting stronger biodiversity effects under more moist and nutrient-rich conditions may further differ between carbon pools, as high soil resource availability may enhance aboveground biomass production more than belowground biomass production. Moreover, the strength of the BEF relationship (Thompson et al., 2018), as well as the underlying mechanisms related to environmental regulation (Gonzalez et al., 2020) may be scale dependent, therefore the plot area of BEF experiments can also affect ecosystem responses to species richness. Synthesis and theoretical work suggest that biodiversity effects on ecosystem functioning may increase with spatial scale due to multiple non-exclusive mechanisms like covering more environmental conditions (Cardinale et al., 2011). However, how this may translate into changes across different carbon pools has not been explored. In addition to these spatial considerations, the response magnitude of carbon pools to species richness may become stronger with experimental duration, as some ecological mechanisms might need many years to materialize (Reich et al., 2013). These effects of ecological and experimental modulators on the plant diversity–productivity relationship cannot be clarified in case studies of BEF experiments, which need a synthesis of data from BEF studies.

Globally, the soil carbon pool is larger than the atmospheric carbon pool and vegetation carbon pool together (Tarnocai et al., 2009). Plant diversity is likely to promote soil carbon storage by increasing plant carbon inputs and stimulating soil microbial activity (Lange et al., 2015). There is mounting empirical evidence for a positive relationship between plant diversity and soil microbial activity (Lange et al., 2015), which can, in turn, promote the processing of plant-derived resources (Eisenhauer et al., 2017), accumulation of soil microbial encompass, and thus an increase in soil carbon content (Musa Bandowe et al., 2018). Apart from the quantity of plant carbon inputs, higher quality (as indicated by e.g. higher litter nitrogen (N) content, lower litter C to N ratio, lower litter lignin content) and diversity of plant-derived inputs at high plant diversity may contribute to governing soil carbon accumulation (Lange et al., 2015). In addition to biotic effects, beneficial abiotic environments in diverse plant communities, such as higher soil moisture and neutral soil pH, can contribute to explaining the positive relationship between plant diversity and soil carbon storage (Jiang et al., 2015). However, plant diversity, potentially triggering a large diversity of decomposers, can also increase soil respiration (Chen and Chen, 2019). Therefore, soil carbon dynamics and accumulation are affected indirectly by plant diversity due to the variations in the quantity and quality of litter inputs, microbial activity, and the abiotic environment of decomposition under high plant diversity. These imply that plant diversity effects on soil carbon accumulation can be context-dependent and vary across ecosystem types, plot sizes, climatic conditions and change over the course of an experiment (Guerrero-Ramírez, 2017).

2.2 Effect of Environmental Factors on Plant Diversity and Ecosystem Carbon Storage

There is growing interest among ecologists to explore the influence of regional pool diversity and environmental factors on local species diversity and carbon storage pattern in different forest ecosystems. **C**limatic variables greatly influence the forest carbon and carbon sequestration potential (Cao and Woodward 1998;Ma et al.,2012).

The climatic variables, especially the rainfall and temperature (Zhou et al., 2018), significantly influence tree biomass (Weng and Zhou, 2006) and forest vegetation composition (Watson et al., 1996). Forest biomass is influenced by both temperature and precipitation (Li, 2006). Salinity and high-intensity light also affect vegetation growth of a forest negatively (Dong et al. 2015). Studies of the tree ring can predict future climate variation and perceive the longitudinal pattern of trees biomass growth (Kharuk et al., 2009). As a result, tree growth examination and assessment can increase our understanding and can predict the possible fluctuations in forests biomass and carbon sequestration potential (Dulamsuren et al., 2010). Therefore, it is essential to study the dynamics of forest vegetation and its relationship with the climate factors in order to understand the quality of a forest ecosystem and maintain its optimal functioning (Chen and Wang, 2009).

Plant community composition and its associated functional properties are greatly influenced by the number of available niches shaped by local environmental factors (Figueiredo et al., 2018). Therefore, different parent materials and soil types in association with spatial variation of environmental factors may harbour different floristic communities with distinct functional properties. Environmental gradients, differences in soil nutrients and disturbance regime may trigger differences in species composition and functional characteristics of the locally established plant community, such as the mean growth rate, lifespan, or wood density and thus determine the amount of carbon sequestered per area. Tree species richness strongly affects aboveground and belowground carbon storage (Ruiz-Benito et al., 2014) litter production and decomposition Huang et al., (2017) and soil carbon (Gamfeldt et al., 2013). Species richness is known to enhance biomass and carbon stocks of forests (Poorter et al., 2015). In addition to species richness, forest carbon stocks are highly influenced by many stand structural variables, such as tree size and stand characteristics (Sullivan et al., 2001).

Climatic factors such as temperature and precipitation are key drivers to control species distribution directly and ultimately the carbon storage in forests by affecting the photosynthetic activities and other biological processes (Rowe, 2009). Topographic features such as slope, aspect, and elevation can impact local climate as well as soil conditions that in turn have varied effects on vegetation structure and carbon storage (Zhang et al., 2006; Zhang and Zhang, 2007; Zhang et al., 2013, 2016). The relative distance from a water source can also affect the composition and distribution of woody vegetation because of the resulting varying amount of water available for growth (Asanok et al., 2017). Similarly, it has been found that species richness increased with precipitation until it reached 4000 mm in a neo-tropical region (Gentry, 1988). Moreover, rainfall has been shown to have a positive effect on the diameter, basal area (Khaine and Woo, 2015; Toledo et al., 2011), and carbon storage (Fisher et al 2014) of forests.

Physical and chemical soil properties can also influence vegetation patterns on a local scale (Han et al., 2011). For example, higher soil sand ratio lessens water-holding capacity that can lead to water stress on trees (Zhang et al., 2013), and acidity levels affect the distribution of species and is linked to slope and elevation in lowland tropical forests (Nguyen et al., 2015; Vahdati et al., 2017). Soil moisture also significantly changes the growth patterns of trees in drought areas (Marod 2015 and Tilk et al., 2017). In addition, the organic matter in the soil is relevant to an analysis of environmental factors and plant communities in the forest (Zhang et al., 2016). It is found that soil nutrients such as nitrogen, potassium, phosphorus, calcium, and magnesium are correlated with the richness and distribution of plant species in tropical forests (Zhang et al., 2013 and Tilk et al., 2017).

Much research has been done on the relationships of plant biodiversity with productivity, climatic factors and soil fertility in grassland ecosystems, temperate forest stands, and agro-ecosystems of different parts of the world. On the other hand, there is a lack of research and data available about this type of correlation from India.

Therefore, it is very important to enhance our understanding of the underlying mechanistic factors determining forest diversity and ecosystem functioning such as carbon storage at regional scale. Understanding the relationship between biodiversity and carbon storage in forest ecosystem is crucial for devising effective strategies for biodiversity conservation and storage of carbon to mitigate global warming and climate change. Most of the carbon sequestration studies in North-East India consider only plant diversity and structural attributes as the factor of ecosystem carbon dynamics. It is very important to understand the effect of underlying factors on species diversity and carbon storage patterns in this region as the varied topographic and climatic condition of NE India provides ample opportunities to conduct such studies. Additionally, in most of such studies involves only the plant biomass carbon stocks and many times, the effect of edaphic factors on carbon stocks are not taken into consideration.

2.3 Effect of Land Use Changes on Carbon Storage

Greenhouse gas (GHG) emissions from land-use, land-use change and forestry (LULUCF) activities substantially increased in recent days (Dale, 1997; Watson et al., 2000; Houghton 2003) and these land use changes, mainly deforestation accounts for 12% - 20%, to be the second largestsource of anthropogenic GHG emissions (Houghton et al. 2012) The alarming rate of GHG increase held responsible for ongoing climate change has consequently drawn researchattention associated with land use changes Muller et al., (2007). Carbon storage in differentpools (live biomass, litter, deadwood and soil) were directly affected by landuse change (Saatchi et al., 2011) and its rate of change varies in accordance to climatic responses,vegetative cover, choice of species, management practices and anthropogenic interventions (Lal., 2008). Hence, past and current land use practices stand out as anindicator either to be carbon sinks or source (Zhang et al., 2005). Carbon stock in both vegetationand soil have been reported to loss following conversion of primary forestto secondary forest (Ngo et al., 2013), and several other studies also reported variationseither a gain or loss of carbon stock associated with land use change in diverseecosystems (Fan et al., 2016 and Homebegowda et al., 2016). In North East India, the effect of land use and land cover change on carbon storage has not been studied adequately. However, report has been found that Choudhary et al., (2016) studied the effect of land use and land cover change in selected land use system in Tripura. Brahma et al., (2017) conducted a study on effect of land use changes on ecosystem carbon sequestration in Barak Valley of Assam. They have found that restoration of degraded forests and imperata grassland through rubber plantation and agroforestry enhanced ecosystem carbon sequestration rate and reduced CO_2 emissions from LUC. Sahoo et al., (2018) assessed the impact of land use changes on carbon stock of selected land use sectors of Mizoram.

The changes in soilorganic carbon stock owing to management or land use changeis believed to be greater than those generated by change in atmospheric CO_2 or climate disturbances (Paustian et al., 1996). In thepresent global climate change scenario, carbon sequestration in soil is gaining much importance worldwide as it can be a cost effective and uncomplicated method to mitigate the emission of CO_2 into the atmosphere. However, to meet the demand of the growing human population, the forested areas are being converted to agricultural lands and plantations. Of the total SOC stock, deforestation, due to conversion of forest to agricultural land has led to a total loss of 24% SOC stock (Murty et al., 2002; Singh et al., 2018) whereas, the conversion of grassland to agricultural land has led to 59% loss of SOC stock (Guo and Gifford, 2002). An extremely high degree of some 13 million hectares of forests are being destroyed annually with the conversion to agricultural lands which continues to be the major type of land use changes (FAO, 2006). In terrestrial ecosystems, SOC is considered to be one of the major and active carbon pools. The amount of carbon stored in soil is believed to be three times more than the amount stored in living plants and animals. Altogether, soils are estimated tocontain approximately 1200 to 1600 pg of organic carbon in the upper 1m depth and 695-930 pg of inorganic carbon down to the corresponding depth (Sombroek et al., 1993;

Batjes, 1996). The net balance between the C inputs from the vegetation andthe output by processes such as decomposition and leaching contributes to the built up of organic carbon in the soil (Sollins et al., 1996). Therefore, soils can act as a sink or source of carbon dioxide. Several studies have indicated that the amount of organic carbon in soils are affected by many factors such as temperature, rainfall, slope, altitude and parent materials but more significantly by land use types and vegetation cover. Since the amount of soil organic carbon is greatly influenced by vegetation cover, the excessive destruction of vegetation cover aggravates the chances of SOC reduction and soil degradation (Lal, 2015). The carbon stock in soils can be managed in order to heighten or lessen it with cultivation (Lal, 2010). It has also been proven in several studies that by adopting proper agricultural practices, selection of the right land use system and also depending on the climate, there might be an increment in soil carbon stocks or it may become neutral to the soil stocks that existed in the initial vegetation (Ogle et al., 2005; Zinn et al., 2005; Braz et al., 2013). On the other hand, different land use types are known to sequester different amount of soil organic carbon, but not only do soil organic carbon stock varies from one land use system to another, they also varies according to depth within the same land use system (Singh and Sahoo, 2018). Several studies have shown that the concentration of SOC is more in the upper strata of the soil. In contrast, there are studies that reported otherwise. This may be due to some management practices such as tillage, weeding and hoeing which disturbs the upper layers of the soil and enhanced carbon loss of the topsoil, especially in agricultural lands (Abera and Belachew, 2011). The different characteristics of soil such as pH, soil organic matter (SOM), bulk density,water holding capacity, nutrients and soil micro-organisms are also affected by change in land use, climate and vegetation (Islam and Weil, 2000; Lal, 2003; Shreshtha and Lal, 2007). Besides, many studies have documented that loss of soil carbon also leads to depletion and degradation of soil nutrients, soil organic matter and hence results in soil quality degradation. Nevertheless, this problem can be alleviated to a considerable extent by adopting proper and strategic method of management system.

Several initiatives have been reported to reduce anthropogenic carbon emission form land use change with adoption of scientific land use management practices such as tree buffer plantations around farm lands, mulching and soil enrichment fertilizer applications, forest slash and crop residue retention, elongation of fallow periods in shifting cultivation, crop rotation and tree plantation in degraded areas (Montagini, 2004). However, detail studies on carbon stock changes associated with the wide range of prevailing land use types following conversions in Mizoram, North East India have been lacking behind and no importance was given to the carbon implications of various land uses before making land use change decisions.

2.4 Biomass and Carbon Socks in Indian Forests

Large number variations in vegetation and or forest types occur in India due to the varied climatic and topographical differences. But, comprehensive data on biomass and carbon stocks are lacking at local, regional, and national level as required for millennium ecosystem assessment (MEA, 2005) to workout strategies and policies for mitigating atmospheric CO_2 through organizing and conserving different forest vegetations. Attempts have been taken up in recent days to study the biomass and carbon stock of different forest types both at regional and country level. In the late 90s, the biomass and carbon stock of Indian forest for ten years was estimated by Richards and Flint, (1994) with the help of historical records, ecological data, and population based forest biomass degradation model. Hingane, (1991) estimated the carbon stock in two forest types. Dadhwal et al., (1998) calculated phytomass carbon pool of 1980 and 1990 of Indian forests using FAO inventories for ecological zone wise five categories. Manhas et al., (2006) reported the India’s total carbon stock as 1085.06 Mt and 1083.69 Mt in 1984 and 1994, respectively. Chhabra et al., (2002) calculated total standing biomass (above and below ground) of Indian forest using biomass expansion factors. In the year 2011 Sheikh et al., estimated the biomass stock of Indian forest and reported that it varies from 3325 to 3161 Mt for year 2003 to 2007, respectively. Ravindranath et al., (1997) has given a comprehensive account of standing biomass for different forest types of India.

Many workers have also estimated the biomass and carbon stock various plantation forests of India. The average carbon stock of rubber plantation in North-Eastern states of India was assessed by Day, 2005. Raizada et al., (2003) estimated the carbon flux of few selected forests of India. Biomass and carbon stock in *Tectona grandis* plantation of Dehradun forest division was done carried out by Giri et al., (2014). Arora et al., (2014) estimated the biomass and carbon stock of *Populus deltoides* plantation in Central Himalaya region whereby they found that *Populus deltoides*is viable option for carbon mitigation.

Most of the biomass and carbon stock studies on Indian forests are reported from the Himalayan and sub Himalayan belts. Sharma et al., (2008) estimated the above ground biomass of the forests of Himachal Pradesh which was 1158 Mg ha^{-1}. In Garhwal Himalaya of Uttrakhand, the total live tree biomass density ranged from 215.5 to 486.2 Mg ha^{-1} and live C density varied from 107.8 to 234.1 Mg C ha^{-1} (Gairola et al., 2011). Gairola et al., (2011) reported that the total live tree biomass and carbon density in Garhwal Himalaya of Uttrakhand ranged from 215.5 to 486.2 Mg ha^{-1} and from 107.8 to 234.1 Mg C ha^{-1} respectively. According to Sharma et al. (2011), carbon stock in seven major forest types of temperate region of Garhwal Himalaya ranged from 118.1 C Mg ha^{-1} to 469.1 C Mg ha^{-1}. Verma et al., (2012) assessed the carbon storage capacity of *Quercus semecarpifolia* at the high-altitude forests of central Himalayan region which ranged between 210.26 and 258.02 Mg ha^{-1} in their biomass and mean carbon sequestration rate between 3.7 and 4.8 Mg ha^{-1} yr^{-1}, respectively. The other studies on different types of forests reported from Garhwal Himalaya are done by Pala et al., (2013), Nautiyal and Singh, (2013) and Kumar and Sharma, (2015). In the central Himalaya, total biomass of trees ranged between 178 and 431 t ha^{-1}, while carbon stock ranged between 89.07 and 206 t ha^{-1} Rana et al., (2015). Mandal and Joshi, (2015) estimated the highest biomass

(13,559.60 kg ha^{-1}) and carbon density (6373.01 kg ha^{-1}) of *Lantana camara* L. in Western Himalaya.

In the central India, Singh et al., (2016) estimated the carbon sequestration potential of three protected tropical dry deciduous forests of Hariyana. Kale et al., (2004) developed allometric equation of five important tree species in Shivpuri district, Madhya Pradesh, Central India. Bijalwan et al., (2010) estimated the biomass and carbon stock of dry tropical forests of Chhattisgarh region of Central India using remote sensing methods and Lal et al., (2016) estimated carbon storage pattern in natural and plantation forests of sub-humid tropics in Barnawapara Wildlife Sanctuary, Chhatisgarh, India whereby they have concluded that natural forest has an edge over the plantation forest in terms of carbon storage. According to Bhardwaj and Chandra, (2016) the biomass and carbon stocks of different tree plantations of eastern Chhatisgarh, India, were highest (942.50 t ha^{-1}) in *Albizia lebbeck* followed by *Eucalyptus globulus* (520.62 t ha^{-1}), *Terminalia arjuna* (143.12 t ha^{-1}), and *Azadirachta indica* (106.87 t ha^{-1}). Nizalapur et al., (2010) estimated the aboveground biomass of tropical forests and Pandya et al., (2013) estimated the carbon storage in 25 important species from Gujarat state of India, using non destructive method. Chaturvedi et al., (2012) studied the effects of grazing and harvesting on carbon accumulation of juvenile trees of five tropical dry forest of Uttar Pradesh, India. The results concluded that the carbon density in the juvenile tree population ranged from 271 to 966 kg-C ha^{-1} and the rate of carbon sequestration ranged from 10 to 2010 g-C cm^{-2} yr^{-1}.Kumar et al. (2011) estimated the aboveground biomass all the forest types of Northern Haryana and *Butea monosperma* forest ecosystems of Rajasthan. Salunkhe et al., (2014) estimated the aboveground biomass and carbon stock in tropical deciduous forests of the Central India state of Madhya Pradesh where, they have found that the aboveground biomassranged from 3.99 to 53.90 t ha^{-1} and carbon stock ranged from 1.89 to 25.6 t ha^{-1} across different study sites. Salunkhe and Khare, (2016) estimated carbon stock in four different types of forests in the tropical deciduous forest ecosystem of Madhya Pradesh and estimated the carbon stock of mixed non-teak forest as 25–54

Mg ha^{-1}, dry mixed non-teak forest as 13–42 Mg ha^{-1}, teak-dominated forest as 33–53 Mg ha^{-1}, and dry teak forest as 16–24 Mg ha^{-1}. Chaturvedi and Raghubanshi, (2015) described the aboveground carbon density and carbon sequestration patterns of mono and multi specific *Tectona grandis* and *Shorea raobusta* forests in tropical dry region of India which were 136 t cha^{-1} and 5.3 t cha^{-1} $yr.^{-1}$, respectively.

The biomass and carbon stock in South Indian forests were estimated by many workers. Mani and Parthasarathy, (2007) estimated the aboveground biomass of inland and costal tropical dry evergreen forests of Peninsular India which ranged from 39.69 to 170.02 Mg ha^{-1}. Kale et al., (2009) reported that the rate of carbon sequestration was highest in natural plantation (20.27 t ha^{-1}) than mixed moist deciduous natural forest of Western Ghats. According to Bhat and Ravindranath, (2011) the aboveground standing biomass in tropical rain forest of Western Ghat using ranged from 6.40 to 144.67 t ha^{-1}. Sundarapandian et al., (2013) estimated the biomass of four plantations and natural forests at Puthupet, Tamil Nadu. The aboveground biomass for plantations and natural forest were 32.7, 38.1, 121.1, 143.2, and 227.2 Mg ha^{-1}, respectively. Devagiri et al., (2013) estimated the aboveground biomass and carbon stock dry deciduous forest of western part of Karnataka, India, using allometric volume equations. Pragasan, (2014) determined AGB of tree species in the Pachaimalai forest of the Eastern Ghats in India. Sundarapandian et al., (2014) assessed the carbon stock of Pondicherry University campus forests. Rao and Rao, (2015) studied the total standing biomass and carbon stocks of tropical deciduous forest of Nallamalais. Pragasan, (2015) estimated the carbon stock of tropical forests of Bodamalai hills, Tamil Nadu. Vivek and Parthasarathy, (2015) reported trees and lianas carbon stock from tropical dry evergreen forests of Coromandel Coast of India. Subashree and Sundrapandian, (2017) studied the savannah ecosystems of Kanyakumari Wildlife Sanctuary, Western Ghats which was accounted as 216.2 Mg C ha^{-1} and 206.6 Mg C ha^{-1} at two different sites.

In the North-Eastern part of India, Devi and Yadava, (2009) studied the AGB and net primary productivity of semi-evergreen tropical forest of Manipur, following destructive method. Borah et al., (2013) estimated the carbon stock of tropical forests of Cachar District of Barak Valley, Assam. Aboveground biomass ranged from 32.47 Mg ha^{-1} to 261.64 Mg ha^{-1} and carbon stock ranged from 16.24 Mg ha^{-1} to 130.82 Mg ha^{-1}, respectively as per this study. Majumdar et al., (2016) estimated biomass of selected tropical forest patches of Tripura, North East India, using allometric equations. According to Baishya and Barik, 2011, the total biomass carbon production of an old growth *Pinus kesiya* Royle ex Gordon forest in North Eastern India was 460.5 Mg ha^{-1} of which 91.20% was aboveground biomass carbon and 8.8% was below ground biomass carbon. Thokchom and Yadava, (2017) estimated biomass and carbon stock along an altitudinal gradient in the forest of Manipur, Northeast India. Gogoi et al., (2017) estimated carbon stock of rain forests of Upper Assam using suitable volume equation. The results showed that the highest carbon stock (306.61 ± 17.14 Mg C ha^{-1}) was recorded in least disturbed site followed by moderately distributed 169.91 ± 2.59 Mg C ha^{-1}and highly distributed site102.43 ± 3.18 Mg C ha^{-1}. Brahma et al., (2017) studied the ecosystem carbon sequestration of six prominent land use systems of Barak Valley, Assam where they have found that restoration of degraded forest and imperata grass land through rubber plantation and agroforestry enhanced ecosystem carbon sequestration rate and reduced CO_2 emissions from LUC. Niirou and Gupta, (2017) estimated the tree carbon stock of Oak and Pine-dominant forests of Senapati district of Manipur which ranged from 25.59 t ha^{-1} to 164.81 t ha^{-1}. Brahma et al., (2018) estimated the biomass stocks and potential loss of biomass carbon through clear felling of rubber plantations in North East India where, they have found that clear felling of rubber plantations can lead to loss of up to 135 Mg ha^{-1} of biomass carbon. Singh et al., (2018) assessed the growth, carbon stock and sequestration potential of oil palm plantations in Mizoram. Das et al., (2020) studied the implication of landuse change on carbon stock of subtropical forests of East Khasi hills, Meghalaya and concluded that an amount of 86.36% carbon will be emitted in the situation when sub tropical broad leaved forest is converted to abandoned land and amount of 82.67% carbon will be emitted when pine forest is converted into abandoned land. Gogoi et al., (2021) studied the carbon sequestration potential of the planted forest in Brahmaputra flood plains, Assam. They have found that plantation forest in flood plain degraded lands can act as a major carbon sink and store a substantial amount of carbon dioxide after 39-year of the plantation. Das et al., (2021) assessed the aboveground biomass carbon using field, satellite data and model based integrated approach to predict the carbon sequestration potential of major land use sector of Arunachal Himalaya, India. Bordoloi et al.,(2022) worked on the satellite based modelling of carbon stock and carbon sequestration potential of different land uses of North East India. Nath et al., (2022) assessed the biomass carbon stock in old-growth secondary semi-evergreen forests in North East India along an altitudinal gradient.

CHAPTER-3

DESCRIPTION OF THE STUDY AREA

3.1 Introduction

The North-East Indian state of Mizoram is a land of Blue Mountains internationally sandwiched between Myanmar and Bangladesh and surrounded by Indian seven sister states namely Assam and Manipur in the north and Tripura in the west. The state covers an area of 21,087 km^2 which extends from 21°56' N to 24°31' N, and 92°16' E to 93°26' E nestling in the Southern tip of the North-East India. The average altitude ranges from 21 to 2,157 meter above the sea level. The altitude of the hills is 1,000 meters in the West and gradually rises up to 1,300 meters in the East. The Phawngpui Tlang also known as Blue Mountain however situated at 2,257 meters above the sea level which is the highest peak of the state (Bareh, 2007). The Tropic of Cancer runs through the heart of the state (Pachuau, 2009).

Mizoram falls under the Indo-Burma Biodiversity Hotspot Region. The state is very rich in floral and faunal diversity including many rare and endemic species, many of which are still unexplored. According to the Forest survey of India, Mizoram has the highest forest cover (84.53 %) among all the Indian states in terms of percentage to the total geographical area (ISFR, 2021). Forest Cover in the State is 18,005.51 km^2 of which 157.05 km^2 is under very dense forest, 5,800.75 km^2 under moderately dense forest and 12,047.71 km^2 under open forest (Indian State of Forest Report 2021). Agriculture is the prime source of livelihood among the Mizos, of which jhum cultivation still continues to be the prominent practice. Livelihood in the rural areas largely depends either on jhum cultivation or on minor forest products.

3.2 Climate

Mizoram experiences a mild and pleasant climate. The upper part of the hills is predictably cold, cool during the summer, while the lower reaches are relatively warm and humid. The climate is humid and tropical, characterized by short winter, long summer with heavy rainfall. The climatogram of the study area is shown in Figure 3.1. The highest temperature is observed during April and May, and the lowest is during December and January. The study area receives rains from the south-west monsoon. The precipitation is heavy in summer, generally from May to September, and lasts till late October. Normally July and August are the rainiest months while December and January are the driest months. Three seasons are generally observed in Mizoram (Pachuau, 1994).

a) Cold or winter season: The winter season starts from November to February. Temperature ranges between 8^{o}C and 24^{o}C and a very less rainfall which is received from north-east, generally known as retreating monsoon.

b) Warm or spring season: The spring season begins from March to the first part of May and is characterized by a bright sunshine and a clear blue sky. The temperature is fluctuated from 19^{o}C to 32^{o}C. Maximum isolation is received during this period due to the clear blue sky.

c) Rainy or summer season: Rainy season is the longest season, it lasts for nearly six months from second half of May to late October with varying rainfall from 100 mm (May) to 440 mm (August). This season receives south-west monsoon, sometimes with violent storms in the beginning of the season. The temperature is high but declined to very low during raining.

3.3 Soil

According to the Geological Survey of India, the topography of Mizoram is immature and the physiographic expression consists of several North–South longitudinal valleys containing series of small and flat hummocks, mostly anticlinal, parallel to sub-parallel hill ranges and narrow adjoining synclinal valleys with series of topographic highs. The general geology of western Mizoram consists of repetitive succession of Neogene sedimentary rocks of the Surma group and Tipam formation such as sandstone, siltstone, mudstone and rare pockets of shell limestone. The eastern part consist the Barail group (Pachuau, 2009).

The soils of the state are mostly dominated by sedimentary type developed from parent materials such as farraginous sandstones and shale.The soils in the hills are mostly dominated by collocium deposits and in the plain areas it is predominantly alluvial. The young and immature soils of Mizoram can be divided into orders such as ultisols, inceptisols and entisols. The soils in the hills are highly acidic with pH ranging from 4.5 to 5.5 and soils of the valleys are moderately acidic with pH ranging from 5.5 to 6.0. Soil texture is loam to clay loam in the in the upper surfaces. The clay content increases with increasing soil depth. Soil moisture regime is classified as Udic (Colney and Nautiyal, 2013).

3.4 Stratification of the Study Sites

The present study was conducted in four districts of Mizoram covering all the six major forest types of the state. These are namely Aizawl District, Mamit District, Longtlai District and Champhai District of Mizoram. Aizawl District is located in north of the Tropic of Cancer in the northern part of Mizoram which is also the capital of Mizoram whereas; Mamit District is situated in western part of the state which is bordering with the Indian state of Tripura as well as Bangladesh. Longtlai District is situated in the southern part of the state and Champhai District is located in the eastern part of Mizoram. The detail location of the study sites are described in **Figure 3.1**.

Six major forest types were selected in four districts of Mizoram based on the forest classification described by Singh et al. in 2002. According to Singh and Singh (2002), forests of Mizoram is classified into six major types which are listed bellow-

1. Tropical wet evergreen forest. (Up to 900 m ASL)
2. Montane sub tropical forest. (900-1500 m ASL)
3. Temperate forest. (Above 1600 m ASL)
4. Bamboo forest. (Below 1600 m ASL)
5. Quercus forest. (Intermingled areas of sub-tropical and temperate forests)
6. Jhum land. (It is common in the entire state)

Tropical wet evergreen forests are usually grown in the western part of the state up to an altitude of 900 meter above the sea level. Montane sub tropical forests are mostly found between the altitudes of 900-1500 m above the sea level in the eastern fringes areas which are bordering to Myanmar. The temperate forests are grown in few areas of Mizoram above 1600 m from the sea level. These forests are not typical as compared to the other temperate forests found elsewhere in the Eastern Himalaya. They are found in some areas like Lengteng, Naunuarzo, Farpak, Thaltlang, Phawngpui etc. Bamboo forests are seen almost everywhere in the state. They are mostly grown between 40-1500 meter above the sea level. However, in many areas pure dense *Malocana baccifera* forests can be seen. This type of pure bamboo forests mostly occurs in the abandoned jhum fallows throughout the state. Quarcus forests occur in both sub tropical and temperate areas of the state. However, pure quarcus patches are predominant in Lengteng and Farpak areas. Jhum lands are found in all the districts of Mizoram. It is more prevalent and extensively practiced in the eastern part of the state (Singh et al., 2002).

Within each forest type, three permanent of 250m x 250m size plots were selected following standard protocol wherein, the sampling for vegetation, biomass and soil were carried out for the purpose of this study. The sampling plots for the tropical wet evergreen forest were selected in Dampa Tiger Reserve forest of Mamit District, for montane sub tropical forest, sampling plots were selected in Reiek Community Forest of Mamit District, for temperate forest, sampling plots were selected in Phawngpui national park of Longtlai District, sampling plots for the quercus forest were selected in Lengteng Wildlife Sanctuary of Champhai District, for bamboo forest, sampling plots wereselected in Lengpui area of Aizawl District and sampling plots for the jhum land were selected in Sakawrtuichhun area of Aizawl District.The geographical coordinates, altitude, name of the district, forest type of the study plots are shown in the **Table 3.1.**

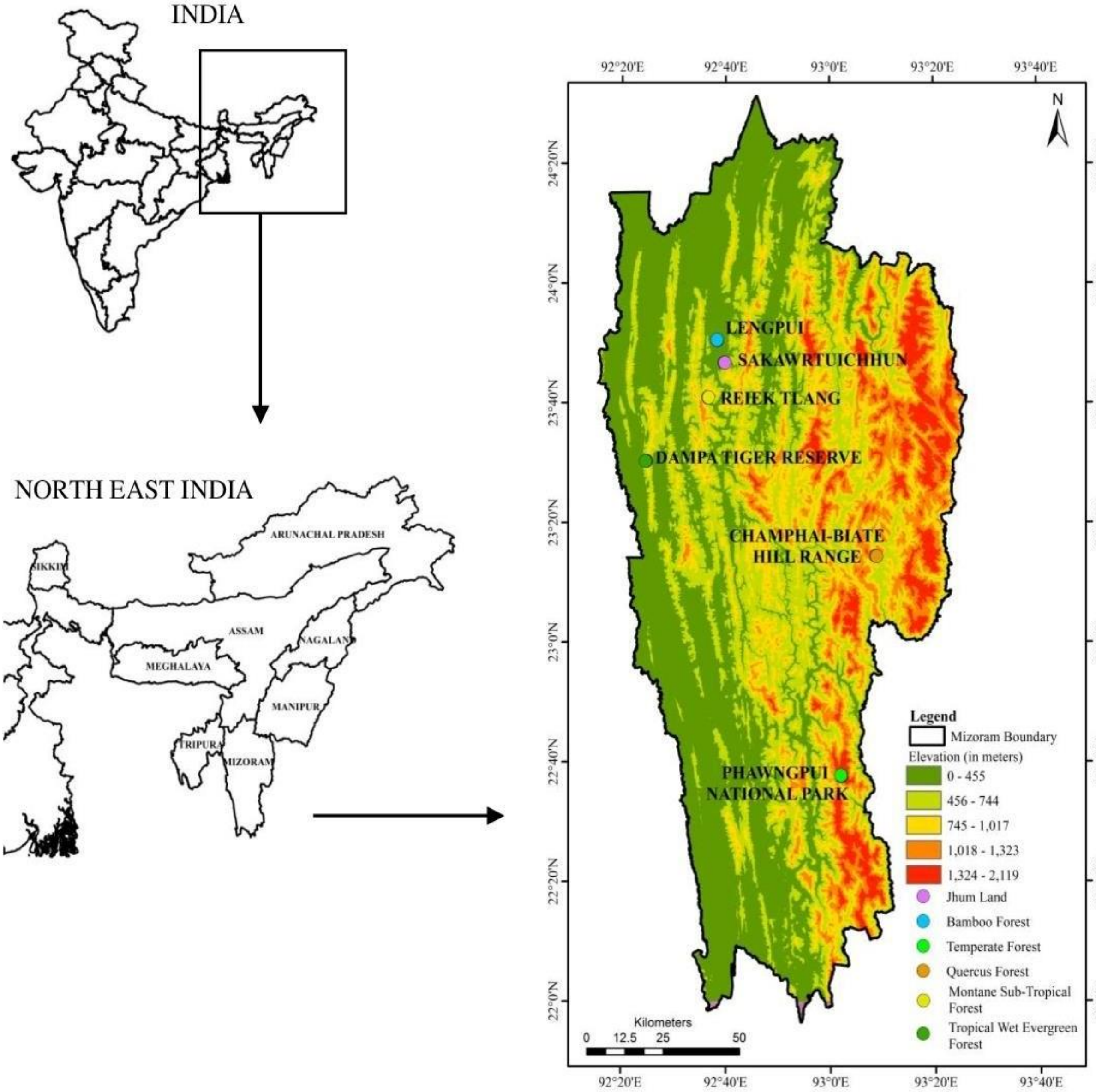


Figure 3.1 Map showing the location of the study sites.

Table 3.1 Geographical coordinates, altitude, name of the district, forest type of the study plots.

PLOT	FOREST TYPE	DISTRICT	STUDY SITE	GEO-CORDINATES	ALTITUDE (m asl)
P-1	Tropical wet evergreen forests	Mamit	Dampa tiger reserve	23 º 41’06.0”N 92º 24’ 44. 7’’E	640
P-2	Tropical wet evergreen forests	Mamit	Dampa tiger reserve	23º 42’ 06. 4’’N 92º 24’ 28. 9’’E	580
P-3	Tropical wet evergreen forests.	Mamit	Dampa tiger reserve	23º 41’ 50.5’’ N 92º 24’ 17.4’’ E	620
P-1	Montane sub-tropical forests	Mamit	Reiek community forest	23º 41’ 33.2’’ N 92º 36’ 17.4’’ E	1287
P-2	Montane sub-tropical forests	Mamit	Reiek community forest	23º 40’ 46.4’’ N 92º 36’ 27.3’’ E	1280
P-3	Montane sub-tropical forests	Mamit	Reiek community forest	23º 42’ 09.0’’ N 92º 26’ 53.2’’ E	1294
P-1	Temperate forests	Longtlai	Phawngpui national park	22º 40’ 35. 1’’N 93º 02’ 38.1’’ E	2108
P-2	Temperate forests	Longtlai	Phawngpui national park	22º 40’ 26.2’’N 93º 02’ 35.3’’ E	2135
P-3	Temperate forests	Longtlai	Phawngpui national park	22º 40’ 54.6’’ N 93º 02’ 36.4’’ E	2123
P-1	Bamboo forests	Aizawl	Lengpui bamboo forest	23º 50’ 31.3’’ N 92º 38’ 20. 6’’ E	381
P-2	Bamboo forests	Aizawl	Lengpui bamboo forest	23º 51’ 42.2’’ N 92º 38’ 41.7’’ E	351
P-3	Bamboo forests	Aizawl	Lengpui bamboo forest	23º 53’ 45.6’’ N 92º 38’ 38.3’’ E	376
P-1	Quercus forests	Champhai	Lengteng wildlife century	23° 50’ 31.9’’ N 93° 12’ 35.3’’ E	1790
P-2	Quercus forests	Champhai	Lengteng wildlife century	23° 44’ 20.7’’ N 93° 17’ 50.4’’ E	1778
P-3	Quercus forests	Champhai	Lengteng wildlife century	23° 52’ 15.8’’ N 93° 13’ 40.3’’ E	1763
P-1	Jhum land	Aizawl	Sakawrtuichhun	23° 42’ 09.0’’ N 92° 26’ 53.2’’ E	614
P-2	Jhum land	Aizawl	Sakawrtuichhun	23° 41’ 11.5’’ N 92° 24’ 53.7’’ E	600
P-3	Jhum land	Aizawl	Sakawrtuichhun	23° 43’ 06.2’’ N 92° 24’ 51.8’’ E	598

CHAPTER- 4

SPECIES DIVERSITY, COMPOSITION AND VEGETATION STRUCTURE OF THE SELECTED FOREST TYPES OF MIZORAM

4. 1 Introduction

Species diversity, floristic composition and plant community structure are the important attributes in plant community ecology. These are the three key indicators to assess the status of a natural forest. Tree species diversity is the fundamental component of total biodiversity of any forest ecosystem, because trees are considered as ecosystem engineers that provide resources and habitats for almost all other organisms in the ecosystem (Huston, 1994; Reilly and Spies, 2015). Species richness is considered as a very important component in shaping the overall biodiversity of a region. From the forest management perspective it is not always better when a particular forest stands have higher species richness, as undesirable species which frequently comprise a high proportion of early successional plant species. Therefore, a comprehensive understanding of plant species diversity, composition and structure is thus necessary in order to evaluate the quality of biodiversity in any particular region (Poorbabaei and Poorrahmati, 2009).

The understanding of the factors influencing the spatial and temporal variation patterns of composition, diversity, and structure of woody species is a challenge in community ecology (Lomolino, 2001).It has been widely demonstrated that the plant community of any region is determined by collective effect of many factors, of which time and altitude plays the key role. However, light, temperature, nutrients, slope, aspect, latitude, rainfall and humidity also play an important role in the formation spatial and temporal patterns of vegetation of any ecosystem (Kharkwal et al., 2005). Apart from these environmental factors, disturbance also plays a critical role in shaping composition and structure of any forest ecosystem. Disturbance whether of natural or human induced is a majorecological force that affects both forest structure and functioning. Anthropogenic pressure causes widespread disturbance leading to forest loss, fragmentation and degradation (FAO, 2015)

The Indian state of Mizoram is very rich in biodiversity. The varied topographical and climatic variations in the state provides home to many rare and endemic species of flora and fauna. The state is a part of Indo-Burma Biodiversity Hotspot and it is also a part of the Mizoram-Manipur-Kachin rainforests eco-region which still retains almost half of its natural habitat (Chatterjee et al., 2006). The number of new species which has been discovered in the recent years from this region shows its potential to harbour many more important species which needs to be explored immediately. However, this region hasn't received sufficient scientific attention. Mizoram has the highest area under forest cover in terms of percentage of geographical area among all the states of India (ISFR, 2018). The forest cover in the state has decreased by 180.49 km ^{2}as compared to the previous assessment reported in ISFR, 2017. It has been seen that the practice of intensive jhum cultivation throughout the state is the major cause of forest loss. The Mizo society is still associated with the age old practice of jhum or shifting cultivation in almost all the parts of the state. The shortening of jhum fellow periods due to population increase has been negatively impacted the sustainability of jhum cultivation on biodiversity and the environment as a whole. The other causes are deforestation, forest fires, over exploitation of natural resources like medicinal plants, bamboo, cane, anchiri etc., habitat destruction due to development activities, mining, monoculture agriculture plantations like areca and oil palm, natural calamities etc. Therefore, the remnant forests need prior attention for conservation of the state's biodiversity for its current as well as future potentials. Very few segregated studies have been carried out to assess the status of the different protected areas of Mizoram. However, no systematic studies have been conducted so far to describe the species diversity, vegetation structure, composition and regeneration status of the major forest types of Mizoram. Therefore, present study aims (1) to assess the species diversity and composition of the major forest types. (2) to study the vegetation structure and population distribution pattern in the major forest type and (3) to evaluate the regeneration status of the major forest type.

4.2 Materials and Methods

4.2.1 Study Area

In the present study, six major forest types were selected in four districts of Mizoram based on the forest classification described by Singh et al., in 2002. These were namely (a) Tropical wet evergreen forest (TWEF) (b) Montane sub tropical forest (MSTF) (c) Temperate forest (TF) (d) Bamboo forest (BF) (e) Quercus forest (QF) (f) Jhum land (JL). The sampling sites of the tropical wet evergreen forest were selected in the undisturbed core areas of the Dampa tiger reserve forest in Mamit District. Whereas, the sampling sites of the Montane sub tropical forest were selected in the Reiek Community forest which is situated in the edge of Mamit and Aizawl District of the state. The sampling sites of the Temperate forest were selected in Phawngpui National Park. Sampling sites of the Quercus forest were selected in and around the Lengteng Wildlife Century situated in Champhai District. Sampling sites of bamboo forest and Jhum fallow were selected in the Lengpui and Sakawrtuichhun area of Aizawl District respectively. The age of the jhum fallows were ranged between 15 to 20 years.

4.2.2 Data Collection &Species Identification

The field survey was carried out in the year 2016. Collection of all the possible passport information of the study sites, calibration of instruments and materials needed for measurements, arrangement for sample collection and standardization of appropriate data recording formats for field data recording and for entering into standard database was done before going to the field. Most of the plant species were indentified in the field itself. The species which could not reliably identify in the field were brought to the laboratory and identified with the help of Mizoram University Herbaria and other published literatures. Species nomenclature in this study was adopted from the plant list.org, version: 1.1, released in September 2013.

4.2.3 Sampling Design

In each forest type, three major permanent plots of 250 m × 250 m size were demarcated following ISRO-GBP/NCP-VCP protocol (Singh and Dadhwal, 2009) wherein, vegetation sampling were carried out. The major plots were selected in such a way that the effect of anthropogenic disturbance could be negligible. Reconnaissance surveys were carried out before selecting the sampling sites to find out homogeneous, least disturbed forest sites.

Within each major permanent plot four 31.62 m x 31.62 m sub plots were demarcated at each corner of the permanent plots for tree, liana and wild banana vegetation inventory. Within each sub plot, two 5m x 5m size quadrats were established for enumerating shrubs and bamboo species. Similarly, for herb and regenerating tree species enumeration two 1m x 1m size quadrats were established within the shrub plots. Thus, vegetation data were collected establishing a sum of twelve 31.62 m x 31.62 m sized plots, twenty-four5m x

5m plots and forty-eight 1m x 1m plots in each major forest type. The pictorial representation of sampling design is shown in the **Figure 4.1**.

All tree and liana individuals of ≥ 10 cm diameter within each sub-plot were tagged and their diameter at breast height (DBH) was measured at 1.37m above the ground. Tree individuals with DBH <10 cm were considered as regenerating plants. Based on the size of their DBH and height, tree species were categorized into (a) seedlings (height up to 20 cm), (b) saplings (height > 20 cm but DBH < 10 cm), and (c) trees (DBH >10 cm) as described by Sundriyal and Sharma (1996). Diameter of bamboo culms was measured at the middle part of the next internode if 1.37m fell on node or near to node portion of culms. Basal diameter of shrubs and tree saplings were measured at 10 cm above the ground using a digital vernier calliper. Herb individuals present inside the respective 1 m x 1 m quadrates were counted and their species names were recorded in the field itself.

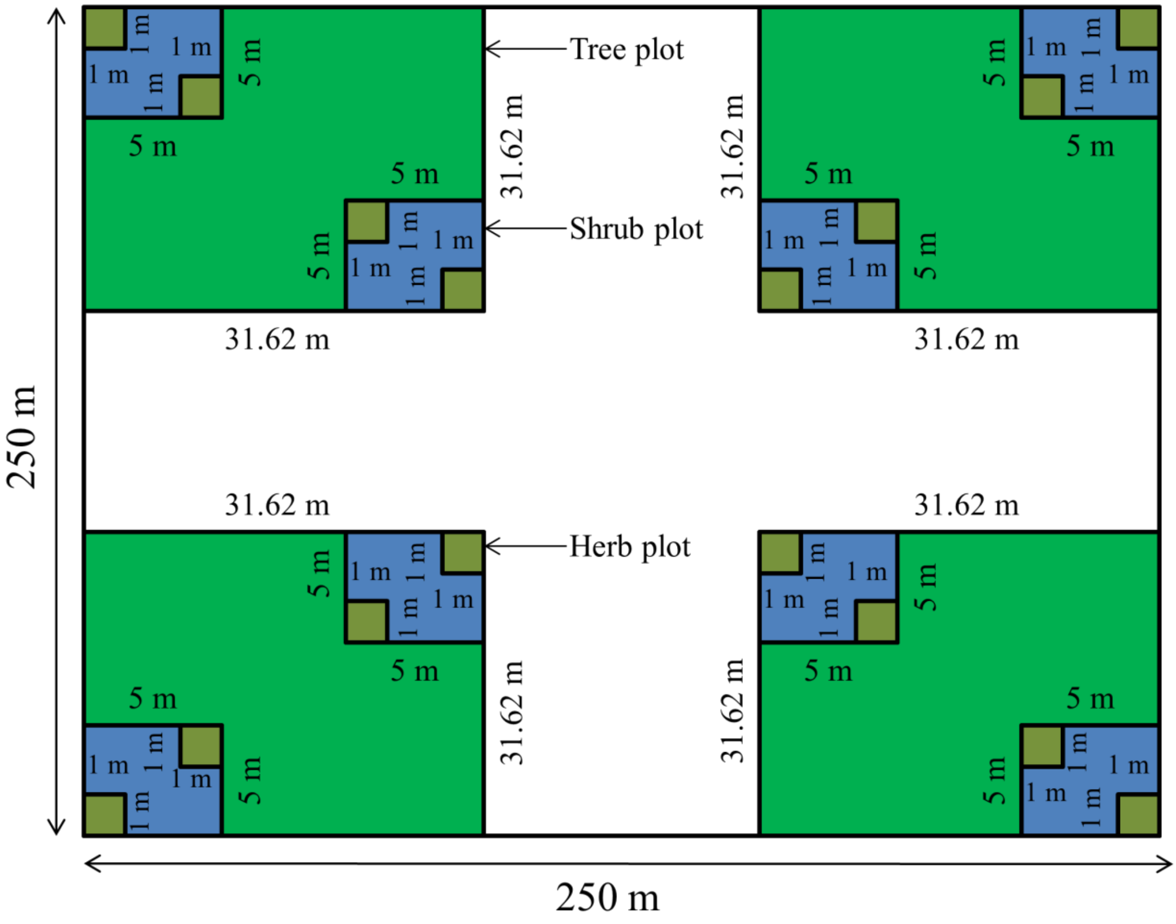


Figure 4.1 layout of the sampling plots and their respective size. (The figure is showing the number and size of tree, shrub and herb sampling plots within the 250m x 250m major plot).

4.2.4 Vegetation Analysis

Plant community composition and structure variables such as density, frequency, abundance, basal area and their relative values were calculated as per Misra, 1968. Importance value index (IVI) was calculated as sum of relative values of density (RD), frequency (RF), and dominance (RD) (Curtis, 1959). Plant diversity measures such as Shannon - Wiener diversity index (H′), Simpson's dominance index (Cd), Pielou's evenness index (E) and Margalef's index of species richness (M), Sorensen's similarity index were estimated as per Shannon and Weanner, (1949); Simpson, (1949); Pielou, (1966); Margalef, (1968) and Sorensen, (1948).

Tree population structure was analyzed across five diameter classes i.e. 10-20 cm, 20-40 cm, 40-60 cm, 60-80 cm, >80 cm. Tree species rarity of each major forest type was calculated following species rarity categorization suggested by Kadavul and Parthasarathy, (1999). This categorization was based on number of individuals of each tree species. Species having less than 2 individuals were considered as very rare followed by species having 2-10 individuals as rare, species having 10-20 individuals were considered as common and species having more than 20 species were considered as dominant. Population distribution pattern was analyzed based on the abundance to frequency ratio (A/F) described by Curtis and Cottam, (1956). Tree species which had less than 0.02 A/F ratio were considered as regular, species having 0.02 - 0.05 A/F ratio were considered as random and species with more than 0.05 A/F ratio were considered as contagious. Regeneration status of tree species was determined for each major forest type based onthe proportion of individuals of seedlings, saplings and trees in the study area, as modified fromShankar (2001). Species were identified and density of all the individuals of seedlings (< 20 cm height), saplings (DBH <10 cm and height > 20 cm) and trees (>10 cm dbh) were determined. Regeneration status was assessed in the following categories: (a) ‘good’, if seedling > sapling > adult; (b) ‘fair’, if seedling > sapling ≤ adult; (c) ‘poor’, if a species survives in only sapling stage, but not as seedlings (though saplings may be less, more or equal to adults); (d) ‘none’, if a species is absent both in sapling and seedling stages, but present as adults; and (e) ‘new’, if a species has no adults, but only saplings and/or seedlings.

4.3 Statistical Analysis

Descriptive statistics were done using SPSS, version-21. One way analysis of variance (ANOVA)was performed to test the significant difference ($p < 0.05$ level) of the means across the major forest types and LSD post hoc test was performed to test the significant difference ($p < 0.05$ level) between the means. Rank abundance curve was prepared following Magurran and McGill, (2011) and species similarity clustering graphs were prepared using PAST, version-3.23.

4.4 Results

4.4.1 Species Diversity and Composition

Out of the six major forest types in the present study, the highest number of tree species richness was recorded in the tropical wet evergreen forest (131 tree species belonging to 89 genera and 42 families), followed by montane sub-tropical forest (106 species belonging to 82 genera and 41 families), temperate forest (70 species belonging to 55 genera and 35 families), quercus forest (51 species belonging to 37 genera and 20 families), bamboo forest (28 species belonging to 37 genera and 23 families) and jhum land (21 species belonging to 20 genera and 14 families) (**Figure 4.2**).

Family wise distribution of tree species richness, genera and tree density showed that Fabaceae, Fagaceae, Lauraceae, Miliaceaeand Moraceae were the five dominant families in the tropical wet evergreen forest which together contributed 30 % of the total species richness, 25 % of the total genera and

49% of the total tree density. Similarly, in the montane sub-tropical forest, Anacardiaceae, Euphorbiaceae, Fabaceae, Fagaceae and Lauraceae were the top five families which represented 36 % of the total species richness, 33 % of the total genera and 36 % of the total density. In the temperate forest, Euphorbiaceae, fagaceae, Lamiaceae, Lauraceae and Meliaceae were the top five families which represented 39 % of the total species richness, 33 % of the total genera and 42 % of the total density. In the quercus forest Fagaceae, Lamiaceae, Lauraceae, Moraceae and Phyllanthaceae were the dominant families which contributed 61 % of the total species richness, 49 % of the total genera and 74 % of the total density. However, in the bamboo forest Euphorbiaceae, Fagaceae, Lamiaceae, Malvaceae and Moraceae were the dominant families which contributed 46 % of the total species richness, 42 % of the total genera and 44 % of the total tree density. Lastly, in the jhum fallow sites Fabaceae, Fagaceae, Lamiaceae, Malvaceae, Phyllanthaceae were the dominant families which represented 57 % of the total tree species richness, 55 % of the total genera and 51 % of the total tree density occurred in the respected sampling sites (**Appendix 2**).

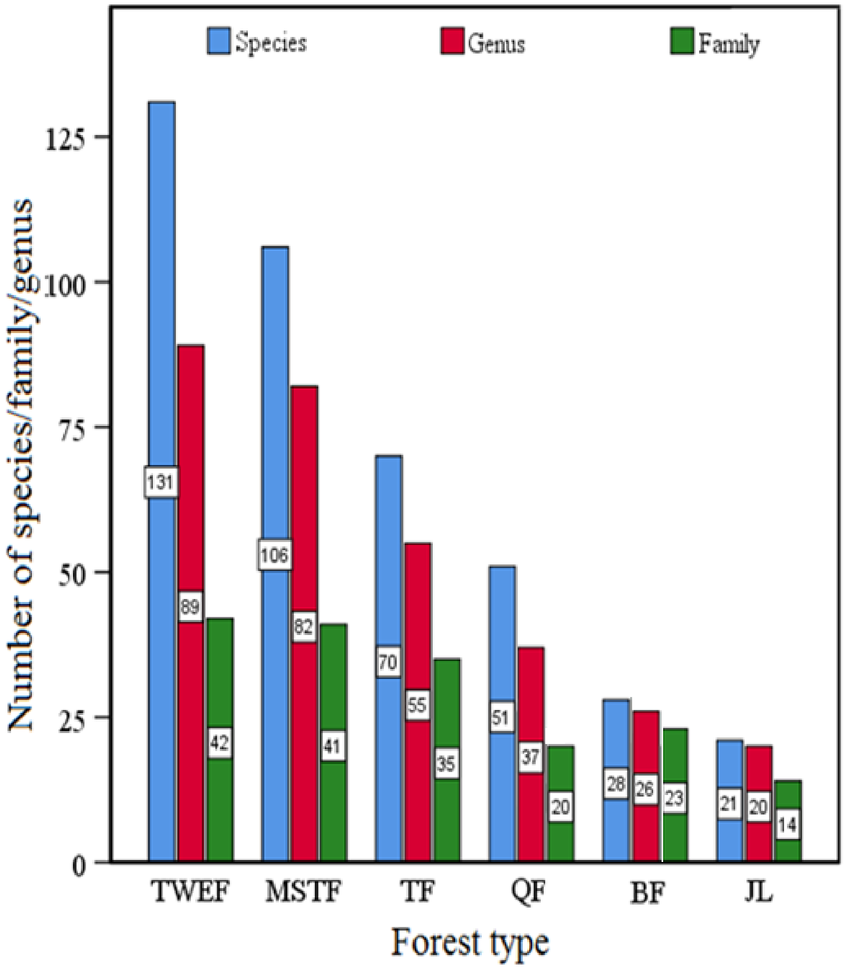


Figure 4.2 Variations in number of tree species, family and genus between six forest types.

Calliandra umbrosa (Wall.)Benth., *Castanopsis tribuloides* (Sm.) A.DC., *Heritiera papilla* Bedd., *Mesua ferrea* L. and *Tectona grandis* L.f. were the top five tree species in the tropical wet evergreen forest based on the IVI values. *Mesua ferrea* L., *Oroxylum indicum* (L.)Kurz, *Quercus oblonga* D. Don, *Triadica cochinchinesis* Lour and *Schima wallichi* Choisy were the top five tree species in the montane sub-tropical forest. *Castanopsis tribuloides* (Sm.) A.DC., *Duabanga grandiflora* (DC.) Walp., *Engelhardtia spicata* Lechen ex Blume, *Quercus floribunda* Lindl. Ex A. Camus and *Rhododendron arboretum* Sm were the top five tree species in the temperate forest. *Lithocarpus obscurs* C.C. Huang & Y. T. Chang, *Mesua ferrea* L., *Quercus graffiti* Hook. f. &

Thomson ex Miq., *Lithocarpus elegans* (Blume) Hatus. Ex Soepadmo and *Quercus serrata* Murray were the top five tree species in the quercus forest. *Callicarpa arborea* Roxb., *Castanopsis tribuloides* (Sm.) A. DC., *Mesua ferrea* L., *Rhus chinensis* Mill. and *Syzygium cumini* (L.) Skeels were the top five tree species in the bamboo forest and in the jhum land, *Callicarpa arborea* Roxb., *Castanopsis tribuloides* (Sm.) A. DC., *Rhus chinensis* Mill., *Schima wallichi* Choisy and *Trema orientalis* (L.) Blume were the top five tree species (**Appendix 1**).

Comparison of Shannon - Weiner diversity index, Margalef's species richness index and Simpson's dominance index in the six major forest types showed significant differences among the forest types but Pielou's evenness index didn't show any significant difference among the different forest types. Diversity index ranged from 4.20 to 2.40, species richness index ranged from 12.67 to 2.81, dominance index ranged from 0.09 to 0.02 and evenness index ranged from 0.97 to 0.99. Shannon - Weiner diversity index and Margalef's species richness index were highest in the tropical wet evergreen forest (4.20, 12.67) followed by montane sub-tropical forest (3.94, 10.40), temperate forest (3.77, 7.78), quercus forest (3.52, 6.91), bamboo forest (3.12, 5.64) and jhum land (2.40, 2.81). Simpson's dominance index followed opposite trend. Pielou's evenness index was highest in the montane sub-tropical forest (0.99) and bamboo forest (0.99) and it was lowest in the tropical wet evergreen forest (0.97). LSD post hoc test results of Shannon- Weiner diversity index and Margalef's species richness index between the six forest types showed that except montane sub-tropical forest all the forest types had significant differences with the tropical wet evergreen forest and the species richness, diversity and dominance index values in the jhum land were significantly different from rest of the forest types. However, Pielou's evenness index didn't vary significantly between the different forest types (**Table 4.1**).

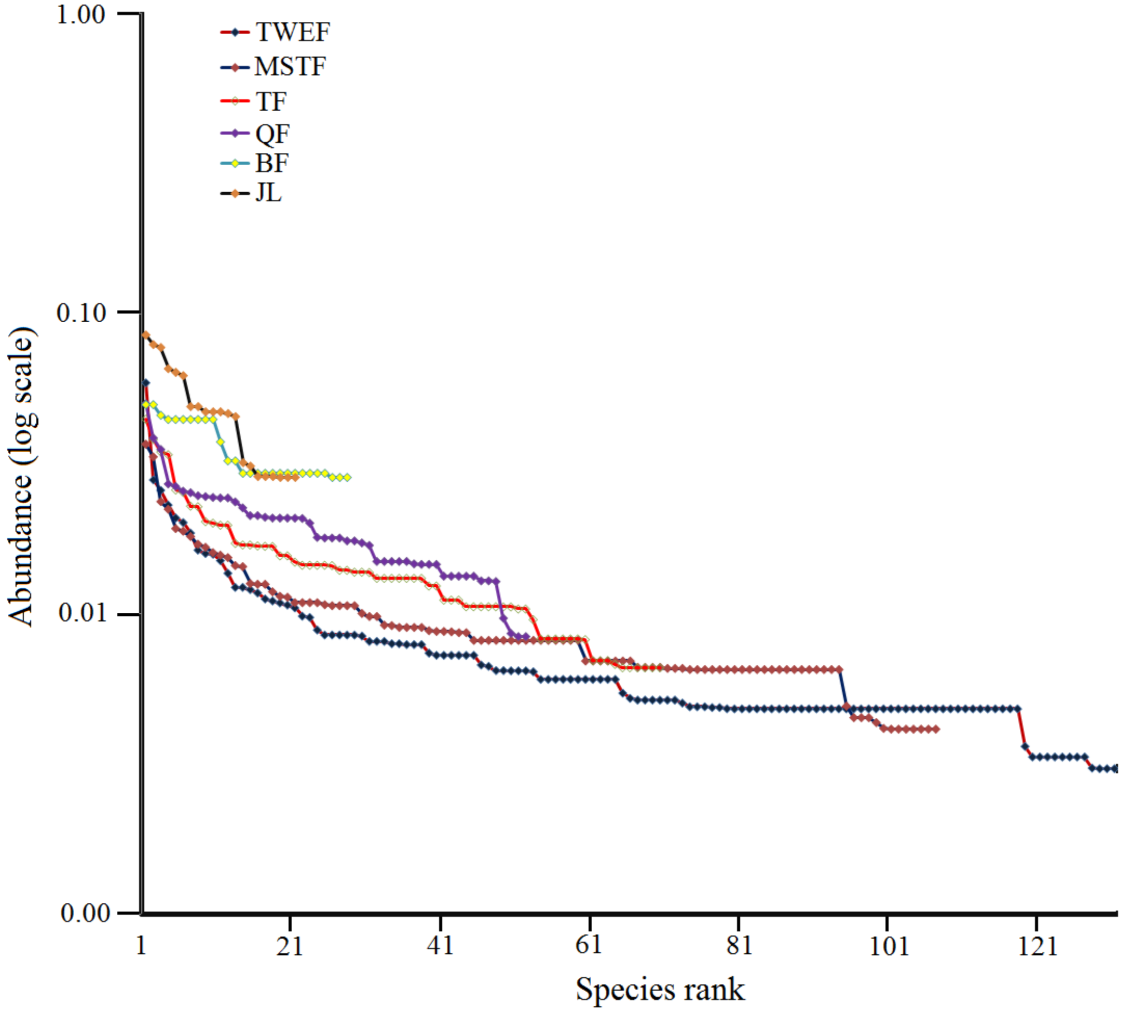


Figure 4.3 Rank abundance curves of tree species in the six major forest types. (TWEF-tropical wet evergreen forest, MSTF-montane sub-tropical forest, TF-temperate forest, QF-quercus forest, BF-bamboo forest, JL-jhum land).

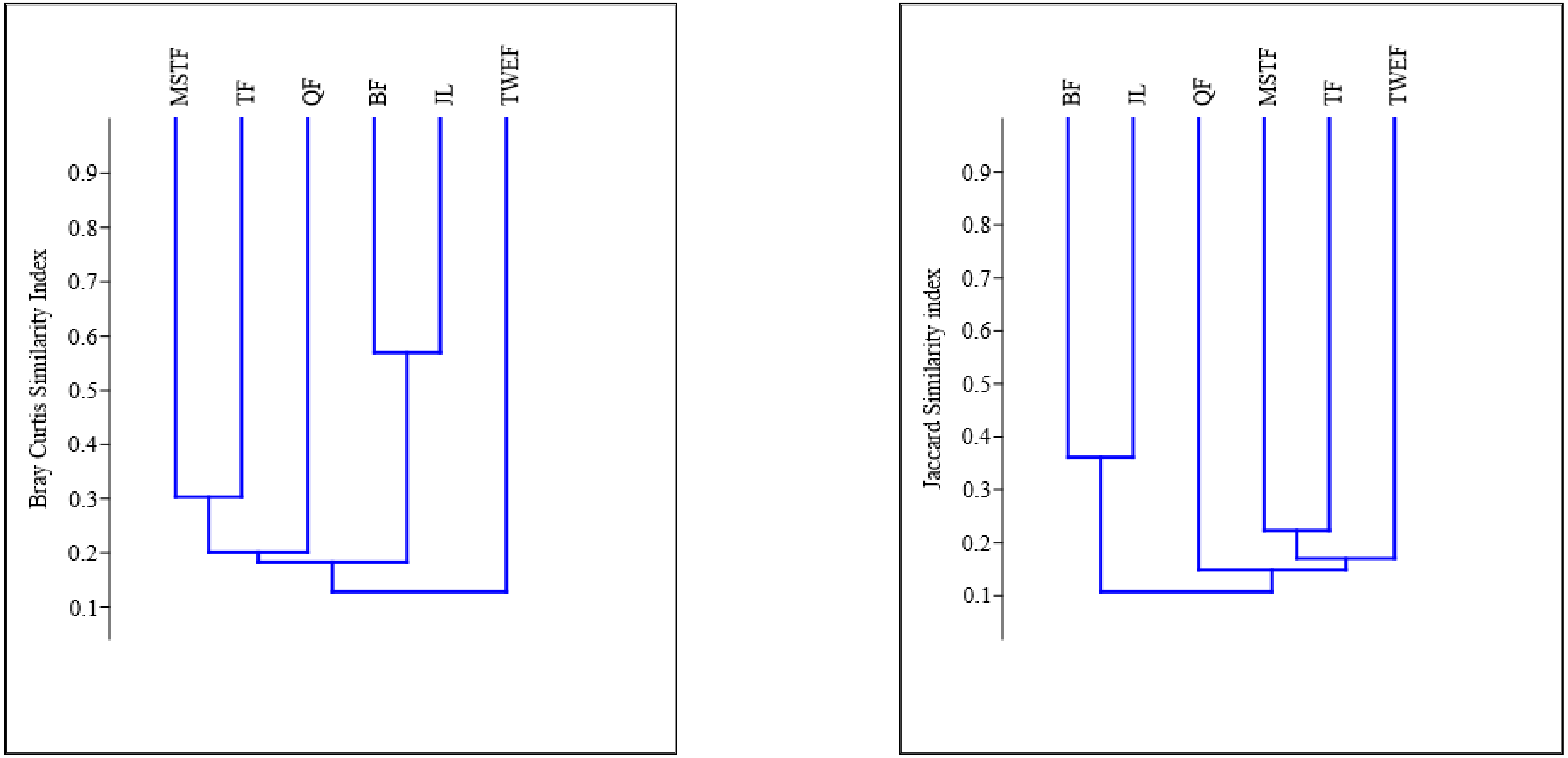


Figure 4.4 Bray Curtis and Jaccard similarity indices between the six forest types.

Table 4.1 Variations in density, basal area and plant diversity indices between six major forest types.

Plant diversity and structural attributes	**Growth form**	**Forest type**						***p* value**
		TWEF	**MSTF**	**TF**	**QF**	**BF**	**JL**	
Density (ha^{-1})	Tree (DBH>10cm)	880.15^{a}(51.51)	639.28^{ab}(133.18)	517.59^{b}(156.36)	377.57^{bc}(6.62)	140.86^{cd}(8.33)	99.18^{d}(3.33)	0.00
	Small tree (DBH<10cm)	3838.33^{a}(139.87)	5274.33^{a}(210.32)	3669.00^{ab}(247.97)	4320.33^{ac}(448.98)	2324.00^{b} (356.42)	3276.33^{bc}(644.92)	0.11
	Shrub (non tree)	7873.67^{a}(853.36)	7666.67^{b}(592.55)	6066.67^{ab}(240.39)	4266.67^{ab}(545.69)	9466.67^{c}(352.77)	12066.67^{d}(520.68)	0.00
	Liana	186.33^{a}(4.70)	136.00^{b}(3.79)	94.00^{c}(2.08)	77.00^{d}(1.73)	40.00^{e}(4.36)	27.67^{f}(1.45)	0.00
	Bamboo	NA	NA	NA	NA	19091.67^{a}(1752.30)	5559.00^{b}(748.18)	0.02
	Banana	NA	NA	NA	NA	179.33^{a}(29.01)	336.67^{a}(47.17)	0.18
	Herb	17806.67^{a}(1470.25)	28500.67^{ab}(764.42)	42290.67^{bc}(2932.11)	48951.00^{c}(999.91)	71879.67^{d} (9337.59)	98729.00^{e} (10730.95)	0.00
Basal area (m^{-2} ha^{-1})	Tree	54.31^{a}(1.81)	48.85^{a}(1.81)	39.02^{b}(6.62)	33.77^{b}(1.03)	11.12^{c}(0.62)	2.04^{d}(0.28)	0.00
	Small tree (DBH<10cm)	3.77^{ab}	4.87^{a}	3.34^{b}	3.94^{ab}	2.83^{b}	3.26^{b}	0.10
	Shrub (non tree)	3.77^{a}(0.28)	3.06^{b}(0.27)	2.77^{c}(0.18)	2.17^{c}(0.48)	3.98^{a}(0.51)	4.05^{a}(0.09)	0.00
	Liana	1.08^{a}(0.16)	0.80^{b}(0.07)	0.52^{c}(0.05)	0.44^{c}(0.03)	0.29^{c}(0.03)	0.15^{c}(0.02)	0.00
	Bamboo	NA	NA	NA	NA	12.45^{a} (1.46)	6.32^{b} (0.44)	0.05
	Wild banana	NA	NA	NA	NA	1.52^{a} (0.34)	2.72^{a} (0.53)	0.27
Margalef's species richness index	Tree	12.67^{a}(0.67)	10.40^{ab}(2.60)	7.78^{bc}(1.52)	6.91^{bc}(0.38)	5.64^{c}(0.60)	2.81^{d}(0.08)	0.00
Shannon - Weiner diversity index	Tree	4.20^{a}(0.08)	3.94^{ab}(0.24)	3.77^{bc}(0.30)	3.52^{bc}(0.04)	3.12^{c}(0.09)	2.40^{d}(0.04)	0.00
Simpson's dominance index	Tree	0.02^{a}(0.00)	0.02^{ab}(0.01)	0.04^{bc}(0.01)	0.03^{bc}(0.00)	0.05^{c}(0.00)	0.09^{d}(0.00)	0.00
Pielou's evenness index	Tree	0.97^{a}(0.00)	0.99^{a}(0.00)	0.98^{a}(0.01)	0.98^{a}(0.00)	0.99^{a}(0.00)	0.98^{a}(0.01)	0.35

Note: Values within the parenthesis represents standard error of means.*P* values are significant at 0.05 level and the different superscripted letters represent significantly different mean values between the forest types. (NA-not available, TWEF-tropical wet evergreen forest, MSTF-montane sub-tropical forest, TF-temperate forest, QF- quercus forest, BF-bamboo forest, JL-jhum land.

The graphical representation of rank abundance curves of the six major forest types indicatedhighest equitability or lowest dominance in the tropical wet evergreen forest and lowest equitability or highest dominance in the jhum land. The equitability pattern in the studied forest types followed the order of- Tropical wet evergreen forest > montane sub-tropical forest > temperate forest > quercus forest > bamboo forest > jhum land (**Figure 3**).

4.4.2 Vegetation structure and population distribution pattern

Density values of trees, shrubs, liana, bamboo and herbs were significantly varied among the different forest types. However, small tree and banana density didn't show any significant differences among the forest types.Tropical wet evergreen forest possessed the highest number of tree density per hectare followed by montane sub-tropical forest, temperate forest, quercus forest, bamboo forest and jhum land. Comparison of the LSD post hoc test results between the different forest types showed that tree density of tropical wet evergreen forest significantly differed with the temperate forest, quercus forest, bamboo forest and jhum land but didn't show any significant difference with the montane sub-tropical forest. Likewise, basal area values also followed the same trend as density values within and between the different forest types (**Table 4.1**).

Density and basal area distribution of mature tree species across five diameter classes indicated higher density in the lower diameter classes and vice versa whereas, tree basal area tend to be higher in the mid diameter classes (20cm - 80cm). Tree density and basal area values of tropical wet evergreen and montane sub-tropical forest were highest across all the diameter classes and it was lowest in the higher diameter classes of the bamboo forest.It was also observed that mature tree density and basal area of jhum land were gradually decreasing with the increasing diameter classes but it was absent beyond 60 cm diameter class. The number of tree species of almost all the forest types was highest in the lower diameter classes whereas, it was absent in the higher diameter classes of the jhum land (**Figure 4.5**).

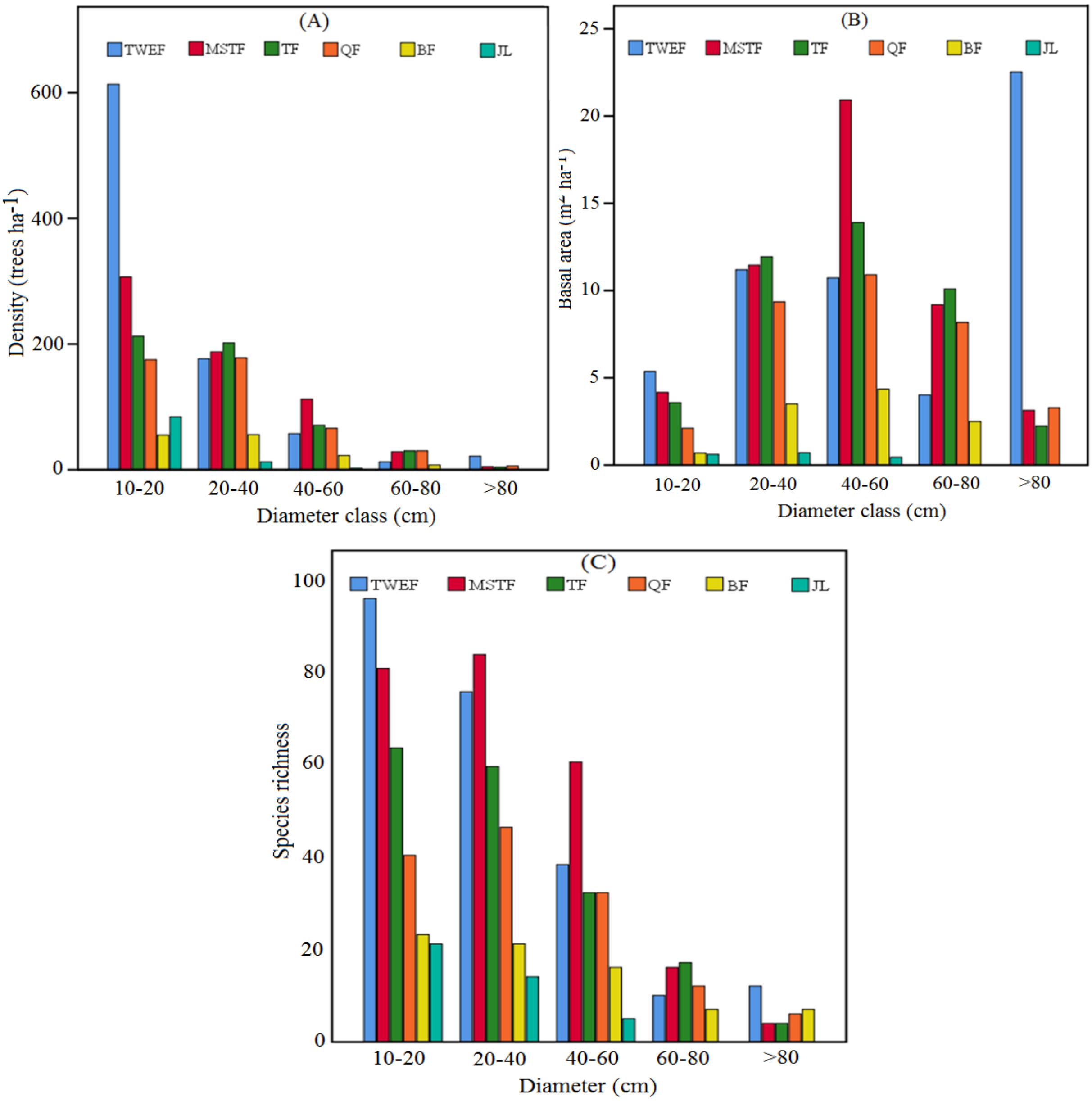


Figure 4.5 Variations in distribution of (A) tree density (B) tree basal area and (C) tree species richness of six forest types across five diameter classes.

Tree species rarity classifications based on the number of individuals indicated that majority of the species in all the forest types were belonged to rare category followed by common, very rare and dominant category. Out of the 131 species in the tropical wet evergreen forest, 71 (54 %) species belonged to rare category followed by 37 (28 %) species belonged to very rare category, 12 (9 %) species belonged to dominant category and 11 (8 %) species belonged to common category. Out of the 106 species in the montane sub-tropical forest, 66 (62 %) species belonged to rare category followed by 20 (18 %) species belonged to very rare category, 12 (11 %) species belonged to common category and 8 (7 %) species belonged to dominant category.

Table 4.2 Tree species rarity classifications of the six major forest types.

Species rarity based on number of individuals	**TWEF**	**MSTF**	**TF**	**QF**	**BF**	**JL**
Very rare	37	20	7	4	NA	3
Rare	71	66	44	33	23	14
Common	11	12	12	10	5	4
Dominant	12	8	7	4	NA	NA
Total	**131**	**106**	**70**	**51**	**28**	**21**

Note: Very rare (< 2 individuals), rare (2-10 individuals), common (10-20 individuals), dominant (>20 individuals), NA- not available.

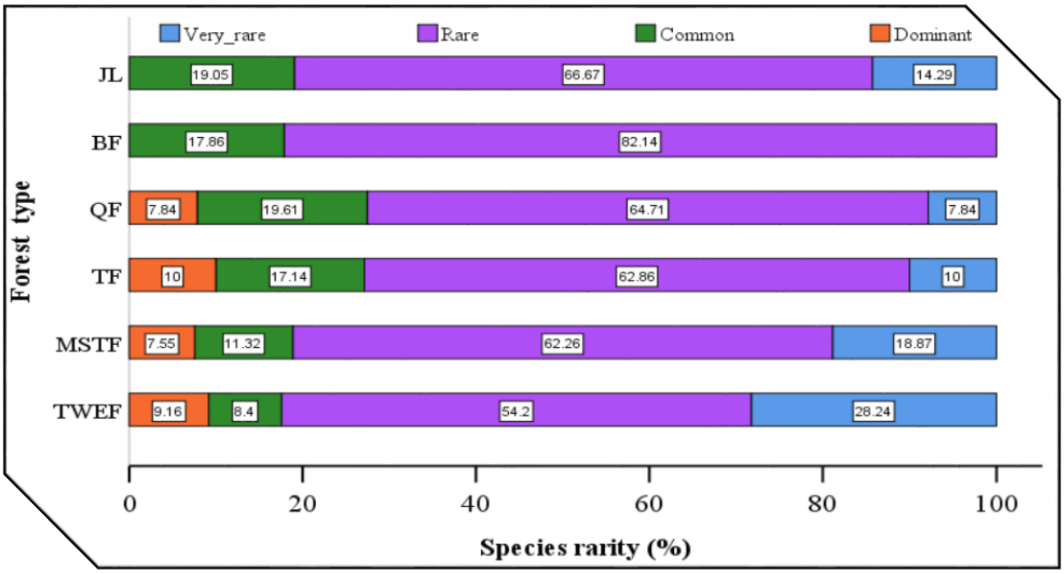


Figure 4.6 Percentage distribution of tree species rarity in the six major forest types.

Out of the 70 species in the temperate forest 44 (62 %) species belonged rare category followed by 12 (17 %) species belonged to common category, 7 (10 %) species belonged to very rare category and 7 (10 %) species belonged to dominant category. Out of the 51 species quercus forest, 33 (64 %) belonged to rare category followed by, 10 (19 %) species belonged to common category, 4 (7 %) species belonged to very rare category and 4 (7 %) species belonged to dominant category. In the bamboo forest, out of the 28 species, 23 (82 %) species belonged to rare category, 5 (17 %) species belonged to common category and species in both the very rare and dominant category were absent. In the jhum land, 14 (66 %) species belonged to rare category followed by 4 (19 %) species belonged to common category, 3 (14 %) species belonged to very rare category and species in the dominant category was absent (**Table 4.2 & Figure 4.6**).

Table 4.3 Population distribution pattern in the six major forest types.

Distribution pattern	**TWEF**	**MSTF**	**TF**	**QF**	**BF**	**JL**
Regular	NA	19	NA	NA	NA	NA
Random	29	NA	6	10	14	NA
Contagious	102	118	64	41	14	21
Total	**131**	**106**	**70**	**51**	**28**	**21**

Note: regular- A/F ratio < 0.02, random- A/F ratio ranged 0.02-0.05, contagious- A/F ratio >0.05.

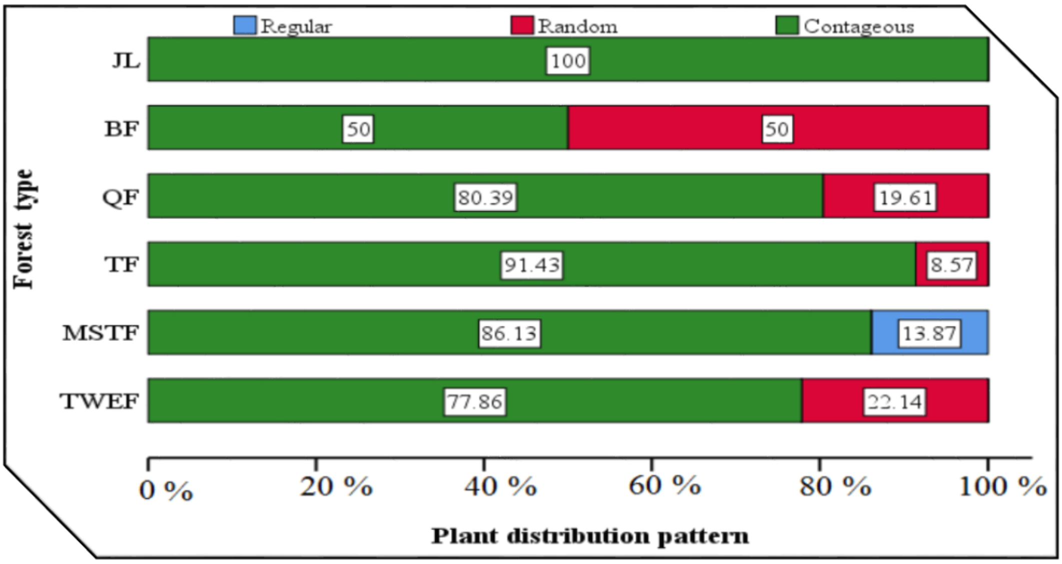


Figure 4.7 Percentage of the population distribution pattern in the six forest types.

Population distribution pattern in the six major forest types indicated that majority of the tree species exhibited contagious distribution pattern followed by random and regular distribution pattern. Out of the total 131 species in the tropical wet evergreen forest, 102 (77 %) species exhibited contagious distribution pattern and 29 (22 %) species exhibited random distribution pattern. Out of the 106 species in the montane sub-tropical forest, 118 (86 %) species exhibited contagious distribution pattern and 19 (13 %) species exhibited regular distribution pattern. Out of the 70 species in the temperate forest, 64 (91 %) species exhibited contagious distribution pattern and 6 species exhibited random distribution pattern. Out of the 51 species in the quercus forest, 41 (80 %) species exhibited contagious distribution pattern and 10 (19 %) species exhibited random distribution pattern. Out of the 28 species in the bamboo forest, 14 (50 %) exhibited random distribution pattern and 14 (50 %) species exhibited contagious distribution pattern and in the jhum land, out of the 21 species all the species exhibited contagious distribution pattern. However, it was observed that regular distribution pattern was absent in tropical wet evergreen forest, temperate forest, quescus forest, bamboo forest and jhum land and random distribution pattern was absent in montane sub-tropical forest and jhum land (**Table 4.3& Figure 4.7**).

4.4.3 Regeneration status

The overall regeneration status was good in montane sub-tropical forest, temperate forest, quercus forest and jhum land. However, tropical wet evergreen and bamboo forest exhibited fair regeneration pattern. In the tropical wet evergreen forest 116 species were found to be regenerating which represented 88 % of the total speciesand 3 new species were recorded in this forest type. 59 species exhibited fair regeneration pattern followed by 43 species exhibited good regeneration pattern, 15 species didn’t regenerate, 14 species had poor regeneration.

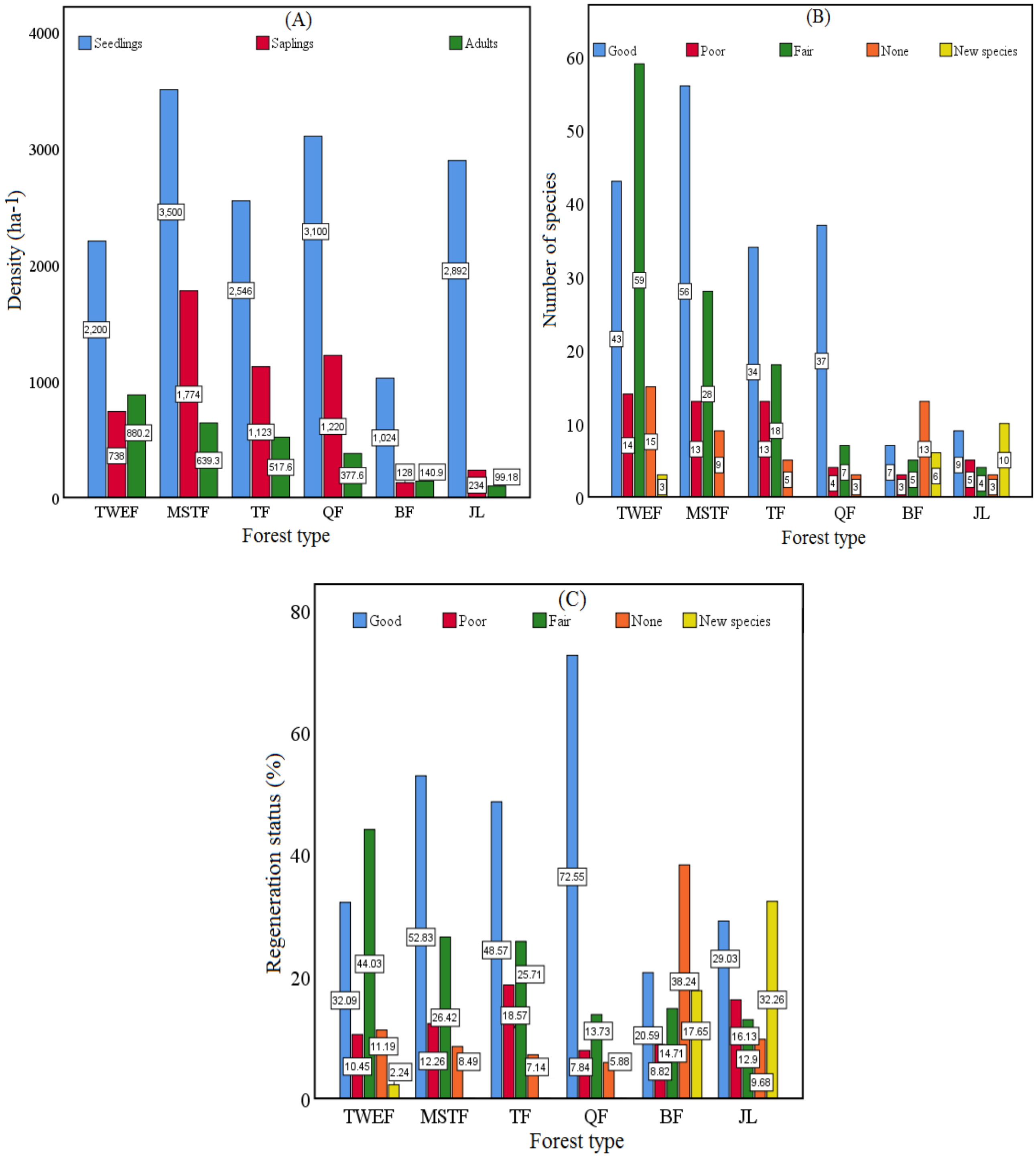


Figure 4.8 (A) distribution of seedling, sapling and adult tree density (B) regeneration status and (C) regeneration percentage across six major forest types.

In the montane sub-tropical forest, 97 species responded to regeneration which represented 91 % of the total species. Out of the 106 species present in these forests, 56 species exhibited good regeneration followed by 28 species exhibited fair regeneration, 13 species exhibited poor regeneration and 9 species didn’t regenerate. In the temperate forest, 65 species were found to be regenerating which represented 92 % of the total species. Out of the 70 species present in these forests, 34 species had good regeneration followed by 18 species had fair regeneration, 13 species had poor regeneration and 5 species didn’t regenerate. In the quercus forest, 48 species responded to regeneration which represented 94 % of the total species. Out of the 51 species present in the quercus forest, 37 species had good regeneration followed by 7 species had fair regeneration, 4 species had poor regeneration and 3 species didn’t respond to regeneration. In the bamboo forest only 15 species were found to be regenerating which represented 53 % of the total species and 6 species were newly recorded. 13 species didn’t regenerate followed by 7 species exhibited good regeneration, 5 species exhibited fair regeneration and 3 species exhibited poor regeneration. Out of the 21 species present in the jhum land, 18 species responded to regeneration which represented 85 % of the total species and 10 new species were recorded. In the jhum land, 9 species exhibited good regeneration, 5 species exhibited poor regeneration, 4 species exhibited fair regeneration and 3 species didn’t regenerate.

Seedling density was highest in the montane sub-tropical forest (3,500 seedlings ha^{-1}) followed by quercus forest (3,100 seedlings ha^{-1}), jhum land (2,892 seedlings ha^{-1}), tropical wet evergreen forest (2,200 seedlings ha^{-1}) and bamboo forest (1,024 seedlings ha^{-1}). Sapling density was highest in the montane sub-tropical forest (1774 seedlings ha^{-1}) followed by quercus forest (1220 seedlings ha^{-1}), temperate forest (1123 seedlings ha^{-1}), tropical wet evergreen forest (738 seedlings ha^{-1}), jhum land (234 seedlings ha^{-1}) and bamboo forest (128 seedlings ha^{-1}) (**Figure 4.8**).

4.5 Discussions

Species composition is one of the key components of species diversity (Li et al., 2017). In the present study we found that secondary forests i.e., jhum land and bamboo forest had lesser tree species diversitythan those of primary forest types. This may be attributed to the past disturbance history in the secondary forest types. The bamboo forests are mostly occur between 40 to 1,520 m altitudinal range in the jhum fallow areas of tropical and sub-tropical regions of Mizoram. The slashing and burning activities during jhum cultivation negatively impacts the soil seed bank and thus reduces its potential to restore local diversity. The aggressive growth of bamboo species like *Malocanna baccifera*, *Dendrocalamus strictus*, *Bambosa tulda* etc. also inhabits the succession of tree species in those forests. The lower number of tree species richness in jhum lands may due to the shortening of jhum fallow cycle in present days. However, studies have shown that these dominant land use system have potential to restore plant diversity and carbon storage as natural forest with increasing jhum fallow age.

Among the primary forest types, tropical wet evergreen forest had the highest number of tree diversity, whereas it was lowest in the quercus forest. High rainfall, lower altitude and mild average temperature might have favoured tree species richness in tropical wet evergreen forest. Studies have shown that one hectare of tropical wet evergreen forestharbours over 100 tree species with a girth exceeding 10cm and the number canreach almost 500 (Valencia et al., 1994). By comparison, temperate deciduous broad leaved forest attains only 25–30 tree species per hectare, at best (Richards, 1996). However, the single dominance of oak species in the quercus forest might have inhibited the growth of other species and thus become species poor as compared to rest of the primary forest types.

The distribution of families in the six forest types showed that Moraceae, Fagaceae, Fabaceae, and Lauraceae were the dominant families in all the six different forest types. However, dominant species were varied across the forest types. Tree species richness of tropical wet evergreen forest in the present study is comparable with those of tropical wet evergreen forest reported from the Anamalai hills of Western Ghats where a total of 144 tree species of dbh ≥ 30 cm were recorded in four hectare sampling plots (Muthuramkumar et al., 2006) and tropical wet evergreen forests in Namdapha National Park, Arunachal Pradesh (130 species in forty 50 × 20 m^2 transacts) (Bhuyan et al., 2003). As compared to the reports from other North East Indian States, the present study record in tropical wet evergreen forestis much higher thanreported 59 tree species from Meghalaya (Shankar and Tripathi, 2017), 54 species from Arunachal Pradesh (Deb et al., 2009) and 52 species from Assam (Borogayary et al., 2018). Tree species richness in the montane subtropical forest is comparable to subtropical forests of Meghalaya and Nagaland (Mishra et al., 2005, Ao et al., 2021). The number of species richness in the montane subtropical forest is lower than the earlier study records reported by Devi et al., (2018). Tree species richness in the temperate forest is lower than the previous record by Malsawmsanga and Lalramnghinglova, (2011) and is comparable to those of thetemperate forests in Nagalandand Sikkim as reported by Ao et al., (2020) and Sundriyal and Sharma, (1996). However, tree species richness in the quercus forest is higher than the mix species oak forests of Garhwal Himalaya.

The graphical representation of rank abundance curves of the six major forest types indicated highest equitability or lowest dominance in the tropical wet evergreen forest and lowest equitability or highest dominance in the jhum land. In the tropical wet evergreen forest the relative abundance was distributed more or less evenly among different tree species and the dominance was seemed to be shared by more than one species. On the other hand, in the jhum land, the distribution of relative abundance showed a very uneven pattern and the dominance wasshared by a single species. The single species dominance in the jhum land is due to rigorous tree felling during slash and burning. Overall, the species equitability was found to be highest in the primary forests and the same was found to be lowest in the secondary forests.

Tree population distribution pattern in the six forest types indicated that majority of the tree species exhibited contagious distribution pattern. Odum, (1971), emphasized that contagious distribution pattern is the most common distribution pattern in nature. Several workers have also reported the contagious distribution pattern as a common phenomenon in natural forests (Kershaw, 1973, Gairola et al., 2011; Kumar and Bhatt, 2006). Moreover, the variation in tree distribution pattern across different forest types seems to be associated with a large number of factors, especially the micro environment and biotic nature (Joshi and Tiwari, 1990). However, tree species rarity classifications based on the number of individuals indicated that majority of the species in the primary forests belonged to rare category (having 2-10 individuals per species). This may be attributed to the high equitability in the primary forests. Whereas, common (having 10-20 individuals per species) and dominant (having >20 individuals per species) species were found to be highest in number in the secondary forests which may be attributed to the past anthropogenic disturbances in those forest types. Forest disturbance might have altered the species mosaic and increased the number of common as well as dominant species.

Tree density and basal area values were found to be highest in tropical wet evergreen forest followed by montane sub-tropical forest, temperate forest, quercus forest, bamboo forest and jhum land. The maximum tree density and basal area in the tropical wet evergreen forest may be due to the favourable climatic condition. The higher tree density and basal area in the primary forests than the secondary bamboo forests and jhum land is due to the comparatively higher level of protection prevailing in the primary forest types. Whereas, anthropogenic disturbance is the main cause of lesser tree density in the secondary forest types. Tree density is always seems to be lesser in bamboo dominated forest due to its invasive growth. Fadrique et al., (2021) has found that dominance of bamboo species reduces tree density and basal area in bamboo dominated mixed species forests. According to Ziccardi et al., (2019), bamboo abundance following anthropogenic disturbances reclines large diameter trees. Higher dominance of bamboo species also has negative influence on regenerating trees and thus reduces tree density and basal area. Overabundance of bamboo species can significantly alter the forest structure and dynamics (Lima et al., 2012). In case of jhum lands, slash and burn activities during jhumming is the main reason for decline in tree density and basal area. Jhumming also depletes the soil seed bank and thus reduces tree diversity and density (Sahoo, 1996). However, with increase in fallow age it gradually recovers both vegetation and carbon storage (Gogoi et al., 2020).

Distribution of species richness, density and basal area of mature tree species across five diameter classes indicated higher species richness and density in the lower diameter classes and tree basal area tended to be higher in the mid diameter classes. This signifies that the numbers of young tree species as well as individuals were higher in the lower diameter classes in all the forest types and mid diameter classes had relatively bigger individuals. It was observed that no tree species recorded in the more than eighty centimetre diameter class in the jhum lands. This may be attributed to the young age of the selected jhum fallows.

Tree regeneration was found to be good in four forest types i.e., montane sub-tropical forest, temperate forest, quercus forest and jhum land. Whereas, tropical wet evergreen forest and bamboo forest exhibited fair regeneration pattern. Fair regeneration in the bamboo forest may be attributed to the invasive growth of bamboo culms and other non woody weeds which inhibits regeneration of the tree species in those forests. Dominance of bamboo culms and their litter reduces tree regeneration (Larpkern et al., 2010). They have also found that removal of bamboo litter increased seedling abundance and species diversity. Therefore, intensive management is required to enhance tree regeneration. Dense canopy cover in the tropical wet evergreen forest may be the reason for fair regeneration as Yuan et al., (2013) have found that dense canopy inhibits tree regeneration. Good regeneration in the jhum land may be due to the longer fallow period (10-15 years) of the selected jhum land in the study area. Ferguson et al., (2001) have found that jhum lands following succession are comprised of fast growing species with high regeneration and species accumulation. Raman, (1998) has also has found rapid regeneration of bamboo and other plants in more than ten years old jhum fallows.

CHAPTER-5

VARIATIONS INSOIL ORGANIC CARBON STORAGE AND ITS INFLUENCING FACTORS IN SELECTED FOREST TYPES OF MIZORAM

5.1 Introduction

Soil contributes largely to the global carbon cycle because it comprises of an active carbon pool (Prentice et al.,2001). In the terrestrial ecosystem, soil is considered to be the largest sink of organic carbon storing more than three times carbon compared to the amount stored in the atmosphere and 3.8 times more than the amount stored in biotic pool (Zomer et al.,2003). Therefore, the substantial sequestration of carbon in soils can provide a significant opportunity to mitigate global warming (Singh et al.,2011). Enhancing the capture and storage of atmospheric CO_2 in different land use systems can be a successful approach to lower its concentration while also improving the quality of soil (Lal et al., 1998; Lal et al., 1999). Soil profile in the top 1m stored 1500 Pg C soil organic carbon (SOC) globally, out of which Indian soil holds about 9 Pg C where the Himalayan zones account for about 33% of the total SOC reserves owing to thick forest vegetation (Bhattacharyya et al. 2008). SOC can either be increased or decreased depending on various factors such as soil type, climate, topography and soil management practices. However, SOC is greatly influenced by vegetation through organic matter input and therefore land use change is one of the most important factors which influences SOC stock builds up. For example, it was reported that the conversion of farmland to apple orchard led to the decrease in the quality of soil owing to the reduced SOC stocks (Shi et al., 2015). Soil carbon stock, following forest-pasture conversions, decreased to 51% in 20–30 years old pasture converted from wet tropical forest in Costa Rica, while SOC stock increased to 164% in 33 years old leguminous pasture converted from native vegetation in Western Australia (Murty et al., 2002). A meta-analysis reported that SOC stock decreased 13% and 42% when native forest converted to plantation and crop land respectively (Guo and Gifford, 2002).

In natural ecosystem like forest and agroforestry, the soils are less disturbed due to less cultural operations and therefore may contain adequate nutrients and soil microorganisms when compared to agricultural lands (Lemenih et al., 2005; Sheikh and Tiwari 2013; Gupta et al., 2014). Intensive management and cultural practices in agricultural lands increase the turnover rates of macro aggregates and lead to destabilization of the labile soil organic matter compounds (Six et al., 1999). Study reported from Northeast India showed the highest SOC stock in dense forest (140.4 Tg) and the least in shifting cultivation (10.7 Tg) with a total SOC stock (339.82 Tg), irrespective of the land use system for an area of 10.10 million ha, wherein forest soils contributed more than 50% with great implications for SOC sequestration in the region (Choudhury et al., 2013). Studies from northern Bangladesh reported highest SOC concentration in agroforestry system (1.063%) and least in fallow land (0.249%) (Iqbal et al., 2013), whereas a similar study from homegardens in Aizawl, Mizoram reported SOC stock of 258.43 t C ha^{-1} in 1 m soil depth (Singh and Sahoo 2015). Soil carbon sequestration proves to be a key indicator of soil health and crop efficiency (Yadav et al., 2000;Bolinder et al., 2007), responsible for climate change mitigation and at the same time improving soil physical properties through moisture and nutrient retention (Leu, 2009). However, the removal of biomass through deforestation and land use change can accelerate soil erosion resulting in significant loss of soil organic carbon from the surface soil (Sombroek et al., 1993;Lal, 2017). The state of Mizoram reported a high percentage of forest cover (86.27% with respect to the total geographical area); however, forest cover has decreased considerably (by 531 km^2 from 2015 to 2017) due to shifting cultivation, biotic pressure, illegal felling, conversion of forest lands for developmental activities and agriculture expansion (FSI, 2017). Despite the great potential of forest to sequester soil organic carbon, studies on SOC stock in forest and various land use conversions are limited in

Mizoram (Singh et al., 2018; Singh and Sahoo, 2018; Devi et al., 2018). Estimating SOC stock in various forest types has become very essential because it will aid policy makers to work out techniques for managing land use systems sustainably as well as preventing extreme loss of SOC. Hence, the present study was undertaken with objectives (1) to assess the soil physical and chemical properties in the selected forest types. (2) to quantify various SOC contents (very labile, labile, less labile and non labile) and their relative proportions in total organic carbon (TOC) across different forest types. (3) to estimate soil organic carbon stocks in the selected forest types. (4) to assess the relationships between SOC stock and various ecosystem parameters.

5.2 Materials and Methods

5.2.1 Study Area

In the present study, six major forest types were selected in four districts of Mizoram based on the forest classification described by Singh et al., in 2002. These were namely (a) Tropical wet evergreen forest (TWEF) (b) Montane subtropical forest (MSTF) (c) Temperate forest (TF) (d) Bamboo forest (BF) (e) Quercus forest (QF) (f) Jhum land (JL). The sampling sites of the tropical wet evergreen forest were selected in the undisturbed core areas of the Dampa tiger reserve forest in Mamit District. Whereas, the sampling sites of the Montane subtropical forest were selected in the Reiek Community forest which is situated in the edge of Mamit and Aizawl District of the state. The sampling sites of the Temperate forest were selected in Phawngpui National Park. Sampling sites of the Quercus forest were selected in and around the Lengteng Wildlife Century situated in Champhai District. Sampling sites of bamboo forest and Jhum fallow were selected in the Lengpui and Sakawrtuichhun area of Aizawl District respectively. The age of the jhum fallows were ranged between 15 to 20 years.

5.2.2 Soil Sampling

In each forest type, a permanent plot measuring 250m x 250m was demarcated using a measuring tape andgeo-coordinates were taken at the centre of the plot.Soil samples were collected from thethree random locations within the 250 m x 250 m sized major plots. Samples were collected from four soil depths viz., 0-15 cm, 15-30 cm, and 30-45 cm and analysed for soil organic carbon and other physical and chemical properties. Thus, a sum of 36 soil samples from each studied forest (4 locations within a plot x 3 depth x 3 major plot) was collected. Equal numbers of soil samples from the same depths were collected for soil bulk density estimation using a soil corer of known volume(106.07 cm^3). After collection, samples were placed in plastic bags and labelled before brought to the laboratory for further processing. The soil samples were mixed thoroughly andlarge plant debris, roots and stones were removedmanually by hand.They were later air-dried at room temperature before being passed through a 2 mm sieve to remove coarse rocks, pebbles and plant debris.For each depth, threereplicatesof each composite were analyzed.

5.2.3 Analysisof Soil Physical and Chemical Properties

Soil Bulk density was determined by corer method (Brady and Weil, 2008). The soil samples were air dried and roots and other plant parts were removed and then kept in hot air oven at 105^o C for drying till the constant weight was achieved. After attaining constant weight, it was divided by the volume and finally the bulk density value of soil was obtained. Soil texture was determined by Hydrometer method (Bouyoucos, 1926) using the USDA textural classification chart.Soil pH and moisture content percentage was determined within 36 hours of sampling following standard procedures. Soil pH was determined usingsoil-water ratio method (Anderson and Ingram, 1989).Soil moisture content was determined following the gravimetric method where soil samples were weighed before and after the sample was oven dried at 105°C until the constant weight was attained. Total nitrogen (TN) was determined using CHNS/O Elemental Analyzer. Soil organic carbon was analyzed by Walkley-Black rapid titration method (Walkley and Black, 1934).Available phosphorous was analyzed following Allen et al.(1974) method. Potassium (K)was determined using theAgilent 4100 Microwave Plasma-Atomic Emission Spectrometer (MP-AES).

5.2.4 Estimation of Active and Passive Soil Organic Carbon Pools

The total carbon (TC) in the soil samples were determined by using CHNS analyzer. Inorganic soil carbon (SIC) was analyzed using dilute HCl (Jakson, 1973). Total organic carbon (TOC) in soil was estimated by subtracting the concentration of SIC from TC. For classifying the different pools of C according to the degrees of lability, the original Walkley and Black method is used in modified form with solutions in which the H_2SO_4 concentration varies at stable concentration of $K_2Cr_2O_7$ (Chan et al., 2001). 5, 10 and 20 ml of concentrated H_2SO_4 were used giving three acid-aqueous solution ratios of 0.5:1, 1:1 and 2:1 (which corresponded respectively to 12N, 18N and 24N of H_2SO_4). The 24N H_2SO_4oxidizable C is equivalent to the standard Walkley and Black method (Walkley and Black, 1934). The concentration of organic carbon (OC) was determined using the three acid-aqueous solution ratios allowed separation of TOC into the following four fractions of decreasing oxidizability/lability.

1. Very labile (VLC): Organic C oxidizable under 12N H_2SO_4
2. Labile (LC): Difference in SOC oxidizable under 18N and that under 12N H_2SO_4
3. Less labile (LLC): Difference in SOC oxidizable under 24N and that under 18N H_2SO_4
4. Recalcitrant/ Non-labile (NLC): Residual SOC after reaction with 24N H_2SO_4 when compared with TOC.

The very labile and labile pool may be summed up and it may be designated as active pool. Similarly, less labile and non-labile pool may be summed up and designated as passive pool. Whereas, organic carbon in rock fragments fraction is negligible; the fine soil (<2 mm size) is of prime interest that contains the SOC. The soil samples were oven dried at 105˚C for 24 hours and passed through a 2 mm sieve to obtain the mass of fine soil. Hence, fine soil stock (FSS) in different soil depths was calculated as the product of soil layer depth with the ratio of total mass of the fine soil contained in the sample to the internal volume of the metallic core.

5.2.5 Estimation Soil Organic Carbon Stock

Soil carbon stock for each depth class was estimatedby multiplying with corresponding values of fine bulkdensity and SOC content. SOC stock was calculatedfollowingthe formula given by IPCC, (2003).

$$C\ storage = \sum_{\text{horizon}=1}^{\text{horizon}=n} (SOC \times Bulk\ Density \times Depth \times (1 - frag) \times 10)horizon$$

Where,

SOC = representative soil organic carbon stock, Mg C ha^{-1}, SOC horizon = SOC stock for a constituent soil horizon, Mg C ha^{-1}, SOC = concentration of soil organic carbon, g C (kg soil)$^{-1}$, Bulk Density = soil mass per sample volume, Mg soil m^{-3}, Depth = horizon depth or thickness of soil layer in meter, Frag = % volume of coarse fragments/100, dimensionless.

5.3 Data Analysis

The mean and standard deviation of the replicate samples were calculated using a descriptive statistical tool. Mean values of the different soil properties were compared using one-way analysis of variance (ANOVA) and a significant difference at P<0.05 was declared using the Tukey honest significance difference (HSD) test. The Shapiro-Wilk test was used to test normal distribution and the Leven test was carried out to test homogeneity of variance in data. Data were log transform to pass the primary assumption associated with the use of ANOVA. The linear relationship between the soil properties and different carbon fractions was established using Pearson correlation analysis using SPSS 21.0 (SPSS Inc. Chicago, USA) and principal component analysis was performed using PAST.

5.4 Results

5.4.1 Variations in soil physical and chemical properties

Soil physical & chemical properties of different soil depths in the studied forest types are presented in **Table 5.1**and the mean values of the soilproperties are presented in the **Figure 5.1**. The average percentage of soil particles in various textural classes increased with increasing soil depth (**Table 5.1**). Proportion of sand and silt were found to be higher in the secondary forests whereas; clay proportion was higher in the primary forests. Within the six forests type, the average percentage of sand particle (0-45 cm soil depth) was highest in the jhum land (62.06%) followed by bamboo forest (61.63%), temperate forest (61.50%), tropical wet evergreen forest (60.65%), quercus forest (60.39%) and montane sub-tropical forest (60.17%). No significance difference was observed between TWEF, MSTF, TF, QF and BF. However, MSTF and JL differed significantly. Silt percentage was highest in the BF (25%) followed by MSTF (21.22%), TF (20.88%), and QF 20.88%), TWEF (20.53%) and JL (20.44%). There was no significant difference between TWEF, MSTF, TF, QF and JL whereas; BF had significant difference with all the forest types. Clay percentage was highest in the TF (19.41%) followed by TWEF (18.83%), MSTF (18.61%), QF (17.97%), JL (17.50%) and BF (13.04%). Clay percentage didn’t vary significantly between

TWEF, MSTF, TF, QF and JL whereas; BF had significant difference with all the forest types as the same was also observed case of silt particles **(Figure 5.1)**.

Soil pH values decreased with increasing soil depth in all the forest types (**Table 5.1**). The average soil pH (0-45 cm soil depth) ranged from 4.46 to 5.14 in the six forest types. The pH value was recorded highest in the TWEF (5.14) followed by MSTF (4.86), TF (4.70), BF (4.62), JL (4.52) and QF (4.46). Soil pH value in the TWEF significantly differed from all the forest types. pH value in the MSTF significantly differed from QF, BF and JL but didn’t have any significant difference with TF. TF had significant difference only with TWEF and QF. Except with JL, QF had significant difference with rest of all the forest types. BF had significant difference with TWEF, MSTF and QF but didn’t have significant difference with rest of the three forest types and JL had significant difference only with TWEF and MSTF **(Figure 5.1)**.

Soil moisture content decreased with the increasing soil depth in all the forest types (**Table 5.1**). The average soil moisture content (0-45 cm) was highest in the TWEF (34.18%) followed by TF (33.41%), QF (29.65%), BF (27.70%), JL (26.33%), MSTF (25.76%). Soil moisture content in the TWEF, MSTF and TF significantly varied from QF, BF and JL. There was significant difference between TWEF and MSTF and MSTF and TF. However, no significant difference was observed between QF, BF and JL and between TWEF and TF **(Figure 5.1)**.

Soil bulk density followed an increasing trend with the increasing soil depth in all the forest types (**Table 5.1**). It was found to be higher in primary forests than the secondary forests. Within the six forest types, bulk density (0-45 cm) was highest in the BF (1.21 g cm^{-3}) followed by QF (1.20 g cm^{-3}), JL (1.17 g cm^{-3}), TWEF (1.13 g cm^{-3}), MSTF (1.12 g cm^{-3}) and TF (1.05 g cm^{-3}). Bulk density value in the TF significantly differed from all the forest types and bulk density values in the

TWEF and MSTF significantly differed from rest of the four forest types. However, there was no significant difference between QF, BF and JL and between TWEF and MSTF **(Figure 5.1)**

Table 5.1 Soil physical and chemical properties along three soil depth classes. (Different letters in the parenthesis indicate significant difference (at < 0.05 level) of the mean values of three soil depth classes within same row. TWEF-tropical wet evergreen forest, MSTF-montane sub-tropical forest, TF-temperate forest, QF-quercus forest, BF-bamboo forest, JL-jhum land).

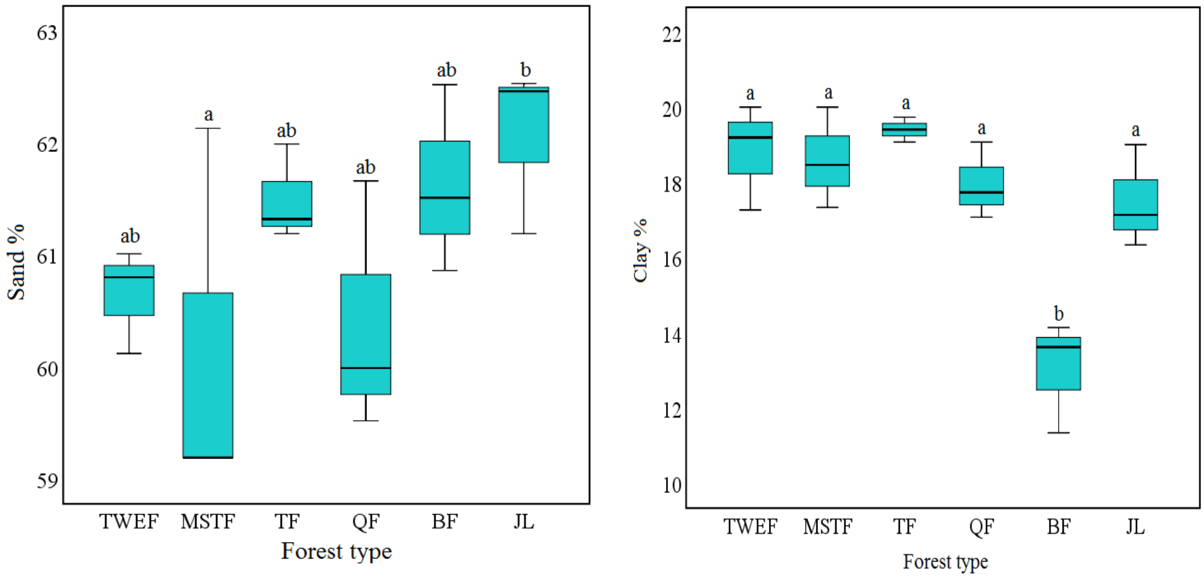
Forest type	**Soil depth**	**Clay (%)**	**Silt (%)**	**Sand (%)**	**Bulk density (g cm^{-3})**	**Soil moisture (%)**
TWEF	0-15	17.46 ± 2.03^{a}	18.54 ± 0.67^{a}	56.14 ± 0.65^{b}	1.10 ± 0.00^{b}	36.17 ± 1.20^{a}
	15-30	18.08 ± 1.33^{a}	20.13 ± 0.82^{ab}	61.79 ± 0.87^{a}	1.11 ± 0.00^{b}	34.34 ± 1.00^{ab}
	30-45	20.94 ± 1.53^{a}	22.92 ± 1.36^{b}	64.00 ± 1.53^{a}	1.18 ± 0.01^{a}	32.03 ± 1.33^{b}
MSTF	0-15	19.01 ± 1.11^{a}	18.87 ± 0.88^{a}	56.40 ± 0.31^{b}	1.09 ± 0.01^{a}	32.13 ± 2.40^{a}
	15-30	17.01 ± 1.40^{a}	21.00 ± 0.99^{a}	61.99 ± 2.39^{a}	1.13 ± 0.00^{a}	25.93 ± 0.33^{b}
	30-45	19.80 ± 2.08^{a}	23.80 ± 1.81^{a}	62.12 ± 1.16^{a}	1.15 ± 0.08^{a}	19.20 ± 0.58^{c}
TF	0-15	17.61 ± 1.15^{a}	16.93 ± 0.67^{a}	62.52 ± 0.33^{a}	1.06 ± 0.01^{a}	34.77 ± 1.45^{a}
	15-30	20.08 ± 1.20^{a}	19.47 ± 0.82^{ab}	62.92 ± 1.63^{a}	1.06 ± 0.00^{a}	33.83 ± 1.73^{a}
	30-45	20.54 ± 0.88^{a}	20.87 ± 1.41^{b}	59.06 ± 2.32^{a}	1.04 ± 0.01^{a}	31.63 ± 0.58^{a}
QF	0-15	16.94 ± 1.86^{a}	18.27 ± 0.88^{a}	57.06 ± 1.69^{a}	1.16 ± 0.01^{a}	33.63 ± 2.31^{a}
	15-30	18.41 ± 1.00^{a}	22.13 ± 0.58^{ab}	60.92 ± 2.37^{a}	1.12 ± 0.00^{a}	28.91 ± 2.31^{a}
	30-45	18.54 ± 1.76^{a}	24.53 ± 1.84^{b}	63.19 ± 1.00^{a}	1.32 ± 0.13^{a}	26.42 ± 2.31^{a}
BF	0-15	12.34 ± 1.67^{a}	18.87 ± 0.33^{a}	57.73 ± 0.64^{c}	1.24 ± 0.00^{a}	30.45 ± 2.89^{a}
	15-30	13.80 ± 1.15^{a}	18.67 ± 0.79^{a}	60.99 ± 0.95^{b}	1.23 ± 0.01^{a}	27.24 ± 1.73^{a}
	30-45	12.96 ± 1.34^{a}	20.47 ± 0.64^{b}	66.17 ± 1.04^{a}	1.17 ± 0.00^{b}	25.40 ± 1.73^{a}
JL	0-15	14.34 ± 0.64^{a}	16.00 ± 0.61^{b}	56.40 ± 0.31^{c}	1.18 ± 0.01^{a}	26.9 ± 0.58^{a}
	15-30	18.01 ± 1.67^{ab}	17.87 ± 0.88^{a}	61.12 ± 1.49^{a}	1.17 ± 0.00^{ab}	26.7 ± 1.73^{a}
	30-45	20.14 ± 1.46^{b}	17.47 ± 1.27^{a}	68.66 ± 0.82^{b}	1.15 ± 0.00^{b}	25.4 ± 2.31^{a}

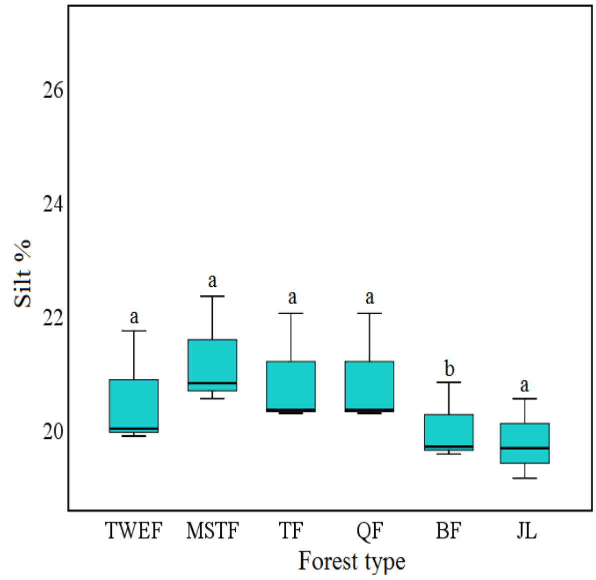
Continued..

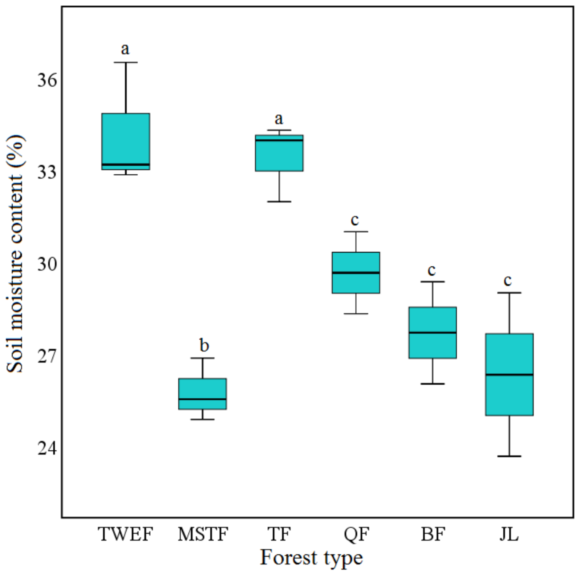
Forest type	**Soil depth**	**Soil pH**	**SOC (%)**	**Total N (%)**	**P_{avail} (mg kg^{-1})**	**K+ (cmol$_{c}$kg $^{-1}$)**
TWEF	0-15	5.87± 0.17^{a}	4.01± 0.13^{a}	0.32 ± 0.01^{a}	4.69 ± 0.05^{a}	0.11 ± 0.01^{b}
	15-30	4.84± 0.04^{b}	2.88± 0.12^{b}	0.31 ± 0.01^{a}	4.51 ± 0.01^{b}	0.15 ± 0.00^{ab}
	30-45	4.70± 0.03^{b}	2.58± 0.03^{b}	0.30 ± 0.01^{a}	4.35 ± 0.04^{c}	0.18 ± 0.01^{a}
MSTF	0-15	5.02± 0.02^{a}	2.81± 0.10^{a}	0.35 ± 0.00^{a}	4.29 ± 0.01^{a}	0.04 ± 0.01^{b}
	15-30	4.87± 0.02^{b}	3.20± 0.05^{b}	0.34 ± 0.01^{a}	4.22 ± 0.03^{b}	0.06 ± 0.00^{b}
	30-45	4.69± 0.03^{c}	2.73± 0.13^{c}	0.33 ± 0.01^{a}	4.14 ± 0.01^{c}	0.09 ± 0.01^{a}
TF	0-15	4.69± 0.32^{a}	4.85± 0.07^{a}	0.37 ± 0.01^{b}	4.52 ± 0.02^{a}	0.09 ± 0.00^{b}
	15-30	4.75± 0.07^{a}	3.49± 0.30^{b}	0.35 ± 0.01^{b}	4.48 ± 0.03^{b}	0.12 ± 0.01^{ab}
	30-45	4.66± 0.02^{a}	2.96± 0.18^{c}	0.34 ± 0.01^{a}	4.38 ± 0.03^{c}	0.14 ± 0.01^{a}
QF	0-15	4.23± 0.01^{a}	2.90± 0.03^{a}	0.23± 0.01^{a}	3.94 ± 0.01^{a}	0.06 ± 0.01^{a}
	15-30	4.65± 0.02^{b}	2.35± 0.13^{b}	0.22 ± 0.01^{a}	3.68± 0.01^{b}	0.07 ± 0.01^{a}
	30-45	4.50± 0.01^{c}	1.69± 0.10^{c}	0.20± 0.01^{a}	3.58± 0.02^{c}	0.08 ± 0.01^{a}
BF	0-15	4.75± 0.03^{a}	1.78± 0.21^{a}	0.24± 0.00^{b}	3.45± 0.01^{a}	0.03 ± 0.00^{b}
	15-30	4.63±0.10^{ab}	1.09± 0.03^{b}	0.23±0.01^{ab}	3.41± 0.03^{a}	0.06 ± 0.01^{ab}
	30-45	4.48± 0.06^{b}	1.12± 0.10^{b}	0.21± 0.00^{a}	3.29± 0.02^{b}	0.07 ± 0.01^{a}
JL	0-15	4.76± 0.03^{a}	1.34± 0.04^{a}	0.26± 0.01^{a}	3.15± 0.01^{a}	0.03 ± 0.00^{b}
	15-30	4.45± 0.03^{b}	1.16± 0.03^{b}	0.26± 0.01^{a}	3.11± 0.01^{b}	0.04 ± 0.00^{b}
	30-45	4.35± 0.03^{c}	0.96± 0.01^{c}	0.25± 0.01^{a}	3.06± 0.01^{c}	0.06 ± 0.01^{a}

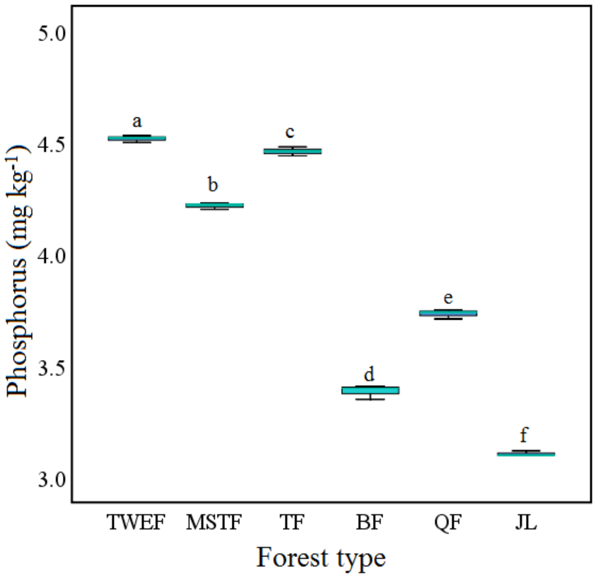
Soil phosphorus content was decreased with increasing soil depth in all the forest types (**Table 5.1**). Mean value of soil phosphorus content (0-45 cm soil depth) was recorded highest in TWEF (4.52 mg kg^{1}) followed by TF (4.46 mg kg^{1}), MSTF (4.22 mg kg^{1}), QF (3.74 mg kg^{1}), BF (3.38 mg kg^{1}) and JL (3.11 mg kg^{1}). Phosphorus content significantly varied among all the forest types **(Figure 5.1)**.

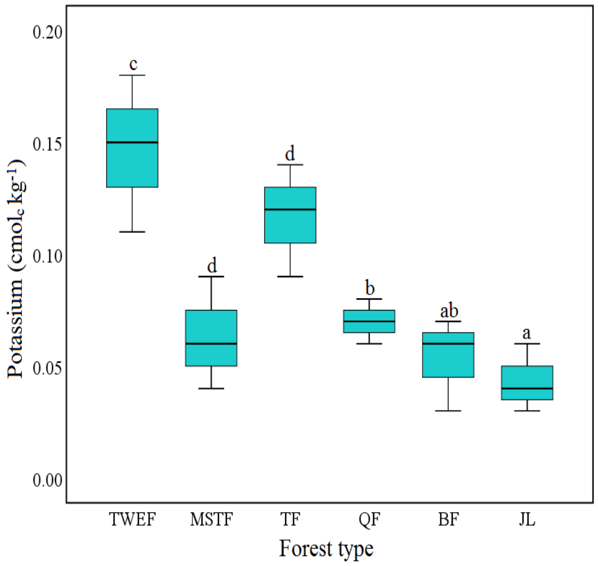
Soil potassium content increased with increasing soil depth in all the forest types (**Table 5.1**). Mean value of potassium content (0-45 cm) was highest in the TWEF (0.15 $\text{cmol}_c\ \text{kg}^{-1}$) followed by TF (0.12 $\text{cmol}_c\ \text{kg}^{-1}$), QF (0.07 $\text{cmol}_c\ \text{kg}^{-1}$), MSTF (0.06 $\text{cmol}_c\ \text{kg}^{-1}$), BF (0.05 $\text{cmol}_c\ \text{kg}^{-1}$) and JL (0.04$\text{cmol}_c\ \text{kg}^{-1}$). TWEF significantly varied among all the forest types. MSTF and TF didn’t vary significantly but had significant difference with BF, QF and JL. Except BF, QF had significant difference with all the forest types. There was no significant difference between BF and JL. However, BF and JL had significant differences with all the forest types **(Figure 5.1)**.




Silt %
26
24
22
20
a
a
a
a
b
a
TWEF
MSTF
TF
QF
BF
JL
Forest type


Soil moisture content (%)
36
33
30
27
24
a
b
a
c
c
c
TWEF
MSTF
TF
QF
BF
JL
Forest type


Phosphorus (mg kg^{-1})
5.0
4.5
4.0
3.5
3.0
a
b
c
d
e
f
TWEF
MSTF
TF
BF
QF
JL
Forest type


Potassium (cmol$_c$ kg^{-1})
0.20
0.15
0.10
0.05
0.00
c
d
d
b
ab
a
TWEF
MSTF
TF
QF
BF
JL
Forest type

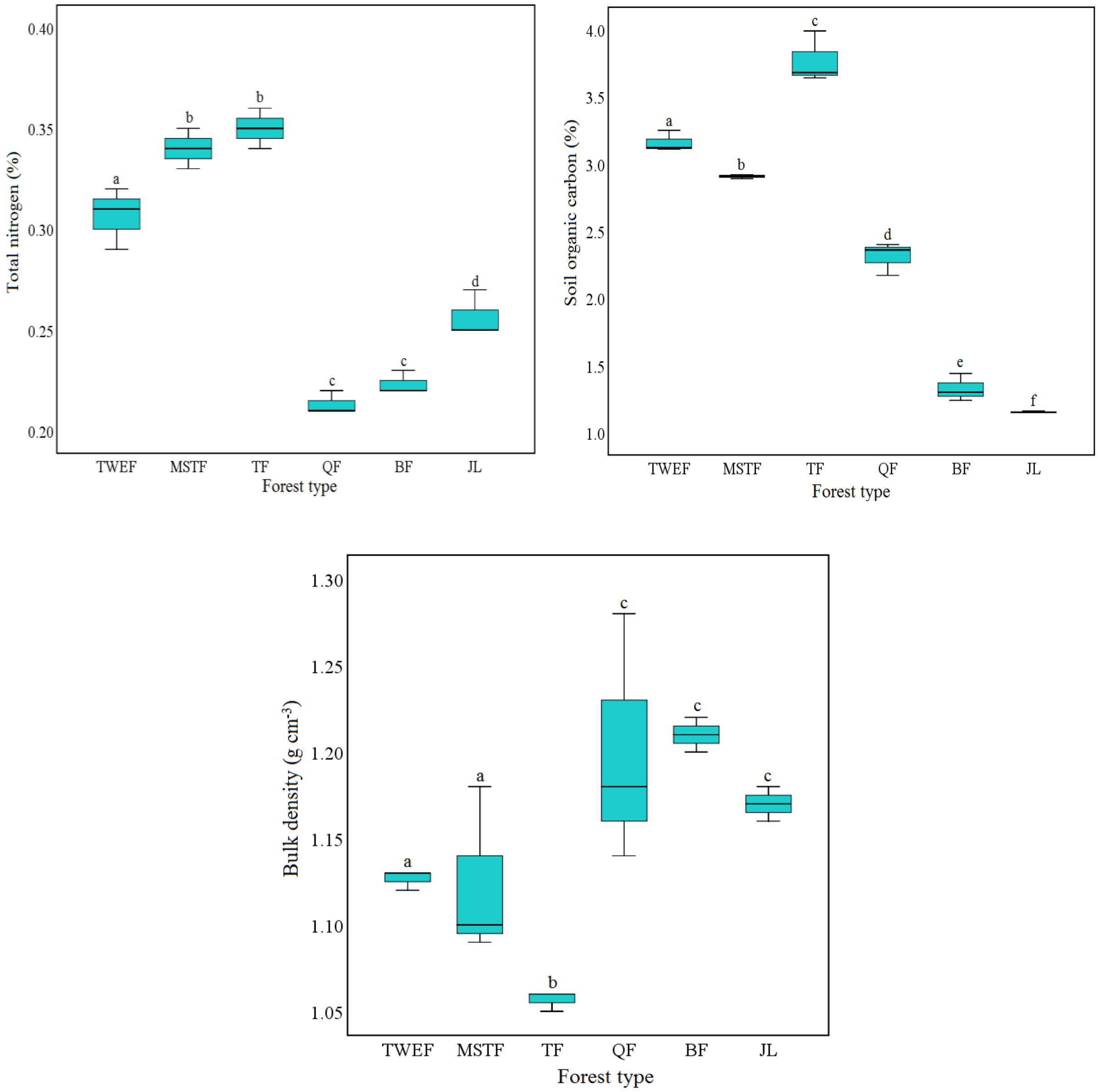


Figure 5.1 Mean value of soil physical and chemical properties in the six forest types. Different letters denote significant difference (at 0.05 level) between different forest type.

5.4.2 Variations in SOC stocks

Soil carbon concentrationsi.e., total carbon,soil inorganic carbon, total organic carbon were significantly highest in the tropical wet evergreen forests followed by montane sub-tropical forest, temperate forest, quercus forest, bamboo forest and jhum land (**Table 5.2**). Soil organic carbon stock was significantly highest in the tropical wet evergreen forest (178.90 Mg ha^{-1}), followed by montane sub tropical forest (161.61Mg ha^{-1}), temperate forest (147.06 Mg ha^{-1}), quercus forest (123.41 Mg ha^{-1}), bamboo forest (72.62 Mg ha^{-1}) and lowest in the jhum land (60.57 Mg ha^{-1}). Significant difference of SOC stocks was observed across different forest types except between the montane sub tropical forest and temperate forest andbetween the bamboo forest and jhum land (**Table5.2**).The distribution of SOC stocks across three depth classes showed that except in temperate forest, the SOC stocks were significantly highest in the top soil depths and gradually decreased with increasing soil depth in rest of the five forest types. In the temperate forest, 15-30 cm soil depth had the highest SOC stock followed by 0-15cm and 30-45 cm. However, no significant difference was observed between the soil depth classes in this forest type. In the tropical wet evergreen forest, temperate forest, quercus forest and bamboo forest, there was a significant difference between 0-15 cm depth class and 15-30 cm depth class and 0-15 cm depth class and 30-45 cm depth class. However, there was no significant difference was observed between 15-30 cm depth class and 30-45 cm depth class. In the jhum land, significant differences were observed between the three depth classes (**Figure 5.2**).

Table 5.2 distribution of total carbon concentration (TC), soil inorganic carbon concentration (SIC), soil organic carbon concentration (TOC) and soil organic carbon stock (SOCS) across different forest types.

Forest type	**TC (%)**	**SIC (%)**	**SOC (%)**	**SOCS (Mg ha^{-1})**
TWEF	3.55 ± 0.15^{a}	0.39 ± 0.04^{a}	3.16 ± 0.13^{a}	161.61 ± 7.66^{a}
MSTF	3.10 ± 0.16^{b}	0.19 ± 0.01^{b}	2.91 ± 0.16^{b}	147.06 ± 7.25^{a}
TF	4.20 ± 0.06^{c}	0.43 ± 0.02^{c}	3.77 ± 0.06^{a}	178.90 ± 3.24^{b}
QF	2.50 ± 0.09^{d}	0.18 ± 0.01^{b}	2.31 ± 0.08^{c}	123.41 ± 3.56^{c}
BF	1.51 ± 0.07^{e}	0.18 ± 0.00^{b}	1.33 ± 0.07^{d}	72.62 ± 3.54^{d}
JL	1.30 ± 0.01^{e}	0.14 ± 0.01^{b}	1.16 ± 0.02^{d}	60.57 ± 0.55^{d}

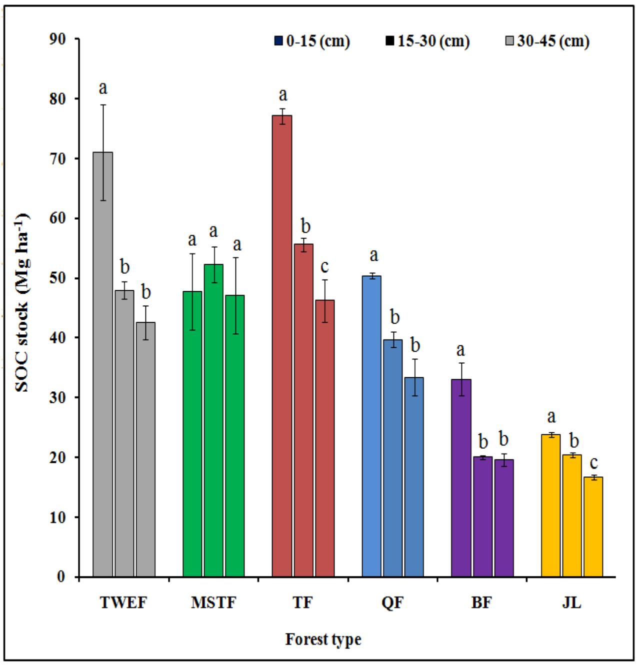


Figure 5.2 Soil organic carbon stock across three depth classes. Different letters represent significant difference between the mean values of the three depth classes within the same forest type.

Table 5.3 Soil organic carbon concentration (%) in varying lability classes at different soil depths across six forest types.

Forest type	**SOIL DEPTHS**					
	0-15 cm	**15-30 cm**	**30-45 cm**	**0-15 cm**	**15-30 cm**	**30-45 cm**
	Very Labile Carbon (C_{VL})			**Labile Carbon (LC)**		
TWEF	1.63 ±0.37^{a}	0.82 ±0.02^{a}	0.90 ±0.10^{a}	0.62 ±0.16^{a}	0.77 ±0.04^{a}	0.53 ±0.16^{a}
MSTF	1.14 ±0.11^{ac}	0.65 ±0.10^{b}	0.50 ±0.04^{b}	0.53 ±0.06^{a}	0.23 ±0.05^{b}	0.31 ±0.02^{bc}
TF	2.48 ±0.03^{b}	1.39 ±0.04^{c}	0.86 ±0.00^{c}	1.12 ±0.08^{b}	0.78 ±0.01^{a}	0.48 ±0.01^{ab}
QF	1.01 ±0.14^{dc}	0.58 ±0.06^{d}	0.43 ±0.04^{b}	0.59 ±0.06^{a}	0.27 ±0.01^{b}	0.23 ±0.02^{c}
BF	0.62 ±0.04^{c}	0.45 ±0.00^{d}	0.42 ±0.03^{b}	0.23 ±0.04^{c}	0.14 ±0.03^{c}	0.18 ±0.04^{c}
JL	0.60 ±0.01^{c}	0.44 ±0.01^{d}	0.38 ±0.02^{b}	0.30 ±0.02^{c}	0.20 ±0.01^{c}	0.23 ±0.02^{c}
Less Labile Carbon (LLC)				**Non Labile Carbon (NLC)**		
TWEF	0.51 ±0.04^{b}	0.41 ±0.10^{b}	0.54 ±0.17^{bc}	0.64 ±0.24^{ab}	1.91 ±0.33^{b}	1.38 ±0.34^{b}
MSTF	0.83 ±0.12^{c}	0.82 ±0.09^{a}	0.58 ±0.16^{b}	0.43 ±0.20^{ab}	0.50 ±0.11^{a}	1.04 ±0.15^{b}
TF	1.25 ±0.15^{a}	0.70 ±0.09^{a}	0.96 ±0.18^{a}	0.51 ±0.07^{ab}	0.58 ±0.05^{ac}	0.19 ±0.04^{ac}
QF	0.53 ±0.07^{b}	0.38 ±0.13^{b}	0.32 ±0.03^{bc}	0.77 ±0.13^{a}	1.13 ±0.25^{c}	0.71 ±0.16^{c}
BF	0.30 ±0.02^{d}	0.18 ±0.01^{b}	0.19 ±0.03^{c}	0.63 ±0.07^{ab}	0.31 ±0.04^{a}	0.33 ±0.08^{ac}
JL	0.22 ±0.03^{d}	0.26 ±0.01^{b}	0.19 ±0.02^{c}	0.22 ±0.04^{b}	0.27 ±0.00^{a}	0.16 ±0.02^{a}

Note: ± indicates standard error of mean. Values in same column followed by different letters are significantly different ($p<0.05$).

Table 5.4 Soil organic carbon concentration (%) of varying lability classes in different forest types (0–45 cm soil depth) of Mizoram.

Forest type	**Very labile**	**Labile**	**Less labile**	**Non labile**	**Active pool**	**Passive pool**
TWEF	1.12 ±0.12^{a}	0.64 ±0.12^{a}	0.97 ±0.08^{a}	0.43 ±0.03^{ad}	1.76 ±0.18^{a}	1.40 ±0.08^{a}
MSTF	0.76 ±0.05^{b}	0.35 ±0.03^{b}	0.49 ±0.09^{b}	1.31 ±0.26^{b}	1.12 ±0.08^{b}	1.80 ±0.18^{b}
TF	1.58 ±0.01^{c}	0.79 ±0.02^{a}	0.74 ±0.08^{a}	0.66 ±0.07^{ad}	2.37 ±0.02^{c}	1.40 ±0.06^{a}
QF	0.67 ±0.05^{bd}	0.36 ±0.02^{b}	0.41 ±0.03^{b}	0.87 ±0.11^{a}	1.03 ±0.05^{b}	1.28 ±0.08^{a}
BF	0.50 ±0.00^{d}	0.18 ±0.03^{c}	0.22 ±0.01^{c}	0.42 ±0.03^{d}	0.68 ±0.04^{d}	0.64 ±0.03^{c}
JL	0.47 ±0.01^{d}	0.24 ±0.01^{bc}	0.22 ±0.01^{c}	0.22 ±0.01^{d}	0.72 ±0.01^{d}	0.44 ±0.00^{c}

5.4.3 Variations in organic carbon pools and fractions.

Assessment of soil organic carbon concentration in different carbon pools reveal that soil organic carbon concentrations of varying lability classes decreased with increasing soil depth in almost all the forest types. SOC concentration of varying lability classes in the three soil depth classes varied significantly among most of the forest types except between bamboo forest and jhum land (**Table 5.3**). Very labile carbon concentration in different forest types of Mizoram ranged from 0.47 to 1.58.Very labile carbon was significantly highest in the temperate forest followed by tropical wet evergreen forest, montane sub-tropical forest, quercus forest, bamboo forest and lowest in the jhum land. Labile carbon concentration was highest in the temperate forest followed by tropical wet evergreen forest, quercus forest, montane sub-tropical forest, jhum land and bamboo forest. Less labile carbon was highest in the tropical wet evergreen forest followed by temperate forest, montane sub-tropical forest, quercus forest and bamboo forest and jhum land had the same amount of LLC concentration. Non labile carbon concentration was highest in the montane sub-tropical forest followed by quercus forest, temperate forest, tropical wet evergreen forest, bamboo forest and jhum land (**Table 5.4**).

Active carbon concentration was highest in the temperate forest followed by tropical wet evergreen forest, montane sub-tropical forest, quercus forest, jhum land and bamboo forest. Carbon concentration of the passive pool was highest in the montane sub-tropical forest, tropical wet evergreen forest, temperate forest, quercus forest, bamboo forest and jhum land (**Table 5.4**). The proportion of active carbon pool (labile & non labile) was higher that the passive carbon pool (non labile & less labile) in all the forest types (**Figure 5.3**).

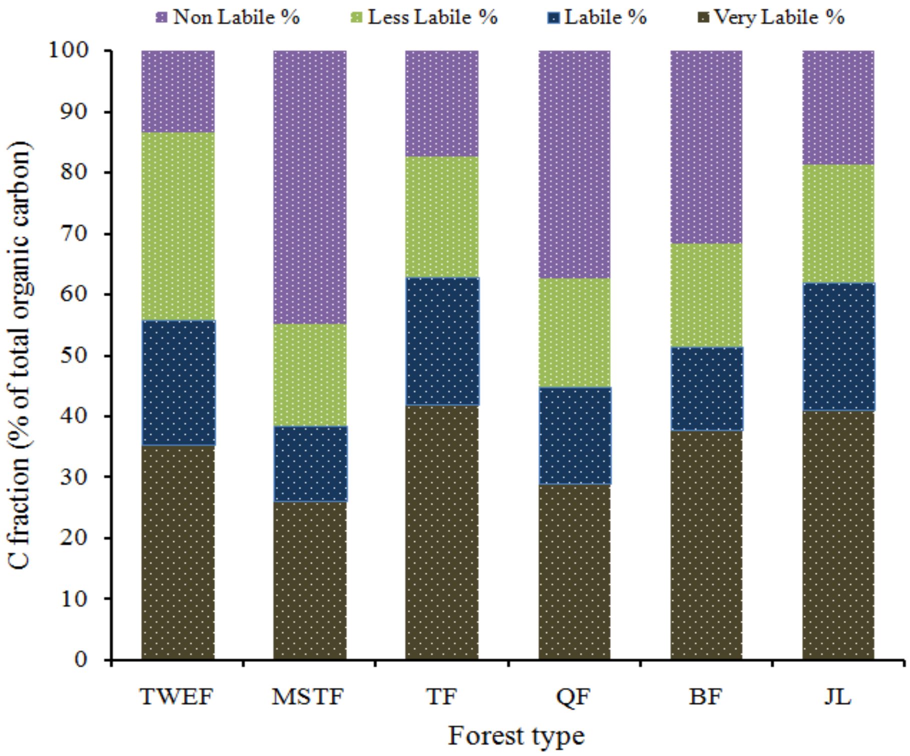
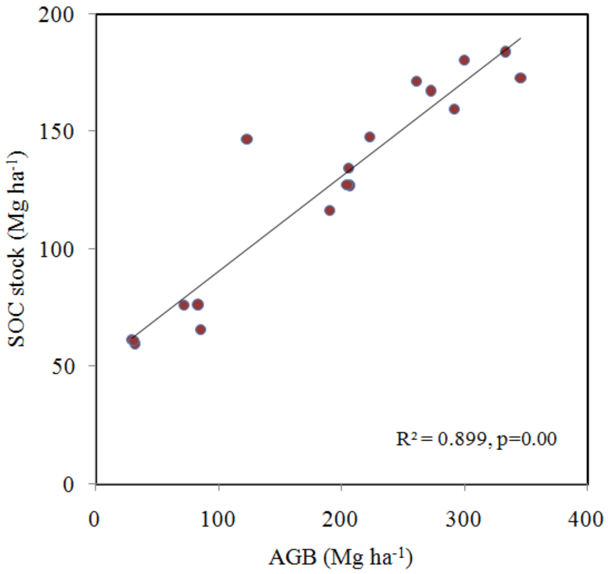
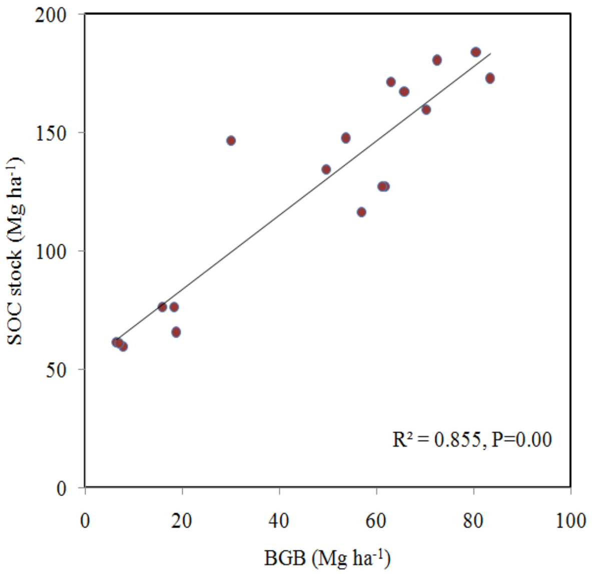
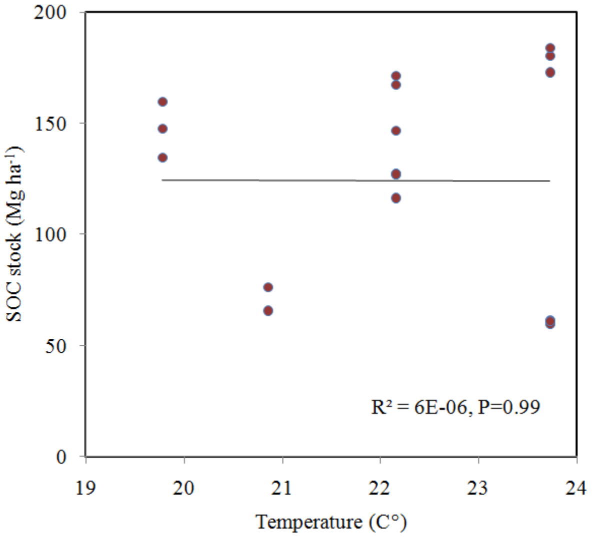
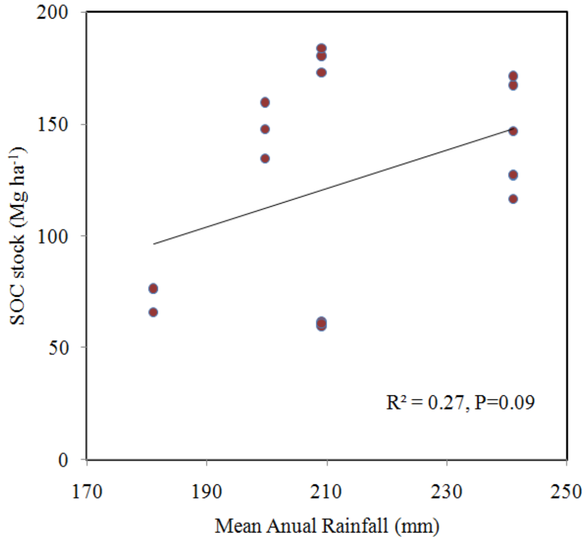


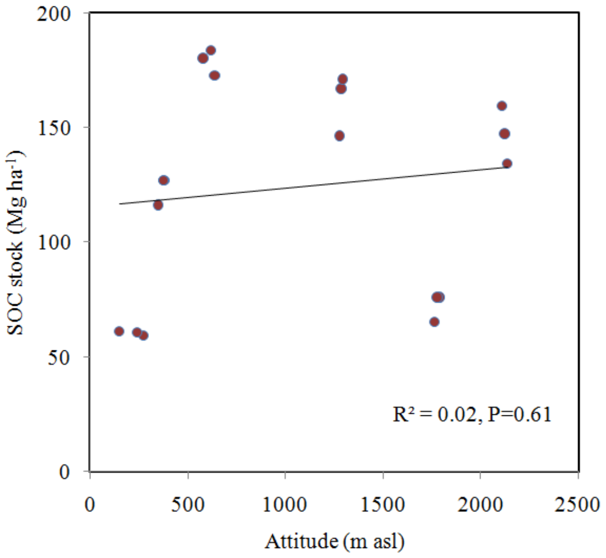
Figure 5.3 Distribution of soil organic carbon fractions in different lability classes (% of total organic carbon) of different forest types (0–45 cm soil depth) of Mizoram.

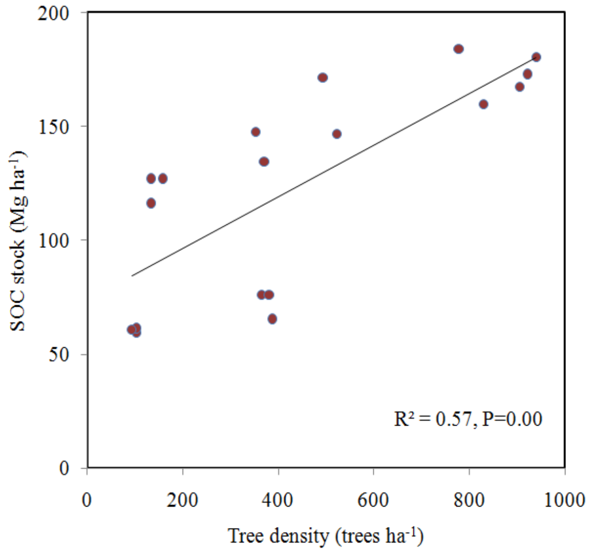

200
150
100
50
0
SOC stock (Mg ha-1)
0
100
200
300
400
AGB (Mg ha-1)
R² = 0.899, p=0.00

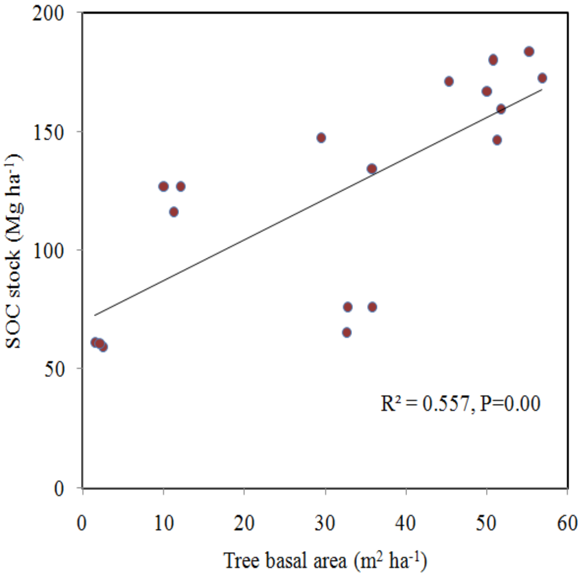

200
150
100
50
0
SOC stock (Mg ha-1)
0
20
40
60
80
100
BGB (Mg ha-1)
R² = 0.855, P=0.00

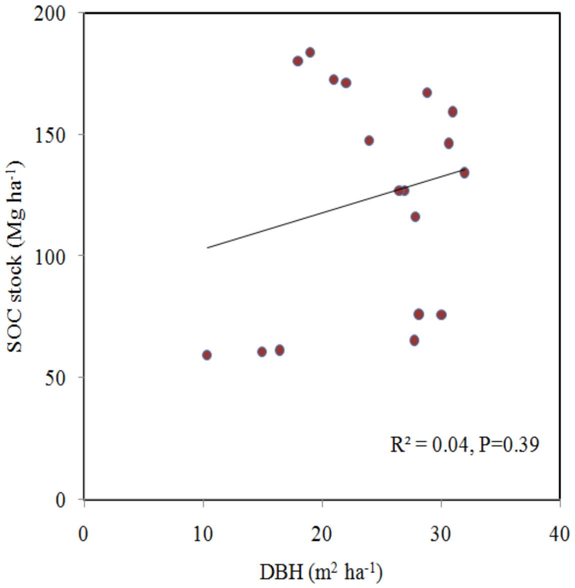

200
150
100
50
0
SOC stock (Mg ha-1)
19
20
21
22
23
24
Temperature (C°)
R² = 6E-06, P=0.99

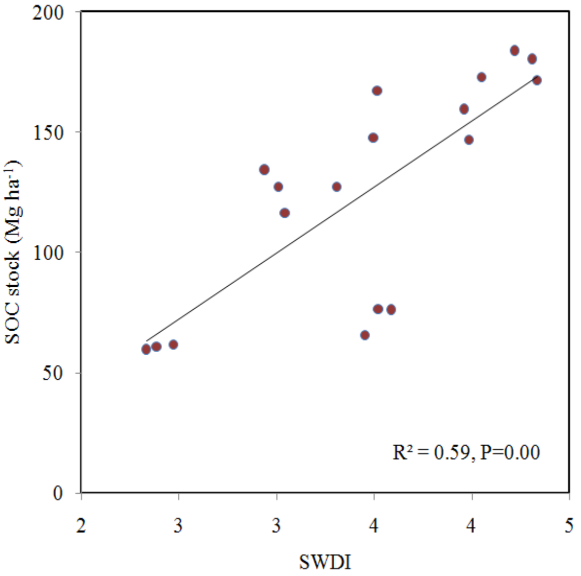

200
150
100
50
0
SOC stock (Mg ha-1)
170
190
210
230
250
Mean Anual Rainfall (mm)
R² = 0.27, P=0.09

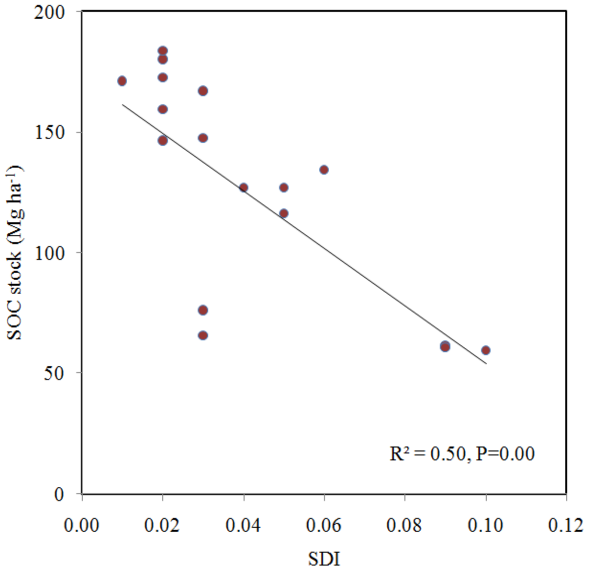

200
150
100
50
0
SOC stock (Mg ha-1)
0
500
1000
1500
2000
2500
Attitude (m asl)
R² = 0.02, P=0.61

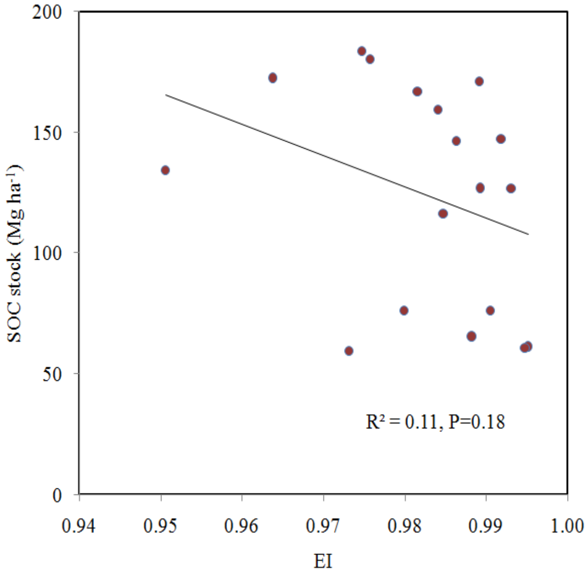

200
150
100
50
0
SOC stock (Mg ha-1)
0
200
400
600
800
1000
Tree density (trees ha-1)
R² = 0.57, P=0.00

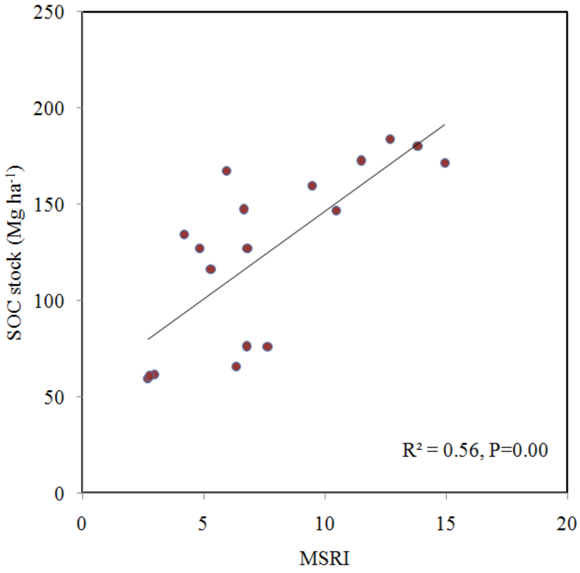

SOC stock (Mg ha-1)
200
150
100
50
0
0
10
20
30
40
50
60
Tree basal area (m2 ha-1)
R² = 0.557, P=0.00

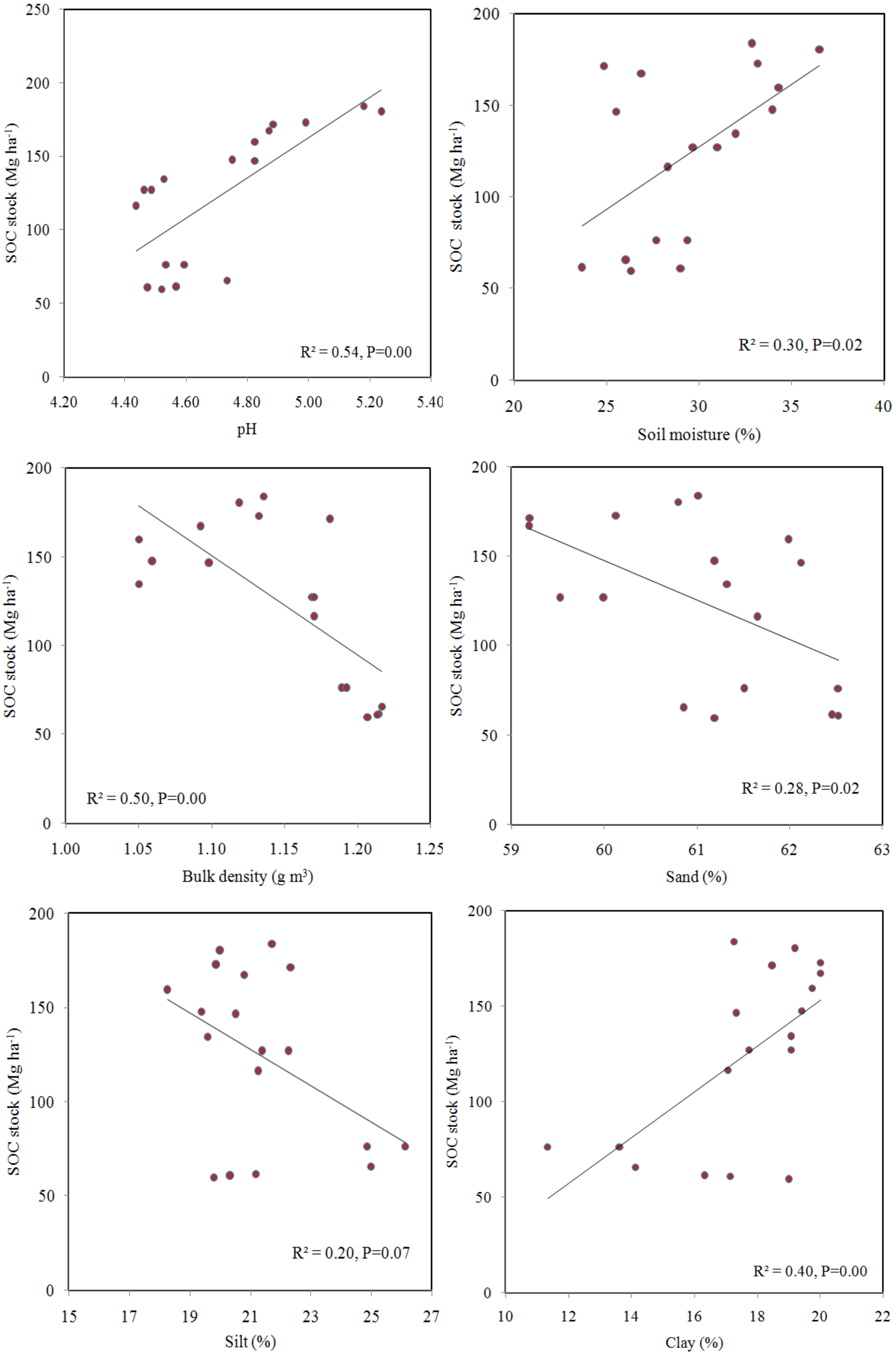

SOC stock (Mg ha-1)
200
150
100
50
0
0
10
20
30
40
DBH (m2 ha-1)
R² = 0.04, P=0.39


SOC stock (Mg ha-1)
200
150
100
50
0
2
3
3
4
4
5
SWDI
R² = 0.59, P=0.00


SOC stock (Mg ha-1)
200
150
100
50
0
0.00
0.02
0.04
0.06
0.08
0.10
0.12
SDI
R² = 0.50, P=0.00


SOC stock (Mg ha-1)
200
150
100
50
0
0.94
0.95
0.96
0.97
0.98
0.99
1.00
EI
R² = 0.11, P=0.18


SOC stock (Mg ha-1)
250
200
150
100
50
0
0
5
10
15
20
MSRI
R² = 0.56, P=0.00


SOC stock (Mg ha^{-1})
250
200
150
100
50
0
4.20
4.40
4.60
4.80
5.00
5.20
5.40
pH
R² = 0.54, P=0.00
SOC stock (Mg ha^{-1})
200
150
100
50
0
20
25
30
35
40
Soil moisture (%)
R² = 0.30, P=0.02
SOC stock (Mg ha^{-1})
200
150
100
50
0
1.00
1.05
1.10
1.15
1.20
1.25
Bulk density (g m^{3})
R² = 0.50, P=0.00
SOC stock (Mg ha^{-1})
200
150
100
50
0
59
60
61
62
63
Sand (%)
R² = 0.28, P=0.02
SOC stock (Mg ha^{-1})
200
150
100
50
0
15
17
19
21
23
25
27
Silt (%)
R² = 0.20, P=0.07
SOC stock (Mg ha^{-1})
200
150
100
50
0
10
12
14
16
18
20
22
Clay (%)
R² = 0.40, P=0.00

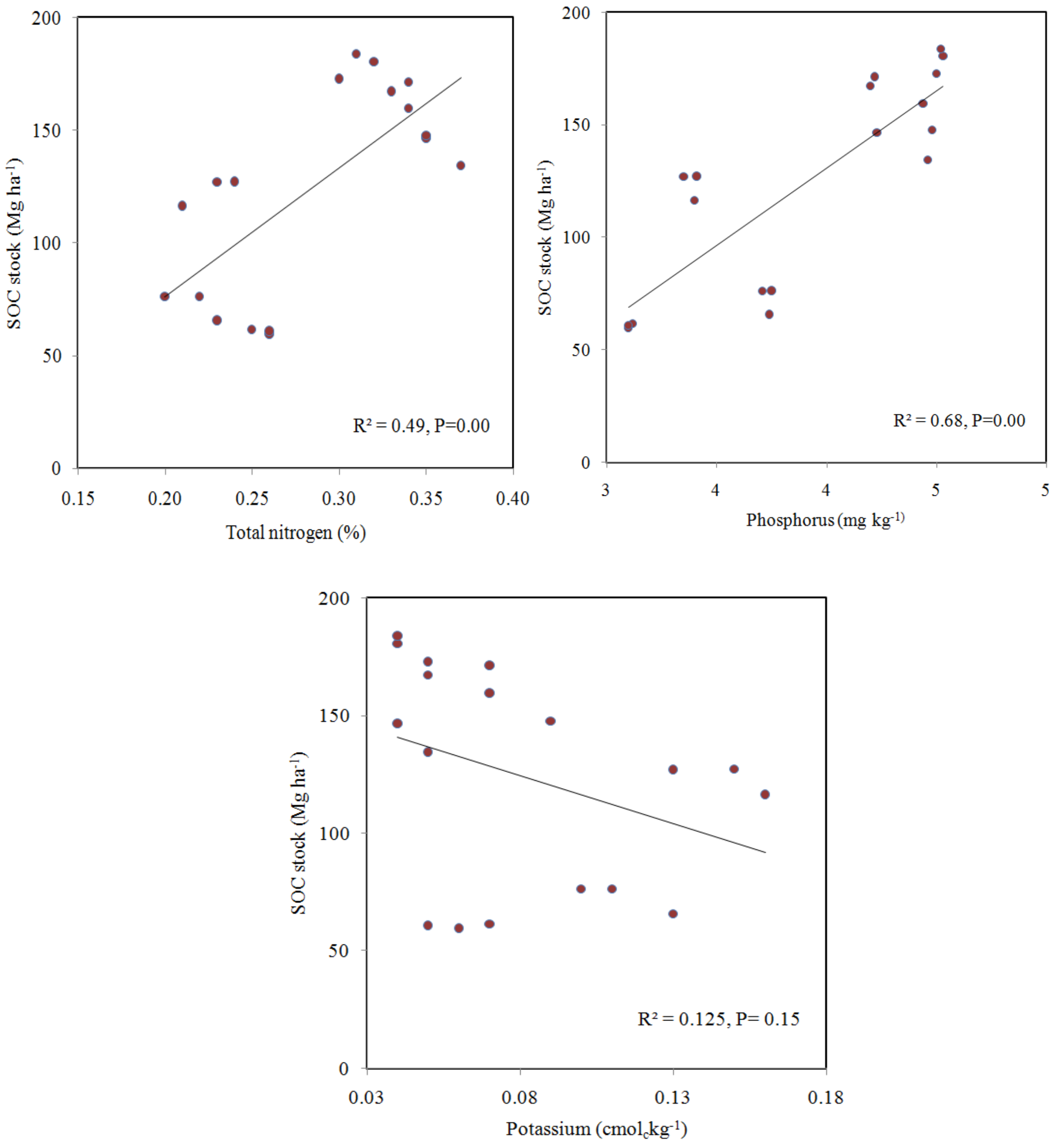


Figure 5.4 linear relationships between soil organic carbon stock (0-45 cm) and ecosystem parameters.

5.4.4 Relationships between SOC stock and ecosystem parameters

Linear regression of SOC stock versus 21 ecosystem parameters showed significant relationship with phosphorus, total nitrogen, bulk density, clay, sand, soil moisture, pH, Margalef's species richness index, Simpson's dominance index, Shannon Weinner's diversity index, tree basal area, tree density, aboveground biomass and belowground biomass and no relationship with potassium, silt, tree DBH, evenness index, temperature, altitude and mean annual rainfall (**Figure 5.4**). Phosphorus, total nitrogen, clay, soil moisture, pH, Margalef's species richness index, Shannon Weinner's diversity index, tree basal area, tree density, aboveground biomass and belowground biomass were significantly and positively correlated with SOC stock. In contrast, bulk density sand and species dominance were showing significant negative correlation with SOC stock (**Figure 5.4**).

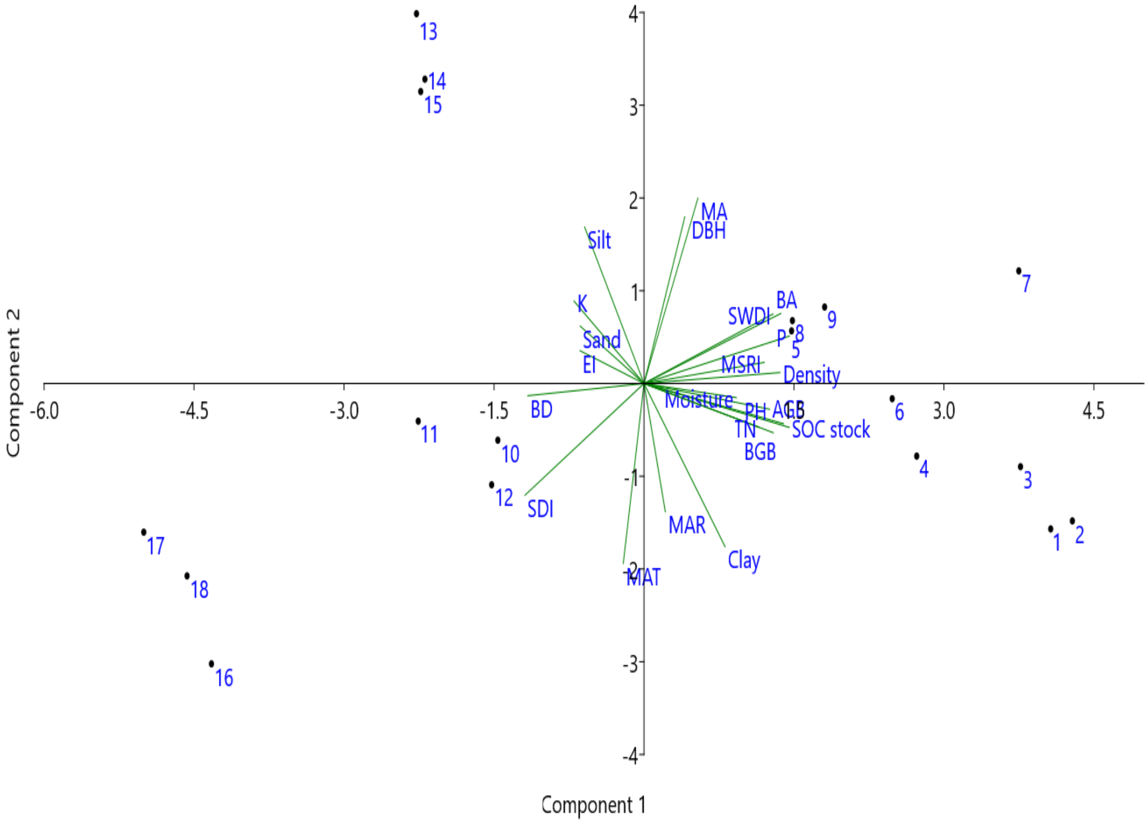


Figure 5.5 Biplot of the first two PCA axes of environmental factors (mean annual rainfall, mean annual temperature and altitude), plant biomass (aboveground biomass, belowground biomass), plant structural attributes (tree density, basal area, DBH), plant diversity indices (Simpson's dominance index, Shannon Weinner's diversity index, Evenness index and Margalef's species richness index), soil physical and chemical properties (soil moisture content, pH, bulk density, soil texture, soil phosphorus, total nitrogen, and potassium).Abbreviations: MAR: men annual rainfall, MAT: mean annual temperature, MAP: mean annual precipitation, AGB: aboveground biomass, BGB: belowground biomass, SDI: Simpson’s dominance index, EI: Evenness index, SWDI: Shannon-Wiener index, MSRI: Margalef's species richness index, SOC: soil organic carbon stock, BD: bulk density, K: potassium, P: phosphorus, TN: total nitrogen.

The principal component analysis results showed that the first two PCs (Component-1 and component-2) explained 46.40% and 16.93% of the variance in the study area (**Table 5.5**). The PCA results confirmedthat soil organic carbon was significantly correlated with plant biomass, plant structural attributes, plant diversity and soil physical and chemical properties. Out of the independent variables, sand, silt, potassium, mean annual temperature and Simpson’s dominance index negatively correlated with soil organic carbon stock and aboveground biomass, belowground biomass, total nitrogen, soil pH, clay, soil moisture, mean annual rainfall, mean altitude, Margalef's species richness index, Shannon Weinner's diversity index, phosphorus, tree basal area,tree DBH and tree density positively correlated with soil organic carbon stock. However among all the variables, SOC showed stronger positive relationship with aboveground biomass, belowground biomass, total nitrogen, soil pH, soil moisture, tree density, Margalef's species richness index, Shannon Weinner's diversity index, phosphorus and tree basal area (**Figure 5.5**).

Table 5.5 Eigen values and contribution percentage of the dominant axis of the principal component analysis (PCA).

Component	Eigenvalue	Contribution rate (%)	Cumulative contribution rate (%)
1	10.21	46.40	46.40
2	3.73	16.93	63.33
3	2.63	11.93	75.26
4	2.24	10.18	85.45

Dendrogram of hierarchical agglomerative cluster analysis of different forest types on the basis of soil physical and chemical parameters showed that tropical wet evergreen forest and montane sub-tropical forest had similar soil properties whereas; quercus forests and jhum fallow had similar soil properties. However, the soil properties of the temperate forests and bamboo forests were similar to each other and completely different from rest of the forest types (**Figure 5.6**).

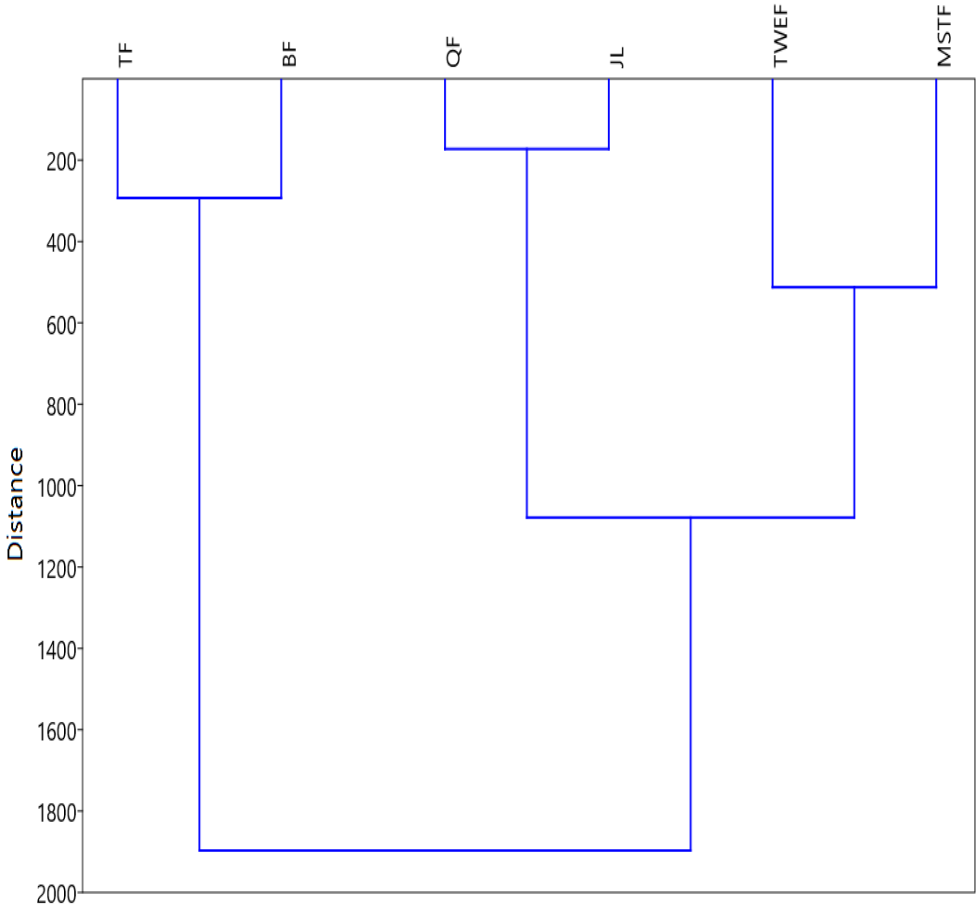


Figure 5.6 Dendrogram of cluster analysis of different forest types on the basis of soil physical and chemical parameters using Ward’s linkage method.

5.4.5 Effect of land use & land cover change on SOC stock

Natural forests of Mizoram had a range of SOC stock that varied from 23.8 Mg C ha^{-1} (jhum land) to 77.1 Mg C ha^{-1} (temperate forest) in tops soils and 44.2 Mg C ha^{-1} in jhum land to 132.7 Mg C ha^{-1} in temperate forest at 0 – 30 cm depth (Fig. 8). SOC stock was estimated significantly ($P < 0.05$, F=50.14) higher in temperate forest (132.7 Mg C ha^{-1}) in both the soil depth but the differences between the SOC stock of bamboo forest (53.1 Mg C ha^{-1}) and jhum land (44.2 Mg C ha^{-1}) was insignificant. The overall SOC stock (0 – 30 cm) was recorded in the order of temperate forest >tropical wet evergreen forest>montane subtropical forest >quercus forest >bamboo forest >jhum land.

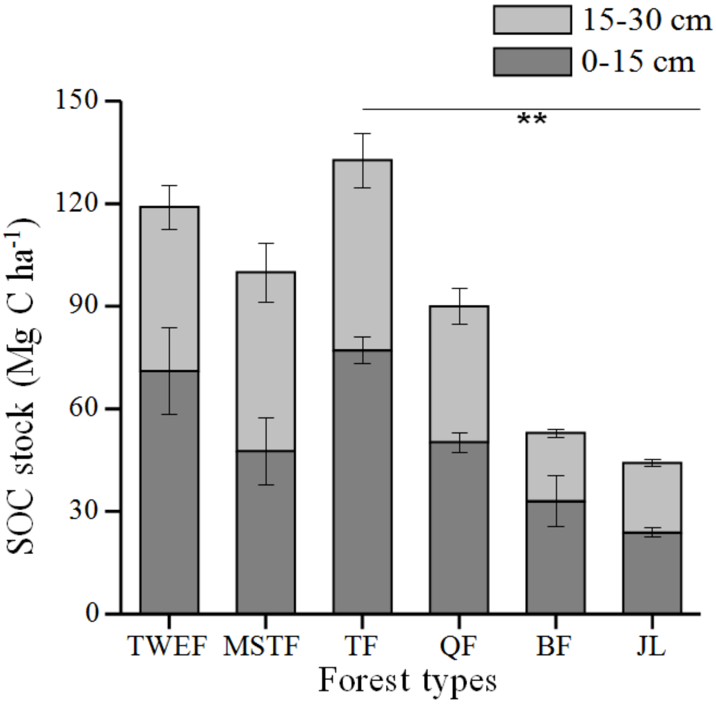


Figure 5.7 Variation in soil organic carbon stock (Mg C ha^{-1}) among the forest types. TWEF; Tropical wet evergreen forest, MSTF; Montane subtropical forest, TF; Temperate forest, QF; Quercus forest, BF; Bamboo forest, JL; Jhum land. ** indicate significant difference at $P < 0.05$.

Conversion of natural forests to bamboo forest and jhum land substantially reduced the SOC stock that ranged from 29% to 69% (Fig. 9). For instance, conversion of tropical wet evergreen forest to bamboo forest and jhum land reduces SOC stock by 51.3% and 65.3%, respectively. Changes in SOC stock were highest when temperate forest converted to jhum land (69.1%) and bamboo forest (57.0%). Whereas the minimum changes in SOC stock (28.8%) were observed when montane subtropical forest was converted to a bamboo forest. Overall, the average reduction in SOC stock was higher due to the conversion of natural forest to jhum land (58%) compared to bamboo forest (43%).

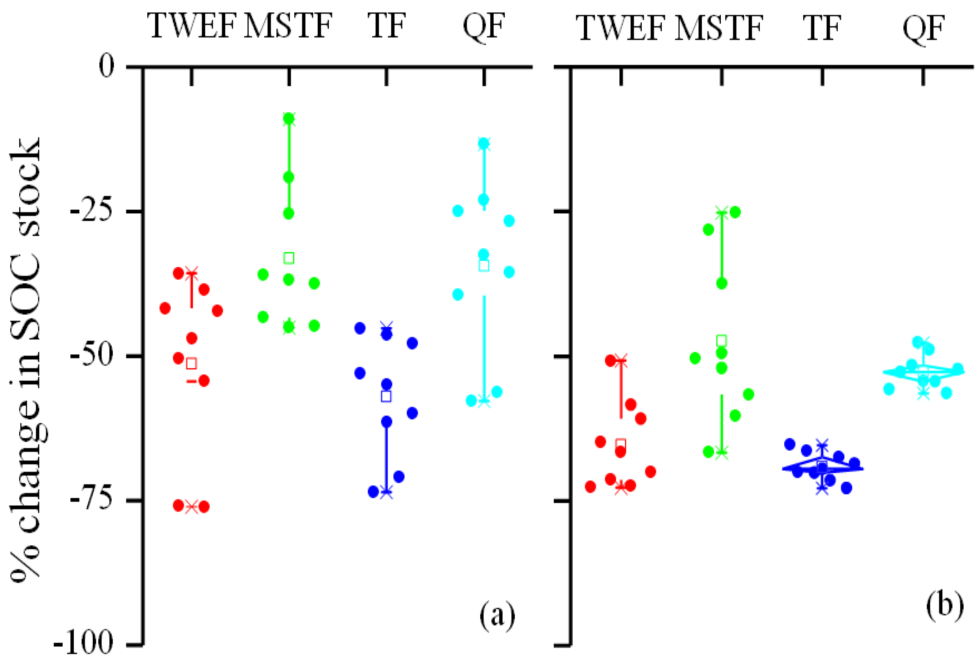


Figure 5.8 Percentage change in soil organic carbons stock after conversion of natural forests to (a) bamboo forest and (b) jhum land. TWEF; tropical wet evergreen forest, MSTF; montane subtropical forest, TF; temperate forest, QF; quercus forest.

Land cover changes in the natural forests of Mizoram lead to a change in the lability of carbon pool. Being a dominant forest in Mizoram, montane sub tropical forest was selected as a reference forest to calculate changes in lability of carbon pool and its effect on carbon indices in a bamboo forest and jhum land. Bamboo forest (0.72) show lesser values of lability index (LI) compared to jhum land **(Table 5.6).** In contrast, recalcitrancy index (RI) values in bamboo forest (54.7) were three-fold higher than in the jhum land. Values of the carbon pool index (CPI) were higher in bamboo forest (0.65) compared to jhum land (0.50) that indicating lesser changes in SOC pool when natural forests were converted to bamboo forest, whereas SOC pools decline to 50% in jhum land

Table 5.6 Changes in soil carbon indices after conversion of dominant natural forests (montane subtropical forest) to bamboo forest and jhum land.

Forest types	Carbon indices		
	Lability index (LI)	Recalcitrancy index (RI)	Carbon pool index (CPI)
Bamboo forest	0.72 ± 0.51	54.75 ± 28.34	0.65 ± 0.19
Jhum land	1.95 ± 0.19	17.20 ± 5.86	0.50 ± 0.12

5.5 Discussions

Soil physical & chemical properties vary in space and time because of variation in topography, climate, weathering processes, vegetation cover, microbial activities and other biotic and abiotic factors (Paudel and Jay, 2003; Reddy el al., 2012). Soil organic carbon (SOC) and nutrient cycling are strongly interrelated (Quinton et al., 2010;Finzi et al., 2011), and their dynamics fundamentally determine soil functioning and are closely related to the changing climate (Delgado-Baquerizo et al., 2013). Thus, understanding the mechanisms that control soil carbon and nutrients is crucial for successful ecosystem management and climate change mitigation (FAO, 2015;ViscarraRossel et al., 2019).

Soil texture is mostly influenced by the soil parent materials as well as other environmental factors (Zheng et al., 2011). In the present study, the proportion of sand, silt and clay particles increased with the increasing soil depth.Sand content seemed to be higher in the secondary forests whereas; clay and silt contentwas higher in the primary forests. The higher rate of clay content in the primary forests may be due to the relatively higher soil moisture content in those forests as clay content strongly correlates with soil moisture (Fernandes et al., 2021). The higher silt content in the primary forests may be due to the higher altitude of the primary forest sites. Tellen and Yerima, (2018) found that altitude positively impacts silt contents in natural forests. They have also found that conversion of primary forests into other land uses significantly reduces the silt content. Past anthropogenic disturbances in the secondary forests may be attributed for higher sand content in those forests as loss of finer soil particles such as silt and clay with disturbance in terrestrial ecosystem increases sand content (Eyre, 1968).

Soil bulk density decreased with increasing soil depth in all the forest types. Bulk density typically increases with soil depth due to the reduced organic matter, aggregation, root penetration, less pore space, soil compaction in the subsurface layers as compare to surface layers (USDA, 2008). Bulk density is affected by many factors such as water, aeration status, root penetration, soil texture, soil organic matter, land use and management etc. The higher bulk density in the secondary forests may be attributed to the lower rate of soil organic matter in those forests. Leifeld et al., (2005) suggested that lower soil organic matter increases soil bulk density. Many similar studies have also found negative correlation between bulk density and soil organic matter (Athira et al., 2019; Sakin, 2012;Mestdagh, 2006; Prevost, 2004).

Soil pH and moisture content decreased with the increasing soil depth and their mean values were found to be higher in the primary forests as compared to secondary forests. The soil pH in the study sites was highly acidic in nature which is common in all the North East Indian states. The highly acidic soil of this region is mainly due to higher precipitation, humid climate, high altitude and presence of rich organic matter etc. Apart from the inherent factors like climate, soil texture, parent materials, relief and topography which can’t be changed, land use and management practices greatly affects soil pH. Vegetation type impacts soil pH. For example, areas of forested land tend to be more acidic than areas of grassland.This is caused by the variation of organic matter (USDA, 2008). The same was observed in the present study. The higher pH in the primary forests than the secondary forests i.e., jhum land and bamboo forest may be attributed to the presence of higher organic matter in the primary forests. The decrease in soil pH in the study siteswith increasing soil depth may also be attributed to the decreasing soil organic matter in the sub surface soils. The higher level of soil moisture content in the primary forests than the secondary forests may be due to the presence of higher density of woody vegetation in the primary forests as compared to the secondary forests. The higher soil moisture content in the surface soil layer is may be due to the presence of higher soil organic matter and root zones in the upper soil layers which holds more soil moisture content as compared to sub surface layers.

Soil nitrogen, phosphorus and potassium are the most limiting macronutrients which influence plant growth and productivity under natural conditions. The decreased total nitrogen content in the secondary forests of the present study could be related to soil erosion in those forest types i.e., bamboo forest and jhum land. Soil erosion is a common phenomenon in the degraded forests of NE India which causes translocation of a considerable amount of soil, and often, both the carbon and nitrogen contents of the moving materials. Additionally, it can also be related to lesser tree density in secondary forests asnutrients can be lost from deforested sites by increased soil nutrient mobilization and leaching, especially when little vegetation is present at the site (Hajabbasi et al., 1997). The spatial distribution of total nitrogen in the present study forest revealed higher nitrogen content in the primary forest sites as compared to the secondary forests. This may be attributed to higher tree density and rich organic matter present in the primary forest sites. Berihu et al., (2017) have found that soils under dense forests have higher total nitrogen than soils under disturbed areas like grazing land and farmland.Higher stand density increases deposition of increased amount of soil organic matter and thus lead to higher total nitrogen content (Lei et al., 2019).

Many studies have found that the vertical distribution of soil phosphorus concentrations significantly decreased with increasing soil depth across regional scales (Yang et al., 2012, Zhang et al., 2014;Qiao et al., 2018). The present study results corroborate with these past studies. The decreasing trend of phosphorus concentration with increasing soil depth may be attributed to the decrease in soil organic matter in the sub-surface soils. The higher soil phosphorus content in the upper soil layer in the present study can also be explained by the accumulation of soil phosphorus in the top soil. The large-scale precipitation and temperature on the upper most soil layer can enhance bed rock and soil chemical weathering rates and stimulate soil phosphorus accumulation in the top soil profiles (García-Velázquez et al., 2020). The higher phosphorus content in the primary forest soils in the present study may be due to the higher rate of soil nitrogen and clay content in those forests. Studies have found that available phosphorus in forest soil increases with soil nitrogen and soils with higher clay content reduces phosphorus losses from the ecosystem (Lu, 2014; Soong et al., 2020).

Soil potassium content in the present study increased with increasing soil depth. This may be related to leaching of potassium from the soil surface to sub surface layer. The higher potassium content in the primary forests may be attributed to lower sand percentage in those forests. Sandy soils typically have lower potassium content due to enhanced leaching (Craig et al., 2015; Phillips and Burton, 2005).

Forest soils act as an important carbon sink as it store 383 ± 30 Pg C globally (Pan et al., 2011). Presence of highest soil organic carbon concentration and SOC stock in the temperate forest may be attributed to the dominance of coniferous tree species in those forests. Coniferous species generally accumulate greater soil organic carbon in the forest floor layer than the deciduous species (Augusto et al., 2015). Li et al., (2009) found that mountainous cold-temperate regions have high SOC content but large spatial variability, due to variable climate and vegetation. The slower rate of organic matter decomposition among the coniferous species may lead to the higher carbon concentration in the temperate forests. The higher altitude in the studied temperate forest could be another reason for higher soil organic carbon as low air and soil temperature at higher altitude reduce the soil microbial activities (Blume et al., 2002;Xu et al., 2014 and Cardelli et al., 2019) and thus promote soil organic carbon accumulation.

The higher rate of soil organic carbon storage in the primary forest sites as compared to those of secondary forests indicates the effect of prevailing forest management practises in Mizoram. Primary forest sites were selected within the boundary of national parks, tiger reserved forest and in a community forest where intensive forest management practices were carried out by the forest department whereas, secondary forest sites i.e., bamboo forest and jhum land were present in degraded unclassified village forests subjected to high level of anthropogenic disturbances. Johnson, (1992) have found that tree felling induces large net SOC loss and cultivation, on the other hand, results up to 50% of SOC loss in most cases. Additionally, higher tree diversity, density, basal area and biomass stocks in the primary forest sites positively influenced the SOC stocks in those forest sites as the present study results reveals that SOC stock is positively and significantly correlated with tree diversity, basal area, density and biomass.

Conversion of primary forests into jhum land generally lead to reduction of soil organic carbon content which ultimately change soil physical, chemical and biological properties. The present study findings agreed well with the findings of Bhuyan et al., (2013); Bhunia et al., (2016); Namei et al., (2016); Chen et al., (2016); Kenye et al., (2019) where they have observed lesser SOC stocks in bamboo forest and jhum land as compared to primary forests. The continuous disturbances by the human interference in bamboo forest and jhum land increase soil bulk density and declines SOC stock. The lower rate of litter and root biomass production in bamboo forest and jhum land due to younger age of trees ultimately supplies lesser organic matter and thus, resulted lower SOC concentration. However, relatively higher rate of SOC storage in top layers of the secondary forests indicates its potential to enhance soil fertility, regulating C cycling, and mitigate climate change.

The present study also evaluates the SOC losses due to conversion of primary forests in to secondary forest i.e., bamboo forest and jhum land. Our estimates show that

SOC stock reduced by 28% when montane sub-tropical forest got converted to the bamboo forest and up to 57% when tamperate forest was converted to bamboo forest. However, these losses are more pronounced when natural forests are converted to jhum land. For example, the conversion of temperate forest to jhum land reduced SOC stock by 69%. The reduction in SOC stock is mainly attributed to the loss of aboveground litter and belowground biomass when vegetation was cleared for agriculture (Ahirwal et al., 2021; Gogoi et al., 2022). Though regeneration of plant species partially counterbalances SOC losses, this required more time to sequester carbon equivalent to undisturbed forests. Several studies in the North East India Region reported a substantial loss of SOC stock when undisturbed forests converted to jhum land. For instance, SOC stock was reduced by 30.8% in Nagaland (Mishra and Francaviglia, 2021), 63.5% in the eastern Himalayas (Gogoi et al., 2022), 56.5% in Mizoram (Sahoo et al., 2019), and 38% in the rainforest for North East India (Gogoi et al., 2020).

The variation in active and passive carbon pools across different forest types could be attributed to differences in vegetation type, biomass productivity (Sahoo et al., 2019), litter input (Yao et al., 2010) and soil perturbation intensity (Yadav et al., 2019). Land use management practices significantly impacts the active and passive carbon pools (Sahoo et al., 2019). The active and passive carbon pools were significantly greater in the primary forest types. This may be attributed to the higher rate of carbon inputs through forest and root litter, root exudation, minimal soil disturbance and less soil erosion (Kurmi et al., 2020) due to higher level of forest protection. Tillage, slash and burn activities in the jhum land might have reduced the active carbon pools from the soil. Additionally, the relatively higher soil erosion due to absence of larger tree cover might have enhanced the loss of active carbon pool in the bamboo forests and jhum land. The soil carbon fractions like very labile, labile, less labile and non labile carbon were varied considerably across soil depth classes and forest types due to variation in carbon inputs, species diversity, composition and litter inputs. The higher concentration of carbon fractions in the primary forests can be attributed to minimum soil degradation, slow decomposition and variation in chemical composition of trees and shrubs leaf (Nath et al., 2017).

Correlation of SOC stocks with different environmental factors showed that SOC stocks had stronger positive relationship with aboveground biomass, belowground biomass, total nitrogen, soil pH, soil moisture, tree density, Margalef's species richness index, Shannon Weinner's diversity index, phosphorus and tree basal area. Therefore, it can be substantiate that soil organic carbon stock in the study area was significantly influenced by plant biomass, plant structural attributes, plant diversity and soil physical and chemical properties.

CHAPTER-6

VARIATION IN BIOMASS, TOTAL CARBON STOCK AND CARBON SEQUESTRATION POTENTIAL OF THE SELECTED FORESTS OF MIZORAM

6.1 Introduction

Forests occupy 31% of the global land area and are among the richest ecosystems in terms of biodiversity and carbon pool (FAO and UNEP, 2020). Forest ecosystems not only provide livelihood to humans but also play vital role in bioenergy production, carbon sequestration and climate change mitigation (Canadell and Raupach, 2008; Favero et al., 2020). Global estimates reported that forests sequestrate nearly 12% of anthropogenic carbon emissions (Pan et al., 2011; Hurteau et al., 2019). However, the increasing rate of deforestation, land use change and expansion of agriculture in forests has significantly reduced forest area and its carbon pool (Curtis et al., 2018). Also, a global increase in atmospheric CO_2 concentration has negatively affected the functioning of the forest ecosystem and its carbon storage capacity (Cernusak et al., 2013; Sparry et al., 2019). The atmospheric CO_2 concentration has risen at an average rate of 0.33 ppm/year from the pre-industrial level to the end of the 20th century. Nevertheless, since the last two decades, it increases at an alarming rate (2.21 ppm/year) that lead to changes in the earth's surface temperature and global climate. The rapid changes in global climate have led to extensive efforts to find out cost-effective carbon capture technologies. Globally, the natural mechanism of forest carbon sequestration has attracted much attention as it is an inexpensive means of reducing atmospheric CO_2 concentration. Therefore, several countries are now committed to achieving sustainable management of forests and enhancement of forest carbon stocks (UNREDD$^+$).

The participatory countries in the Kyoto Protocol have to monitor the national greenhouse gas emission including changes in forest carbon stock (UNFCCC, 2010). India committed to create an additional carbon sink of 2.5 to 3.0 billion tonnes of CO_2 equivalent by enhancing its forest and tree cover by 2030 under its nationally determined contributions to the Paris agreement. Indeed, based on a projection by forest survey of India, it is observed that the carbon stock in forest and tree cover of India would rise from 28.12 billion tonnes CO2 eq in 2005 to 31.87 billion tonnes CO2 eq in 2030 showing an increase of 3.75 billion tonnes CO2 eq in 25 years (FSI, 2019). Although North-East India provides a wide range of variations in forest types, species diversity, land use patterns, altitude, and climatic conditions, they are fragile and most vulnerable to climate change and land use change. Therefore, it is essential to critically understand the carbon sequestration pattern in different forest types of this region.

India's nationally determined contributions under Paris agreement (2015) makes a commitment to create an additional carbon sink of 2.5 to 3 billion tonnes of CO_2 equivalent through additional forest and tree cover by 2030. Therefore, it is very important to assess the CO_2 sequestration potentiality of all the major forest type so that intensive management can be triggered for optimum mitigation. However, based on a projection by forest survey of India, it is observed that the carbon stock in forest & tree cover of India would rise from 28.12 billion tonnes CO_2 eq in 2005 to 31.87 billion tonne CO_2 eq in 2030 showing an increase of 3.75 billion tonnes CO_2 eq in 25 years. North-East India's forests contribute a significant part of the country's total carbon stock. A GIS based assessment on technically suitable forest lands describes that Peninsular Malaysia and the eastern and north eastern part of India have the highest suitable lands for carbon sequestration among all the countries in tropical Asia (Iverson et al., 1993). Therefore, it is very important to critically understand the carbon sequestration pattern in different forest types of this region. Very few studies have been carried out so far to estimate carbon sequestration pattern in the forests of this region; majority of which mostly concentrates only to the forests of the Barak and Brahmaputra valleys. However, comprehensive studies to understand the plant biodiversity, carbon stock and its sequestration potential of the North-East Indian forests and its relation to the environmental factors are very limited. The varied topographical differences in the hilly state of Mizoram provides the scope for understanding the patterns of the effect of environmental driving factors, altitude and soil nutrients on plant biodiversity, carbon stock and sequestration potential of the different forest types in this region. Apart from the environmental and topographical variations, Mizoram has the highest forest cover among all the Indian states in terms of percentage to total geographical area (ISFR, 2019). However, it is not known whether or not forest cover increase carbon storage as compared to those Indian states which are having highest forest area. The present study aims (1) to assess the variation in biomass and carbon stock in the selected forest types (2) to estimate the carbon sequestration potential in the selected forest types (3) to study the effect of land use change on different carbon components.

6.2 Materials and Methods

6.2.3 Study area

In the present study, six major forest types were selected in four districts of Mizoram based on the forest classification described by Singh et al. in 2002. These were namely (a) Tropical wet evergreen forest (TWEF) (b) Montane sub tropical forest (MSTF) (c) Temperate forest (TF) (d) Bamboo forest (BF) (e) Quercus forest (QF) (f) Jhum land (JL). The sampling sites of the tropical wet evergreen forest were selected in the undisturbed core areas of the Dampa tiger reserve forest in Mamit District. Whereas, the sampling sites of the Montane sub tropical forest were selected in the Reiek Community forest which is situated in the edge of Mamit and Aizawl District of the state. The sampling sites of the Temperate forest were selected in Phawngpui National Park. Sampling sites of the Quercus forest were selected in and around the Lengteng

Wildlife Century situated in Champhai District. Sampling sites of bamboo forest and Jhum fallow were selected in the Lengpui and Sakawrtuichhun area of Aizawl District respectively. The age of the jhum fallows were ranged between 15 to 20 years.

6.2.4 Biomass sampling

The first round of field survey was carried out in the year 2016 and the same was repeated after two years. In each forest type, three major permanent plots of 250 m × 250 m size were demarcated following ISRO-GBP/NCP-VCP protocol (Singh and Dadhwal, 2009) wherein, biomass sampling were carried out. The major plots were selected in such a way that the effect of anthropogenic disturbance could be negligible. Reconnaissance surveys were carried out before selecting the sampling sites to find out homogeneous, least disturbed forest sites.

Within each major permanent plot four 31.62 m x 31.62 m sub plots were demarcated at each corner of the permanent plots for tree, liana and wild banana biomass and vegetation inventory. Within each sub plot, two 5m x 5m size quadrats were established for enumerating shrubs. Similarly, for herb and litter enumeration two 1m x 1m size quadrats were established within the shrub plots. Thus, vegetation and biomass data were collected establishing a sum of 12 tree plots, 24 shrub plots, 48 herb and 48 litter plots in each major forest types. The pictorial representation of sampling design is shown in the **Figure 1**.

All tree individuals of ≥ 10 cm diameter within each sub-plot were tagged and their diameter (DBH) at breast height was measured at 1.37 m above the ground. Tree individuals with DBH < 10 cm were considered as regenerating plants. Based on the size of their DBH and height, tree species were categorized into (a) seedlings (height up to 20 cm), (b) saplings (height > 20 cm but DBH < 10 cm), and (c) trees (DBH >10 cm) as described by Sundriyal and Sharma (1996). Diameter of bamboo culms was measured at the middle part of the next inter-node if 1.37 m fell on node or near to node portion of culms. Basal diameter of shrubs and tree saplings were measured at 10 cm above the ground using a digital vernier calliper. Standing and fallen deadwoods present in the tree sample plots were measured in the field. The required numerical parameters like height, species name, DBH for standing deadwoods and DBH (top, mid, bottom), length, species name, as well as physical condition (cavity, not rotten or decomposing) for fallen deadwoods were recorded in the field itself. The tree roots and stumps of ≥10 cm were also considered as deadwood. All litters and herb individuals present inside the respective 1 m x 1 m quadrates were collected and the fresh weights were recorded in the field itself. From each respective plot 100 gm of litter and herb sample were collected for subsequent laboratory analysis.

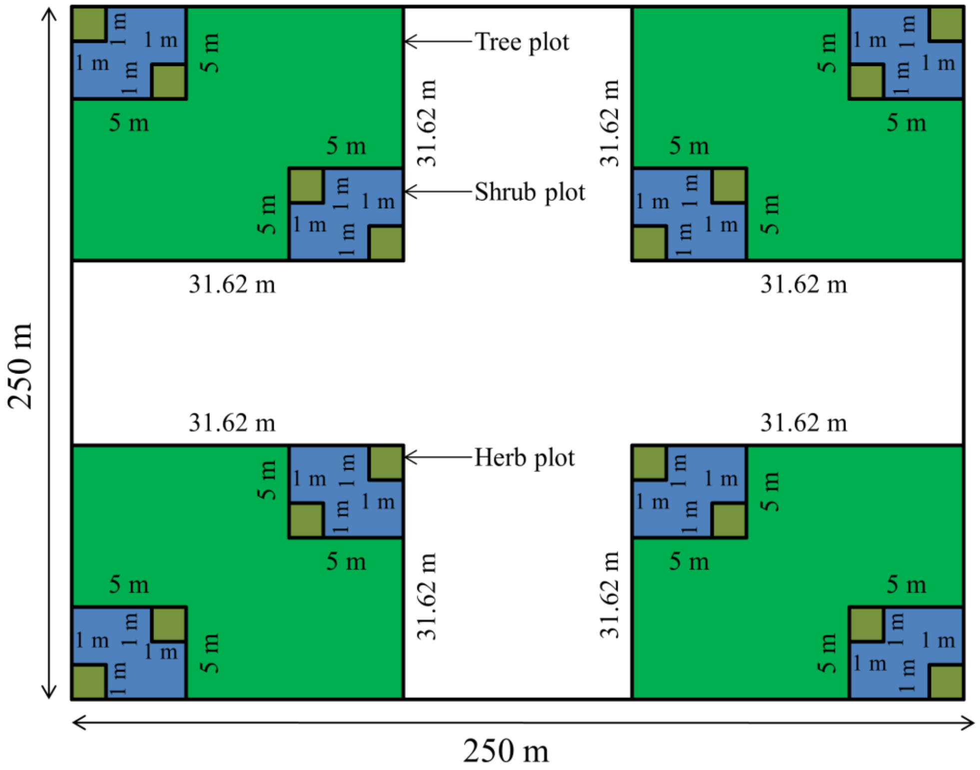


Figure 6.1 Layout of the sampling plots and their respective size. (The figure is showing the number and size of tree, shrub and herb sampling plots within the 250m x 250m major plot).

6.2.5 Soil Sampling

For soil sampling, four random locations within the 250 m x 250 m sized major plots were selected. Soil samples were collected from three soil depths viz., 0-15 cm, 15-30 cm, and 30-45 cm and analysed for active and passive soil organic carbon and other physical and chemical properties. Thus, a sum of 36 soil samples from each studied forest (4 locations within a plot x 3 depth x 3 major plot) was collected for analyzing SOC and other soil parameters. Equal numbers of soil samples from the same depths were collected for soil bulk density estimation using a soil corer of known volume. After collection, samples were placed in plastic bags and labelled before brought to the laboratory for further processing. They were later air-dried at room temperature before being passed through a 2 mm sieve to remove coarse rocks, pebbles and plant debris.

6.2.6 Estimation of Soil Organic Carbon Stock

Soil Bulk density was determined by corer method (Brady and Weil, 2008). The soil samples were air dried and roots and other plant parts were removed and then kept in hot air oven at 105^{o}C for drying till the constant weight was achieved. After attaining constant weight, it was divided by the volume and finally the bulk density value of soil was obtained. The total carbon (TC) in the soil samples were determined by using CHNS analyzer. Inorganic soil carbon (SIC) was analyzed using dilute HCl (Jakson, 1973). Total organic carbon (TOC) in soil was estimated by subtracting the concentration of SIC from TC.

Soil carbon stock for each depth class was estimated by multiplying with corresponding values of fine bulk density and SOC content. SOC stock was calculated following the formula given by IPCC, (2003).

$$C\ storage = \sum_{\text{horizon}=1}^{\text{horizon}=n} \quad (SOC \times Bulk\ Density \times Depth \times (1 - frag) \times 10)\ horizon$$

Where,

SOC = representative soil organic carbon stock, Mg C ha^{-1}, SOC horizon = SOC stock for a constituent soil horizon, Mg C ha^{-1}, SOC = concentration of soil organic carbon, g C (kg soil)$^{-1}$, Bulk Density = soil mass per sample volume, Mg soil m^{-3}, Depth = horizon depth or thickness of soil layer in meter, Frag = % volume of coarse fragments/100, dimensionless.

6.2.7 Biomass Estimation

Tree biomass was estimated using a diameter-only common allometric equation developed for mixed species tree biomass estimation in North East India. A recent study by Nath et al., (2019) reported that the four commonly used generic models developed by Chambers et al. (2001); Brown et al., (1989); Chave et al., (2005); Chave et al., (2014) overestimated biomass stocks by 300–591 kg tree^{-1} in the North-East Indian condition. Although, height is a valuable addition when estimating biomass, the diameter-only equation provides better biomass estimates than diameter-height allometry (Williams and Schreuder, 2000). Therefore, to get accurate site specific estimation, we followed the diameter-only allometric model best fit model suggested by Nath et al., (2019). Small tree biomass was estimated by following Chaturvedi et al. 2012). Biomass of shrubs was estimated using allometric equation developed by Ali et al., (2015). For deadwood biomass estimation, we followed the methodology suggested by Cros and Lopez, (2009). Volume of the dead logs and stumps were first measured following the allometric equation developed by them. Stem length, diameter (mid), and decaying status of each fallen or standing deadwood piece were recorded in the field to estimate their volume. Then, the deadwood volume was multiplied by respective wood density values of different decaying status (freshly cut = 0.48 g cm^{-3}, moderately decomposed = 0.35 g cm^{-3}, highly decomposed = 0.25 g cm^{-3}, and burnt = 0.19 g cm^{-3}) to estimate the deadwood biomass. Liana (Hairiah et al., 2011) and banana (Addo-Fordjour and Rahmad, 2013) biomass was estimated using allometric equation developed for a similar ecological region. Biomass of the bamboo species was estimated using allometric equation developed by Singnar et al., (2017) for North East India. For litter and herb, all the standing biomass present in the quadrats was first measured in the field and 100^{-g} fresh samples were brought to the laboratory for dry biomass estimation. Tree belowground biomass was estimated applying different root to shoot ratio for different forest types (Mokany et al., 2006). Belowground biomass of bamboo, wild banana, shrub, small tree and liana was estimated using root to shoot ratio suggested by Cairns et al,. (1997); Ravindranath and Ostwald, (2008). Biomass in all the compartments was finally extrapolated and scaled to per hectare basis.

Table 6.1 Allometric equations used in this study.

Biomass component	**Allometric equation**	**Reference**
Tree	$AGB_{est} = 0.18D^{2.16} \times 1.32$	Nath et al. (2019)
Small tree	$AGB = 3.344 + (0.443 \times (\ln((DBH)^2)))$	Chaturvedi et al. 2012)
Liana	$AGB = \exp(-1.484 + 2.657 \times (\ln(DBH)))$	Schnitzer et al. (2006)
Shrub	$AGB = \exp(-3.5 + 1.65 \times \ln(CD) + 0.842 \times \ln(H)$	Ali et al. (2015)
Dead wood	$V = (L \times \pi \times D_m^2)/4$	Teissier du Cros and Lopez (2009)
Bamboo	$\ln(AGB) = \ln(\alpha) + \beta(\ln D^2) + \varepsilon$	Singnar et al. (2017)
Wild banana	$AGB = 0.0303 \times D^{2.1345}$	Hairiah et al. (2011)

6.2.8 Estimation of Biomass Carbon Stock

Carbon content in herb and litter biomass was analyzed following dry ashing method (Campbell and Plank 1998) and then the value was multiplied with the respective dry biomass amount. Biomass carbon in rest of the plant components was estimated by multiplying the default value of 47% with the total biomass amount (IPCC, 2006). The total carbon stock in each major forest type was the sum of carbon stocks in all the biomass compartments and the soil organic carbon stock.

6.2.9 Estimation of Carbon Sequestration

Carbon sequestration rate in each of the forest type was estimated following "Stock Difference" method based on the IPCC guidelines (IPCC, 2003, 2006). The stock difference method includes all process that brings about changes in a given pool. The carbon stock was estimated for each pool at two points in time, namely t_1 and t_2**.** In this study the duration between the two points was two years (t_1 =2016 and t_2 = 2018). Thus, the estimated stock at t_2 was deducted from the estimated stock at t_1 and the difference was divided by the number of years between the two periods ($t_2 – t_1$). The "Stock- Difference" was estimated separately for each carbon pool and later summed for each forest type.

6.3 Statistical analyses

Descriptive statistical tools were used to calculate the mean and standard deviation of the dataset. ANOVA and correlation analysis was carried out by SPSS 21.0 (SPSS Inc. Chicago, USA). One-way analysis of variance (ANOVA) was done to compare the means and the Tukey's honest significance difference (HSD) test at $p<0.05$ level was performed to find out the significant difference between the means.

6.4 Results

6.4.1 Distribution of biomass stocks in the six forest types

Total biomass stock was significantly highest in the tropical wet evergreen forests followed by temperate forest, montane sub tropical forest, quercus forest, bamboo forest and lowest in the jhum land. Both aboveground and belowground biomass also followed the same trend as the total biomass stock. However, non living biomass was found to be highest in tropical wet evergreen forest followed by montane sub tropical forest, temperate forest, quercus forest, bamboo forest and jhum land **(Table 6.2)**.

Partitioning of biomass stocks in different ecosystem components showed that living woody aboveground component contributed the highest amount of biomass in all the foresttypes followed by living belowground component, coarse dead wood component, forest litter component, living non woody aboveground component and living non woody belowground component. Within the six forest types, tropical wet evergreen forest had highest amount of both aboveground and belowground biomass followed by temperate forest, montane sub tropical forest, quercus forest, bamboo forest and it was lowest in jhum land. Living non woody aboveground and belowground biomass was recorded highest jhum land followed by bamboo forest, quercus forest, temperate forest, montane sub tropical forest and lowest in the tropical wet evergreen forest. However, coarse dead wood and litter biomass was highest in the tropical wet evergreen forest followed by montane sub tropical forest, temperate forest, quercus forest, bamboo forest and jhum land **(Table 6.3)**.

Among the different plant component, trees had the highest amount of biomass in all the forest types followed by small trees, non woody shrubs and herbs. Liana biomass was present only in the primary forest types. However, it was recorded highest in the tropical wet evergreen forest followed by montane sub tropical forest, temperate forest and quercus forest. Bamboo and banana biomass was present only in secondary forests. Bamboo biomass was higher in the bamboo forest whereas, banana biomass was higher in the jhum fallow **(Table 6.4)**.

Table 6.2 Distribution of total biomass stocks in the selected forest types of Mizoram.

Forest type	**Living Biomass**		**Non Living Biomass**	**Total Biomass**
	Aboveground biomass	**Belowground biomass**		
Tropical wet evergreen forest	326.67 ± 13.56^{a}	78.78 ± 3.25^{a}	46.48 ± 9.67^{a}	451.93 ± 22.21^{a}
Montane sub-tropical forest	219.24 ± 48.12^{b}	52.91 ± 11.48^{b}	38.48 ± 2.68^{a}	310.63 ± 40.18^{b}
Temperate forest	240.52 ± 26.28^{b}	57.87 ± 6.32^{b}	29.61 ± 0.71^{a}	328.00 ± 33.11^{b}
Quercus forest	200.82 ± 5.06^{b}	59.97 ± 1.51^{b}	22.48 ± 0.73^{a}	283.27 ± 7.17^{b}
Bamboo forest	80.36 ± 4.23^{c}	17.66 ± 0.88^{c}	6.21 ± 0.42^{b}	104.23 ± 5.52^{c}
Jhum land	31.22 ± 0.72^{c}	7.11 ± 0.39^{c}	2.49 ± 0.54^{b}	40.81 ± 1.54^{c}
LSD (p<0.05)	**71.54**	**17.13**	**12.72**	**91.54**

Note: Values are given as mean ± standard deviation. Different alphabetical letters indicate significant difference at $P<0.05$ within the same column.

Table 6.3 Biomass stocks (Mg ha^{-1}) in different ecosystem components in the major forest types of Mizoram.

Ecosystemcomponents	**FORESTTYPE**					
	TWEF	**MSTF**	**TF**	**QF**	**BF**	**JL**
Living woody AGB	322.6±23.3^{a}	214.6±83.2^{ab}	234.4±45.71^{ab}	196.09±9.03^{b}	72.34±6.85^{c}	18.34±1.96^{c}
Living woody BGB	77.79±5.59^{a}	51.84±19.9^{a}	56.50±11.0^{a}	58.85±2.71^{a}	15.88±1.50^{b}	4.75±0.47^{b}
Living non-woody AGB	4.05± 0.11^{d}	4.59±0.23^{d}	6.13±0.25^{c}	4.73±0.33^{d}	8.02± 0.48^{b}	12.88±0.72^{a}
Living non-woody BGB	0.99±0.04^{d}	1.07±0.09^{d}	1.37±0.11^{c}	1.12±0.10^{cd}	1.79±0.03^{b}	2.36±0.20^{a}
Coarse dead wood biomass	36.02±16.8^{a}	29.59±4.24^{ab}	22.49±1.44^{abc}	15.79±1.51^{cd}	4.80±0.65^{cd}	2.10±0.89^{d}
Litter biomass	10.47±0.54^{a}	8.89±0.56^{b}	7.12±0.31^{c}	6.69±0.57^{c}	1.41±0.08^{d}	0.39±0.04^{d}

Note: Values are given as mean ± standard deviation. Different alphabetical letters indicate significant difference at $P<0.05$ within the same row. TWEF-tropical wet evergreen forest, MSTF- montane sub-tropical forest, TF-temperate forest, BF-bamboo forest, QF-quercus forest, JL-jhum land, AGB- above ground biomass, BGB-belowground biomass.

Table 6.4 Biomass stocks (Mg ha^{-1}) indifferent vegetation components in the major forest types of Mizoram.

	FOREST TYPE					
Vegetation components	**TWEF**	**MSTF**	**TF**	**QF**	**BF**	**JL**
Tree	392.63 ± 17.18^{a}	259.57 ± 59.77^{b}	285.81 ± 32.50^{b}	251.06 ± 6.68^{b}	73.85 ± 4.29^{c}	12.20 ± 1.62^{c}
Small tree (DBH<10cm)	5.66 ± 0.18^{a}	5.05 ± 0.49^{a}	3.49 ± 0.43^{bc}	2.87 ± 0.14^{bc}	2.27 ± 0.43^{b}	3.72 ± 0.23^{c}
Non woody shrub	4.07 ± 0.09^{a}	4.40 ± 0.22^{a}	5.71 ± 0.27^{b}	4.63 ± 0.26^{a}	6.06 ± 0.30^{b}	7.58 ± 0.39^{c}
Herb	0.97 ± 0.02^{a}	1.26 ± 0.30^{ab}	1.79 ± 0.14^{ab}	1.22 ± 0.02^{ab}	2.14 ± 0.29^{b}	4.98 ± 0.82^{c}
Liana	2.11 ± 0.31^{ab}	1.86 ± 0.26^{ab}	1.59 ± 0.36^{ab}	1.00 ± 0.14^{ac}	NA	NA
Bamboo	NA	NA	NA	NA	12.09 ± 0.56^{a}	7.17 ± 0.54^{b}
Banana	NA	NA	NA	NA	1.60 ± 0.28^{a}	2.68 ± 0.21^{b}

Note: Values are given as mean ± standard deviation. Different alphabetical letters indicate significant difference at $P<0.05$ within the same column. TWEF-tropical wet evergreen forest, MSTF- montane sub-tropical forest, TF-temperate forest, QF-quercus forest, BF-bamboo forest, JL-jhum land.

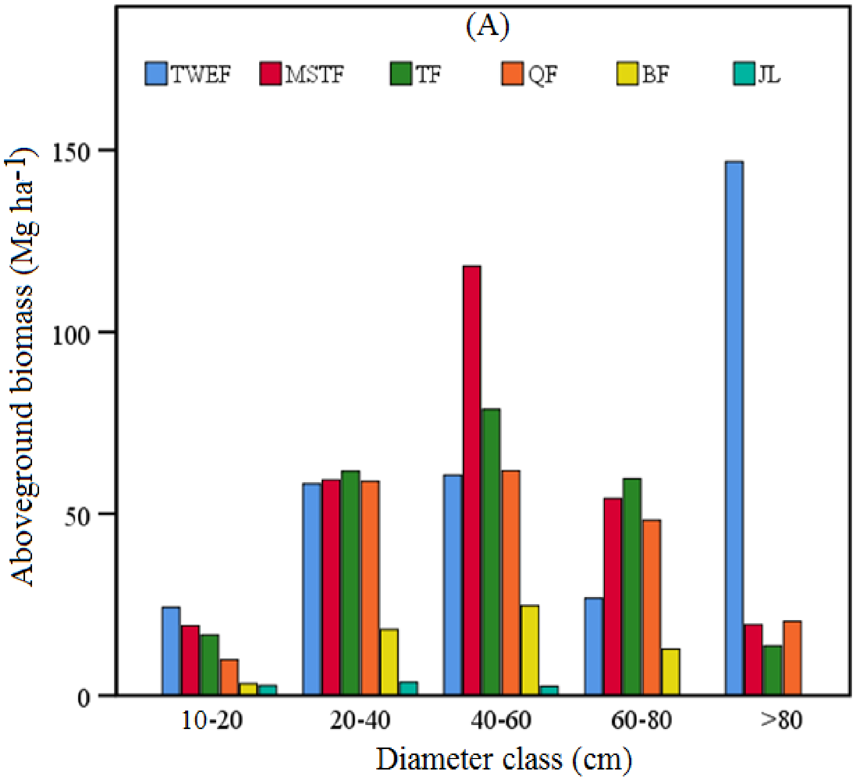


Figure 6.2 Distribution of aboveground biomass across five diameter classes of the selected forest types.

The distribution of aboveground biomass across five diameter classes showed that mid diameter classes (40-60 cm) possessed the highest amount of biomass in all the forest types. Trees of more than 60 cm DBH were absent in the jhum land and more than 80 cm DBH were absent in the bamboo forest **(Figure 6.2)**.

6.4.2 Distribution of carbon stocks in the six forest types

Ecosystem carbon stock was highest in the tropical wet evergreen forests followed by temperate forest, montane sub tropical forest, quercus forest, bamboo forest and jhum land. Soil organic carbon to total ecosystem carbon was found to be highest in the jhum land followed by bamboo forest, temperate forest, montane sub tropical forest, quercus forest and it was lowest in the tropical wet evergreen forest. Partitioning of the different biomass component showed that both living and non living biomass components showed the same trend as the ecosystem carbon stock. However, soil organic carbon stock was found to be highest in the temperate forests followed by tropical wet evergreen forest, montane sub tropical forest, quercus forest, bamboo forest and jhum land **(Table 6.5)**.The distribution of aboveground biomass carbon across five DBH classes revealed that mid diameter class (40-60 cm) constituted the highest amount of carbon storage. Trees of more than 60 cm DBH were absent in the jhum land and more than 80 cm DBH were absent in the bamboo forest **(Figure 6.3)**.

Table 6.5 Distribution of total carbon stock in the six forest types.

Forest type	**Living Biomass**		**Non living biomass carbon**	**SOC Stock**	**Ecosystem carbon stock**	**SOC:TEC**
	AGBC	**BGBC**				
Tropical wet evergreen forest	153.53 ± 6.46^{a}	37.03 ± 1.53^{a}	21.22 ± 4.55^{a}	161.61± 7.66^{a}	373.39 ± 16.69^{a}	43.29 ± 0.94^{a}
Montane sub-tropical forest	102.80 ± 22.53^{b}	24.87 ± 5.39^{b}	17.55 ± 1.25^{a}	147.06 ± 7.25^{b}	292.28 ± 34.80^{bd}	51.35 ± 4.44^{b}
Temperate forest	112.85 ± 12.35^{b}	27.20 ± 2.97^{b}	13.49 ± 0.34^{ab}	178.90 ±3.24^{c}	332.44 ± 12.84^{ab}	54.03 ± 2.84^{bc}
Quercus forest	94.25 ± 2.37^{b}	28.19 ± 0.71^{b}	10.16 ± 0.35^{b}	123.41 ± 3.56^{d}	256.02 ± 6.92^{c}	48.20 ± 0.10^{ab}
Bamboo forest	37.53 ± 1.96^{c}	8.30 ± 0.41^{c}	2.83 ± 0.19^{c}	72.62 ± 3.54^{e}	121.28 ± 2.88^{d}	59.84 ± 2.23^{c}
Jhum land	14.13 ± 0.43^{c}	3.34 ± 0.18^{c}	0.99 ± 0.17^{c}	60.57 ± 0.55^{d}	79.02 ± 0.27^{c}	76.66 ± 0.92^{d}
LSD ($p<0.05$)	**33.55**	**8.05**	**5.97**	**15.26**	**52.03**	**7.39**

Table 6.6 Distribution of carbon stocks in the different ecosystem components across six forest types of Mizoram.

Ecosystemcomponents	**CARBONSTOCK(Mg ha^{-1}) IN SIX FOREST TYPES**					
	TWEF	**MSTF**	**TF**	**QF**	**BF**	**JL**
LivingwoodyAGBC	151.63± 6.34^{a}	100.88 ± 22.59^{b}	110.16 ± 12.42^{b}	92.16 ± 2.45^{b}	34.00 ± 1.86 ^{c}	8.62 ± 0.53^{c}
LivingwoodyBGBC	36.56± 1.52^{a}	24.37 ± 5.41^{b}	26.55 ± 2.99^{b}	27.66± 0.74^{b}	7.46± 0.41^{c}	2.23 ± 0.13^{c}
Livingnon-woodyAGBC	1.90 ± 0.14^{a}	1.91 ± 0.08^{a}	2.69 ± 0.07^{b}	2.09 ± 0.09^{d}	3.53± 0.10^{c}	5.51 ± 0.11^{e}
Livingnon-woodyBGBC	0.47 ± 0.01^{a}	0.50 ± 0.02^{a}	0.65± 0.03^{b}	0.53 ± 0.03^{a}	0.84 ± 0.01^{c}	1.11 ± 0.05^{d}
Coarsedeadwood biomass carbon	16.93 ± 4.55^{a}	13.91 ± 1.15^{ab}	10.57 ± 0.39^{b}	7.42 ± 0.41^{c}	2.26 ± 0.18^{cd}	0.83 ± 0.17^{d}
Litterbiomass carbon	4.29 ± 0.13^{a}	3.65 ± 0.13^{b}	2.92± 0.07^{c}	2.74± 0.14^{c}	0.58 ± 0.02^{d}	0.16 ± 0.01^{e}

Note: Values are given as mean ± standard deviation. Different alphabetical letters indicate a significant difference at P<0.05 within the same row. TWEF-tropical wet evergreen forest, MSTF- montane sub-tropical forest, TF-temperate forest, QF-quercus forest, BF-bamboo forest, JL-jhum land, AGBC- aboveground biomass carbon, BGBC-belowground biomass carbon.

Table 6.7 Carbon stocks (Mg ha^{-1}) in different vegetation components in the major forest types of Mizoram.

Vegetation components	FOREST TYPE						***p* value**
	TWEF	**MSTF**	**TF**	**QF**	**BF**	**JL**	
Tree (DBH<10cm)	195.43 ± 8.52^{a}	134.24 ± 29.09^{b}	144.28 ± 14.99^{l}	129.23 ± 2.24^{b}	41.84 ± 2.03^{c}	11.16 ± 0.72^{c}	0.00
Small tree (DBH<10cm)	2.66 ± 0.08^{a}	2.38 ± 0.23^{a}	1.64 ± 0.20^{bc}	1.35 ± 0.07^{bc}	1.07 ± 0.20^{b}	1.75 ± 0.11^{c}	0.00
Non woody shrub	1.92 ± 0.04^{a}	2.07 ± 0.10^{a}	2.69 ± 0.13^{b}	2.18 ± 0.12^{a}	2.85 ± 0.14^{b}	3.56 ± 0.18^{c}	0.00
Herb	0.45 ± 0.11^{a}	0.35 ± 0.01^{a}	0.65 ± 0.05^{a}	0.44 ± 0.01^{a}	0.77 ± 0.10^{a}	1.79 ± 0.29^{b}	0.00
Liana	0.99 ± 0.15^{a}	0.87 ± 0.12^{ab}	0.75 ± 0.17^{ab}	0.47 ± 0.06^{b}	NA	NA	1.10
Bamboo	NA	NA	NA	NA	5.68 ± 0.26^{a}	3.37 ± 0.25^{b}	0.00
Banana	NA	NA	NA	NA	0.75 ± 0.13^{a}	1.26 ± 0.10^{b}	0.04

Note: Values are given as mean ± standard deviation. Different alphabetical letters indicate significant difference at $P<0.05$ within the same raw. TWEF-tropical wet evergreen forest, MSTF- montane sub-tropical forest, TF-temperate forest, QF-quercus forest, BF-bamboo forest, JL-jhum land.

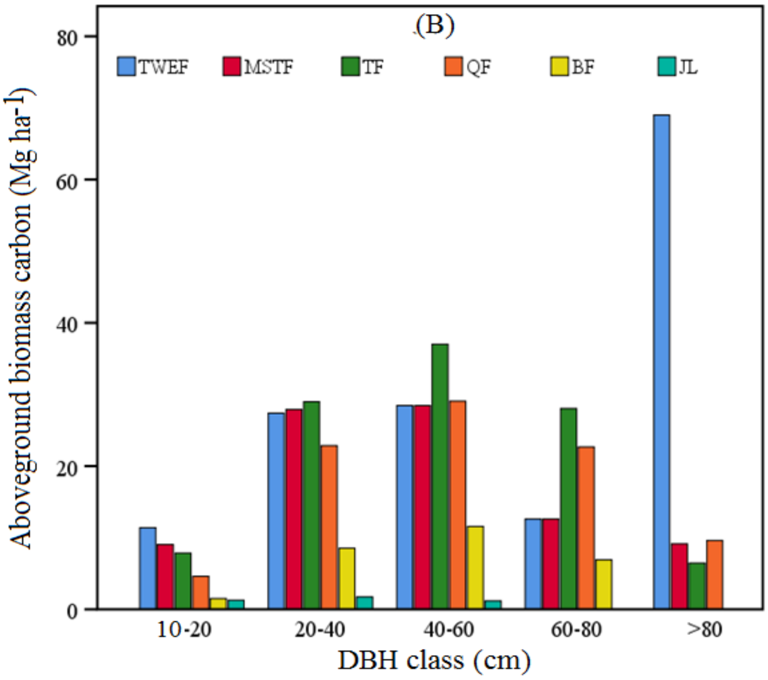


Figure 6.3 Distribution of aboveground biomass carbon across different diameter classes of the six forest types.

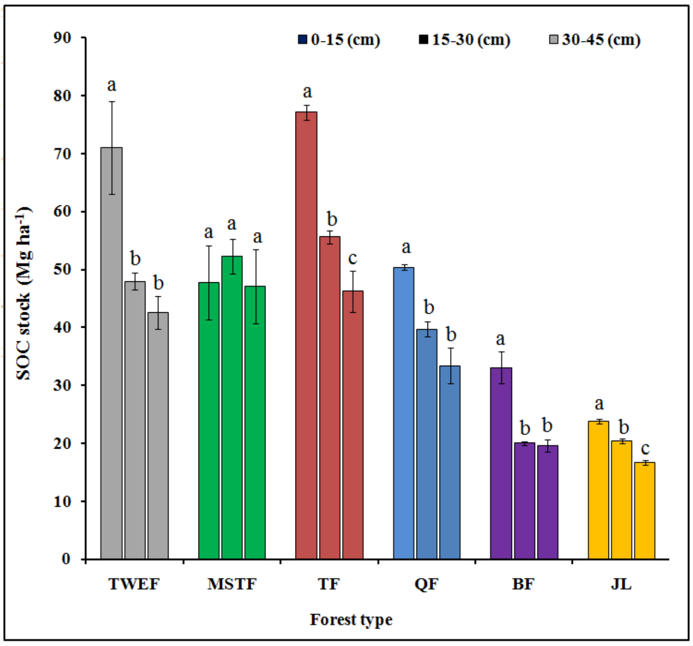


Figure 6.4 Soil organic carbon stock across three depth classes. Different letters represent significant difference between the mean values of three depth classes within the same forest type.

The distribution of living woody aboveground and belowground biomass carbon stock was highest in the tropical wet evergreen forest followed by temperate forest, montane sub tropical forest, quercus forest, bamboo forest and jhum land. Non living aboveground and belowground biomass was highest in the jhum land followed by bamboo forest, temperate forest, quercus forest, montane sub tropical forest and tropical wet evergreen forest. However, coarse dead wood and litter biomass was highest in the tropical wet evergreen forest followed by montane sub tropical forest, temperate forest, quercus forest, bamboo forest and jhum land **(Table 6.6)**.

Partitioning of carbon stocks in different plant component showed that trees contributed the highest amount of carbon stock followed by small trees, non woody shrubs and herbs. Liana was present only in the primary forest types. However, liana carbon stock was highest in the tropical wet evergreen forest followed by montane sub tropical forest, temperate forest and quercus forest. Bamboo and banana were present only in the secondary forest types. Bamboo carbon stock was highest in the bamboo forest than the jhum land and banana carbon stock was highest in the jhum lands than the bamboo forest **(Table 6.7)**. Soil organic carbon stock decreased with the increasing soil depth in all the forest types **(Figure 6.4)**. However, soil organic carbon stock (0-45 cm) was found to be highest in the temperate forests followed by tropical wet evergreen forest, montane sub tropical forest, quercus forest, bamboo forest and jhum land **(Table 6.5)**.

6.4.3 Rate of carbon sequestration in different forest types

The rate of ecosystem carbon sequestration was found to be highest in the primary forests than the secondary forests. It was recorded highest in the tropical wet evergreen forest (13.95 Mg ha yr^{-1}) followed by montane sub tropical forest (12.95 Mg ha yr^{-1}), temperate forest (10.88 Mg ha yr^{-1}), quercus forest (10.48 Mg ha yr^{-1}), bamboo forest

(9.25 Mg ha yr^{-1}) and jhum land (7.55 Mg ha yr^{-1}) **(Figure 6.4)**. Among all the ecosystem components, carbon sequestration rate was highest in the living woody aboveground component followed by living woody belowground biomass, coarse dead wood, litter, living non woody aboveground biomass, soil organic carbon and living non woody belowground biomass (**Table 6.8)**.

Table 6.8 Variation in carbon sequestration rate (Mg ha^{-1} yr^{-1}) in the different ecosystem components across six forest types.

	CARBON SEQUESTRATION					
ECOSYSTEMCOMPONENTS	**TWEF**	**MSTF**	**TF**	**QF**	**BF**	**JL**
Living woody AGBC sequestration	5.25 ± 0.50^{a}	5.59 ± 0.42^{a}	4.91 ± 0.15^{a}	5.15 ± 0.64^{a}	4.60 ± 0.39^{a}	3.53 ± 0.09^{a}
Living woody BGBC sequestration	1.30 ± 0.13^{a}	1.37 ± 0.10^{a}	1.23 ± 0.04^{a}	1.30 ± 0.14^{a}	1.10 ± 0.09^{a}	0.91 ± 0.03^{b}
Living non woody AGBC sequestration	1.01 ± 0.08^{ab}	1.24 ± 0.20^{ab}	0.86 ± 0.10^{a}	0.79 ± 0.07^{d}	1.52 ± 0.04^{bd}	1.87 ± 0.16^{d}
Living non woody BGBC sequestration	0.21 ± 0.01^{ab}	0.24 ± 0.05^{abd}	0.15 ± 0.03^{ac}	0.12 ± 0.02^{d}	0.28 ± 0.01^{bd}	0.33 ± 0.05^{d}
Coarse dead wood biomass carbon sequestration	2.74 ± 1.28^{a}	1.89 ± 0.55^{ab}	1.37 ± 0.27^{ab}	0.99 ± 0.10^{b}	0.63 ± 0.16^{b}	0.15 ± 0.07^{b}
Litter biomass carbon sequestration	2.17 ± 0.11^{a}	1.26 ± 0.18^{bd}	1.15 ± 0.23^{bd}	0.94 ± 0.14^{cd}	0.47 ± 0.16^{cf}	0.07 ± 0.02^{ef}
Soil organic carbon sequestration	0.61 ± 0.09^{a}	0.70 ± 0.09^{a}	0.58 ± 0.04^{a}	0.24 ± 0.06^{b}	0.54 ± 0.13^{a}	0.29 ± 0.02^{b}

Note: Values are given as mean ± standard deviation. Different alphabetical letters indicate a significant difference at $P<0.05$ within the same row. TWEF-tropical wet evergreen forest, MSTF- montane sub-tropical forest, TF-temperate forest, QF-quercus forest, BF-bamboo forest, JL-jhum land, AGBC- aboveground biomass carbon, BGBC-belowground biomass carbon.

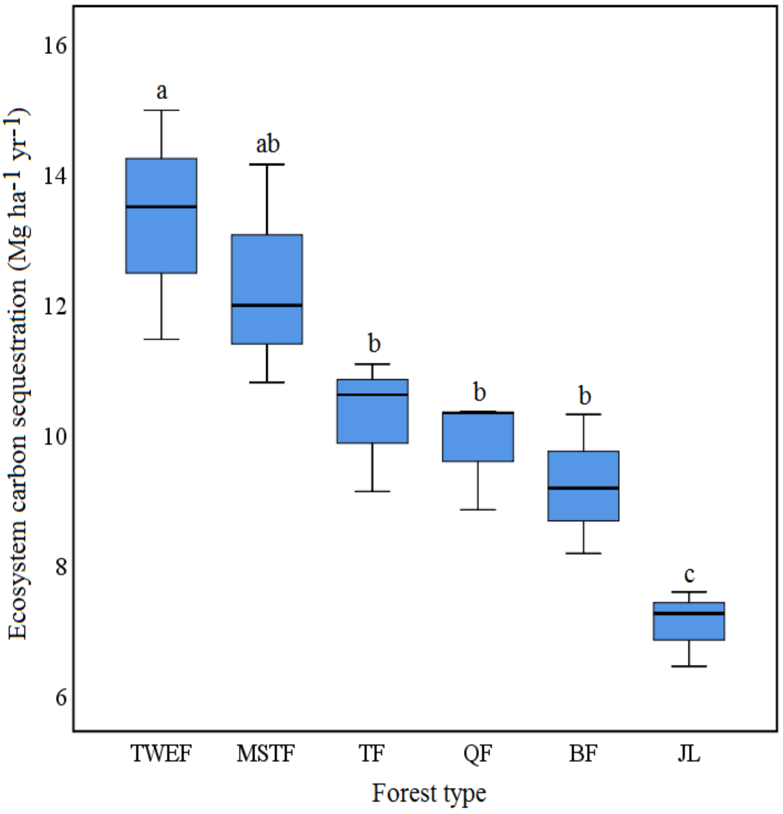


Figure 6.5 Ecosystem carbon sequestration rate in the six forest types**.**

The rate carbon sequestration in the living woody aboveground and belowground biomass was found to be highest in the montane sub tropical forests followed by tropical wet evergreen forest, quercus forest, temperate forest, bamboo forest and jhum land. However, the rate of carbon sequestration in the living non woody biomass was found to be highest in the jhum land followed by bamboo forest, montane sub tropical forest, tropical wet evergreen forest, temperate forest and quercus forest. Carbon sequestration rate in the coarse dead wood and litter biomass was recorded highest in the tropical wet evergreen forest followed by montane sub tropical forest, temperate forest, quercus forest, bamboo forest and jhum land. Soil organic carbon sequestration rate was highest in the montane sub tropical forest followed by tropical wet evergreen forest, temperate forest, bamboo forest, jhum land and quercus forest **(Table 6.8)**.

6.4.4 Effect of land use change on carbon sequestration

Among all the primary forest types, the maximum loss in total ecosystem carbon sequestration rate was observed when tropical wet evergreen forest were converted to jhum land followed by montane sub tropical forest to jhum land, Tropical wet evergreen forest to bamboo forest, montane sub tropical forest to bamboo forest, temperate forest to jhum land, quercus forest to jhum land, temperate forest to bamboo forest and quercus forest to bamboo forest **(Table 6.9)**.

Partitioning of the different ecosystem component in respect of loss in carbon sequestration rate following forest conversion from primary forests to secondary forests showed that the maximum loss in the living woody aboveground and belowground biomass carbon component was observed when montane sub tropical forest was converted to jhum land and the lowest rate was observed when temperate forest was converted to jhum land. In case of living non woody aboveground biomass carbon component, the maximum loss was observed when quercus forest was converted to jhum land and the lowest rate of loss was observed when montane sub tropical forest was converted to bamboo forest. In case of living non woody belowground biomass carbon component, the maximum loss was observed when quercus forest was converted to jhum land and the loss was minimum when montane sub tropical forest was converted to bamboo forest. In case of coarse dead wood and litter biomass carbon components, the maximum loss was observed when tropical wet evergreen forest was converted to jhum land and the loss was minimum when quercus forest was converted to bamboo forest. The loss of soil organic carbon sequestration per year was highest when montane sub tropical forest was converted to jhum land and it was lowest when quercus forest was converted to bamboo forest **(Table 6.9)**.

Table 6.9 Changes in living woody aboveground biomass carbon (LWABC), living woody belowground biomass carbon (LWBBC), living non-woody aboveground biomass carbon (LNWABC), living non-woody belowground biomass carbon (LNWBBC), coarse dead wood biomass carbon (CDWBC), litter biomass carbon (LBC), soil organic carbon (SOC) and total ecosystem carbon (TEC) of different forest types after land use conversion.

Land use change	**Living biomass carbon**				**Non living biomass carbon**		**SOC**	**TEC**
	LWABC	LWBBC	LNWABC	LNWBBC	CDWBC	LBC		
TWEF to JL	-1.72 ±0.57	-0.39 ± 0.15	-0.86 ± 0.24	-0.11 ± 0.06	-2.59 ± 1.35	-2.10 ± 0.12	-0.37 ± 0.12	-6.20 ± 1.34
MSTF to JL	-2.07 ±0.48	-0.47 ± 0.12	-0.63 ± 0.31	-0.09 ± 0.09	-1.73 ± 0.53	-1.20 ± 0.16	-0.46 ± 0.06	-5.20 ± 1.07
TF to JL	-1.39 ±0.13	-0.32 ± 0.04	-1.01 ± 0.13	-0.18 ± 0.04	-1.22 ± 0.21	-1.09 ± 0.21	-0.34 ± 0.07	-3.17 ± 0.25
QF to JL	-1.63 ±0.55	-0.39 ± 0.14	-1.09 ± 0.20	-0.20 ± 0.06	-0.84 ± 0.17	-0.87 ± 0.12	-0.30 ± 0.19	-2.74 ± 0.66
TWEF to BF	-0.65 ±0.59	-0.20 ± 0.16	-0.51 ± 0.11	-0.07 ± 0.02	-2.11 ± 1.31	-1.70 ± 0.18	-0.32 ± 0.11	-4.41 ± 1.64
MSTF to BF	-1.00 ±0.80	-0.27 ± 0.19	-0.28 ± 0.23	-0.05 ± 0.06	-1.25 ± 0.42	-0.79 ± 0.09	-0.41 ± 0.11	-3.40 ± 1.21
TF to BF	-0.32 ±0.24	-0.13 ± 0.06	-0.65 ± 0.09	-0.13 ± 0.03	-0.74 ± 0.41	-0.68 ± 0.14	-0.29 ± 0.07	-1.37 ± 0.06
QF to BF	-0.56±0.55	-0.20 ± 0.22	-0.73 ± 0.09	-0.16 ± 0.03	-0.36 ± 0.11	-0.47 ± 0.18	-0.26 ± 0.13	-0.94 ± 0.91

Note: mean values are expressed in Mg ha^{-1} yr^{-1}.

6.5 Discussions

Forest ecosystem services particularly, carbon sequestration in biomass and soil play a remarkable role in reducing atmospheric CO_2 concentration thus, helps in mitigating global climate change (Canadell and Raupach, 2008; Pan et al., 2011; Li et al., 2020). Moreover, they provide a wide range of social and economic benefits that highlighted the need for resource management. Conservation and proper management of forest ecosystems are critical to managing global carbon cycle and mitigating climate change as it stores store 86% and 73% of the global biomass carbon and soil carbon pool, respectively (Dixon et al., 1994). Earlier the forest C stock is estimated to be 861 Pg C, which is distributed in soils (44%), live biomass (42%), deadwood (8%), and litter (5%) (Pan et al., 2011).

In the present study, primary forest types were found to be storing higher biomass and carbon than the secondary forests. Similarly, the rate of carbon sequestration per year was found to be highest in the primary forest types. Other studies have also found that primary forests contain more biodiversity and carbon than even mature regenerating or secondary forests (Ngo et al., 2013, Lennox et al., 2018). Therefore, protecting old growth primary forests should be a conservation priority. The much greater biomass and carbon stock in primary forests than the secondary forests was due to the presence of higher large size trees. It was observed that no trees were recorded in the 60-80 cm DBH class in the jhum lands and trees >80 cm DBH were completely absent in both the secondary forest types i.e., bamboo forest and jhum land.

Majority of the carbon stock in the present study was stored in aboveground biomass and soil. However, the contribution of these pools to the total carbon stocks varied markedly between the primary and secondary forest types. Specifically, in primary forest types, the dominant pool was aboveground biomass and soil made a smaller contribution, while the opposite was observed in the secondary forest types.The total biomass stock in the primary forests ranged between 283.27 Mg ha^{-1} in the quercus forest to 451.93 Mg ha^{-1} in the tropical wet evergreen forest. On a continental scale, the mean biomass stock is comparable to the corresponding mean values of tropical forest of Africa (429 Mg ha^{-1}) (Lewis et al., 2013) and Asia (457.1 Mg ha^{-1}) (Silk et al., 2010). At the country level scale, the mean value is comparable to the primary forests of Upper Assam (Gogoi et al., 2017) and higher than that estimated (67.4 Mg ha^{-1}) by Haripriya for Indian forests (Haripriya, 2000) and also than the primary forests of Tripura (Majumdar et al., 2016) and Meghalaya (Hussain et al., 2021).

Among all the four primary forest types, tropical wet evergreen forest had significantly highest amount of carbon storage (373.39 Mg ha^{-1}) followed by temperate forest (332.44 Mg ha^{-1}), montane sub tropical forest (292.28 Mg ha^{-1}) and quercus forest (256.02 Mg ha^{-1}).Finding of this study resembles with the study results of Salunkhe et al., 2018, whereby found that tropical wet evergreen forest types appear to stock more biomass and carbon among all the Indian forest. Overall, carbon storage in the primary forests of Mizoram ranged between 373.39 to 256.02 Mg ha^{-1} which is comparable to the primary forests of Upper Assam (Gogoi et al., 2017), Barak Valley (Brahma et al., (2018), Arunachal Pradesh (Das et al., 2021), Central Himalaya (Verma et al., 2012), tropical forest ecosystem carbon stock of Western Ghats (Kothandaraman et al., 2020) and lower than the primary forests of Meghalaya (Chaudhury and Upadhaya, 2016) and Manipur (Waikhom et al., 2018) and Uttarakhand (Kushal and Bashya, 2021). However, the carbon stocks in the secondary forests i.e.,bamboo forest and jhum land are much lower than the jhum land of equivalent age (Thong et al., 2020) and bamboo forest (Thokchom and Yadava, 2012) reported from Manipur.

Forest soils stores a large amount of organic carbon that helps in managing soil quality and carbon cycle. It is estimated that global forest soils store 383 ± 30 Pg C, which is the highest among biomass, deadwood, and litter (Pan et al., 2011). SOC stored in top 45 cm soils among the forest types ranges from 66 Mg C ha^{-1} in jhum land to 178 Mg C ha^{-1} in temperate forest which corresponding to 43–75% of the total ecosystem C stock. Present study results of SOC stock are comparable to the mixed forest (56–110

Mg C ha^{-1}) of Garhwal Himalaya (Krishan et al., 2017) but higher than the least disturbed rainforest (72 Mg C ha^{-1}) of Assam (Gogoi et al., 2017) and tropical mixed deciduous forest (72–91 Mg C ha^{-1}) of Tripura (Deb et al., 2020) in similar soil depth. The continuous disturbance by the human interference in jhum land and rapid erosion of organic soil layers declines SOC stock (66.5 Mg C ha^{-1}). Also, the younger age of tree species produces lesser litter and root biomass which ultimately supplies lesser organic matter thus, SOC concentration in jhum land. Unlike, an undisturbed temperate forest at higher altitude stored greater SOC stock that might be due to greater canopy cover and tree density that also helps in decreasing soil temperature and increases the moisture content. These favourable environmental conditions help reduce the SOC turnover thus, increases SOC stocks (Andriamananjara et al., 2016). The greater potential of SOC storage in top layers in these forests also indicates its potential to enhance soil fertility, regulate carbon cycling, and mitigate climate change.

Deadwood is an important component of nutrient cycling and vital for conserving forest ecosystem carbon stock (Paletto et al., 2014; Pfeifer et al., 2015; De Meo et al., 2019). Despite a large increase in the area of degraded forest where deadwood stored a noticeable amount of carbon, the role of deadwood remains poorly recorded in many parts of the world forests. Highlighting these facts, IPCC (2003) includes it in the five major ecosystem components that stored a significant amount of terrestrial carbon. Logs, snags, and wood boles can store a notable amount of carbon that can help in carbon cycling in different stages of decomposition. We estimated coarse woody debris carbon stock in the range of 0.87 Mg C ha^{-1}in the jhum land to 16.9 Mg C ha^{-1} in the tropical wet evergreen forest. Our values are much greater than deadwood carbon stocks (3.10 Mg C ha^{-1}) estimated for the mountain birch forest of Russia (Paletto et al., 2020) and degraded tropical forest (Pfeifer et al., 2015), except for bamboo forests and jhum land. However, the percentage contribution of deadwood carbon stock (1.0–4.8%) to the total carbon pool was a little lesser than that suggested by Guldin and Kaiser, (2004).

Litter falls and its decomposition in a forest ecosystem effectively coupling nutrient and carbon cycle. Though litter decomposition is one of the fundamental processes of carbon cycling, sometimes its role in predicting global climate change was overlooked particularly at a regional level. Present study estimate shows that litter carbon stock varies among the forest types as it depended on the types of forest, species density, microbial composition, and climatic conditions (De Groote et al., 2018; Keller and Phillips, 2019). We found litter carbon stock in between 0.16 and 4.29 Mg ha^{-1} where jhum land and bamboo forest exhibited lesser litter carbon stock. Overall, the percentage contribution of different ecosystem components to ecosystem carbon stock shows that plant biomass contributed a greater amount of carbon stock in tropical wet evergreen forest while SOC was the major contributor in the jhum land The results showed ecosystem carbon stock in the order of TWEF >TF >MSTF >QF >BF >JL which is distributed in plant biomass (24–55%), soils (43–75%), deadwood (1.07–4.81%), and litter (0.20–1.25%) and varied largely among the forest types.

The rate of ecosystem carbon sequestration per year was greater in the primary forests. The highestrate of carbon sequestration per year in the tropical wet evergreen forests is may be due to the favorable climatic conditions prevailing in those areas. Carbon sequestration rate in the tropical wet evergreen forest (13.95 Mg ha yr^{-1}) is much higher than those of primary forests in Central Himalaya (Rawat and Singh, 1988;Lal and Lodhyal, 2015; Pant and Tiwari,2020; Joshi et al., 2021) and NE India (Deviand Yadava, 2015).

Artocarpus chama Buch.-Ham., *Aporosa octandra* (Buch.-Ham. ex D. Don) Vickery, D*uabanga grandiflora* (D C.) Walp. , *Ficus religiosa* L., *Magnolia champaca* (L.) Baill.ex Pierre, *Mesua ferrea* L., *Terminalia chebula* Retz., *Terminalia myriocarpa* Van Heurck & Müll. Arg., *Tectona grandis* L. f., *Gmelina arborea* Roxb., *Haldina cordifolia* (Roxb.) Ridsdale, *Phoebe hainesiana* Brandis, *Bombax ceiba* L. and *Helicia excelsa* (Roxb.) Blume were the dominant tree species in the primary forests in terms of carbon sequestration.

Whereas, *Albizia procera* (Roxb.) Benth., *Callicarpa arborea* Roxb., *Macaranga indica* Wight, *Schima wallichii* Choisy, *Rhus chinensis* Mill. and *Trema orientalis* (L.) Blume possessed highest carbon sequestration in the secondary forests.

Land use conversions may result either a decrease (Farley et al., 2004) or an increase in rate of SOCS change (Leema et al., 2006). The negative rate of change following conversions of primary forests to secondary forests observed in the present study is similar to reports from China (Chen et al., 2018). Among all the primary forest types, the maximum loss in total ecosystem carbon sequestration rate was observed when tropical wet evergreen forest was converted to jhum land. This is mainly due to the burning of dense forest cover during the slash and burning associated with jhum cultivation. However, the loss was lowest when quercus forest was converted to jhum land.

CHAPTER-7

IMPACT OF UNDERLYING FACTORS CONTROLLING PLANT DIVERSITY AND ECOSYSTEM CARBON STORAGE IN SELECTED FOREST TYPES OF MIZORAM

7.1 Introduction

There is growing interest among ecologists to explore the influence of regional pool diversity and environmental factors on local species diversity and carbon storage pattern in different forest ecosystems. Plant community composition and its associated functional properties are greatly influenced by the number of available niches shaped by local environmental factors (Figueiredo et al., 2018). Therefore, different parent materials and soil types in association with spatial variation of environmental factors may harbour different floristic communities with distinct functional properties. Environmental gradients, differences in soil nutrients and disturbance regime may trigger differences in species composition and functional characteristics of the locally established plant community, such as the mean growth rate, lifespan, or wood densityand thus determine the amount of carbon sequestered per area.Tree species richness strongly affects aboveground and belowground carbon storage (Ruiz-Benito et al., 2014) litter production and decomposition (Huang et al., 2017) and soil carbon (Gamfeldt et al., 2013) Species richness is known to enhance biomass and C stocks of forests (Poorter et al., 2015).In addition to species richness, forest C stocks are highly influenced by many stand structural variables, such as tree size and stand characteristics (Sullivan et al., 2001).

Climatic factors such as temperature and precipitation are key drivers to control species distribution directly and ultimately the carbon storage in forests by affecting the photosynthetic activities and other biological processes (Rowe, 2009).

Topographic features such as slope, aspect, and elevation can impact local climate as well as soil conditions that in turn have varied effects on vegetation structure and carbon storage (Zhang et al., 2006; Zhang and Zhang 2007; Zhang et al. 2013, 2016). The relative distance from a water source can also affect the composition and distribution of woody vegetation because of the resulting varying amount of water available for growth (Asanok et al., 2017). Similarly,it has been found that species richness increased with precipitation until it reached 4000 mm in a neo-tropical region (Gentry, 1988). Moreover, rainfall has been shown to have a positive effect on the diameter, basal area (Khaine and Woo, 2015; Toledo et al., 2011), and carbon storage (Fisher et al. 2014) of forests.

Physical and chemical soil properties can also influence vegetation patterns on a local scale (Han et al., 2011). For example, higher soil sand ratio lessens water-holding capacity that can lead to water stress on trees (Zhang et al., 2013), and acidity levels affect the distribution of species and is linked to slope and elevation in lowland tropical forests (Nguyen et al., 2015; Vahdati et al., 2017). Soil moisture also significantly changes the growth patterns of trees in drought areas (Marod, 2015;Tilk et al., 2017). In addition, the organic matter in the soil is relevant to an analysis of environmental factors and plant communities in the forest (Zhang et al., 2016). It is found that soil nutrients such as nitrogen, potassium, phosphorus, calcium, and magnesium are correlated with the richness and distribution of plant species in tropical forests (Zhang et al., 2013; Tilk et al., 2017).

Many researches has been done on the relationships of plant biodiversity with productivity, climatic factors and soil fertility in grassland ecosystems, temperate forest stands, and agro-ecosystems of different parts of the world. On the other hand, there is a lack of research and data available about this type of correlation from India. Therefore, it is very important to enhance our understanding of the underlying mechanistic factors determining forest diversity and ecosystem functioning such as carbon storage at regional scale. Understanding the relationship between biodiversity and carbon storage in forest ecosystem is crucial for devising effective strategies for biodiversity conservation and storage of carbon to mitigate global warming and climate change. Most of the carbon sequestration studies in North-East India consider only plant diversity and structural attributes as the factor of ecosystem carbon dynamics. It is very important to understand the effect of underlying factors on species diversity and carbon storage patterns in this region as the varied topographic and climatic condition of NE India provides ample opportunities to conduct such studies. Additionally, in most of such studies involves only the plant biomass carbon stocks and many times, the effect of edaphic factors on carbon stocks are not taken into consideration. Therefore, in the present study are emphasizing on the ecosystem carbon stocks and taking into consideration of all the possible underlying factors such as diversity, plant structural factors, environmental factors and edaphic factors. Since, the study sites were selected in the relatively undisturbed and or less disturbed forests, the effect of anthropogenic disturbance is negligible in this study. We hypothesised that regional diversity and ecosystem carbon storage is determined by the combined effect of various ecosystem factors. Therefore, present study was conducted (1) to correlate the effect of environmental factors, soil nutrients and plant structural attributes on species diversity. (2) To correlate the effect of environmental factors, soil nutrients, plant structural and diversity attributes on ecosystem carbon storage pattern in the study area. (3) to study the effect of plant diversity and local environmental factors on soil ecosystem functions.

7.2 Materials and Methods

7.2.1 Study Area

In the present study, six major forest types were selected in four districts of Mizoram based on the forest classification described by Singh et al., in 2002. These were namely (a) Tropical wet evergreen forest (TWEF) (b) Montane sub tropical forest (MSTF) (c) Temperate forest (TF) (d) Bamboo forest (BF) (e) Quercus forest (QF) (f) Jhum land (JL). The sampling sites of the tropical wet evergreen forest were selected in the undisturbed core areas of the Dampa tiger reserve forest in Mamit District. Whereas, the sampling sites of the Montane subtropical forest were selected in the Reiek Community forest which is situated in the edge of Mamit and Aizawl District of the state. The sampling sites of the Temperate forest were selected in Phawngpui National Park. Sampling sites of the Quercus forest were selected in and around the Lengteng Wildlife Century situated in Champhai District. Sampling sites of bamboo forest and Jhum fallow were selected in the Lengpui and Sakawrtuichhun area of Aizawl District respectively. The age of the jhum fallows were ranged between 15 to 20 years.

7.2.2 Vegetation and Biomass Sampling

In each forest type, three major permanent plots of 250 m × 250 m size were demarcated following ISRO-GBP/NCP-VCP protocol (Singh and Dadhwal, 2009) wherein vegetation, biomass and soil sampling were carried out. The major plots were selected in such a way that the effect of anthropogenic disturbance could be negligible. Reconnaissance surveys were carried out before selecting the sampling sites to find out homogeneous, least disturbed forest sites. Within each major permanent plot four 31.62 m x 31.62 m sub plots were demarcated at each corner of the permanent plots for tree, liana and wild banana biomass and vegetation inventory. Within each sub plot, two 5m x 5m size quadrats were established for enumerating shrubs, small trees (DBH ≤ 10 cm) and bamboo species. Similarly, for herb and litter enumeration two 1m x 1m size quadrats were established within the shrub plots. Thus, vegetation and biomass data were collected establishing a sum of 12 tree plots, 24 shrub plots, 48 herb and 48 litter plots in each forest type.

All tree individuals of ≥ 10 cm diameter were tagged and their diameter at breast height (DBH) was measured at 1.37m above the ground. Tree individuals with DBH ≤ 10 cm were considered as small regenerating tree. Diameter of bamboo culms was measured at the middle part of the next internodes if 1.37 m fell on node or near to node portion of culms. Basal diameter of shrubs and small trees were measured at 10 cm above the ground using a digital vernier calliper. Standing and fallen deadwoods present in the tree sample plots were measured in the field. Height, DBH of standing and fallen deadwoods, length of fallen dead woods (top, mid, bottom), species name, as well as their physical condition (cavity, not rotten or decomposing) were recorded in the field itself. The dead tree roots and stumps of ≥ 10 cm were also considered as deadwood.All litters and herb individuals present inside the respective 1 m x 1 m quadrates were uprooted and the fresh weights were recorded in the field itself. From each such plot 100 gm of litter and herb sample were collected for subsequent laboratory analysis.

7.2.3 Soil Sampling

In each land use, a permanent plot measuring 250 m x 250 m was demarcated using a measuring tape and geo-coordinates were taken at the centre of the plot. Soil samples were collected from three random locations within the 250 m x 250 m sized major plots. Samples were collected from three soil depths viz., 0-15 cm, 15-30 cm, and 30-45 cm and analysed for soil organic carbon and other physical and chemical properties. The soils were mixed thoroughly and large plant debris, roots and stones were removed manually by hand. Thus, a sum of 27 soil samples from each studied forest (3 locations within a plot x 3 depth x 3 major plot) was collected. Equal numbers of soil samples from the same depths were collected for soil bulk density estimation using a soil corer of known volume (106.07 cm^3). After collection, samples were placed in plastic bags and labelled before brought to the laboratory for further processing. They were later air-dried at room temperature before being passed through a 2 mm sieve to remove coarse rocks, pebbles and plant debris. For each depth, three replicates of each composite were analyzed.

7.2.4 Vegetation Analysis

Tree density and basal area values were calculated as per Misra, (1968.). Plant diversity measures such as Shannon - Wiener diversity index (H′) and Margalef's species richness index (M), Simpson's dominance index (Cd) and Pielou's evenness index (E) were estimated as per Shannon and Weanner, (1949) and Margalef, (1968), Simpson, (1949) and Pielou, (1966).

7.2.5 Analysis of Soil Physical and Chemical Properties

Soil bulk density was determined by corer method (Brady and Weil, 2008). The soil samples were air dried and roots and other plant parts were removed and then kept in hot air oven at 105^{o}C for drying till constant weight. After attaining constant weight, it was divided by the volume and bulk density of soil was obtained. The oven dried sample from bulk density measurement was then grounded and sieved through 2 mm sieve to find out coarse rocky fragment percentage Soil texture was determined by Hydrometer method (Bouyoucos, 1926) using the USDA textural classification chart. Soil pH and moisture content percentage was determined within 36 hours of sampling following standard procedures. Soil pH was determined using soil-water ratio method (Anderson and Ingram, 1989). Soil moisture content was determined following the gravimetric method where soil samples were weighed before and after the sample was oven dried at 105°C until the constant weight was attained. Total nitrogen (TN) was determined using CHNS/O Elemental Analyzer. Soil organic carbon was analyzed by Walkley-Black rapid titration method (Walkley and Black, 1934).

7.2.6 Biomass Estimation

Tree biomass was estimated using a diameter-only common allometric equation developed for mixed species tree biomass estimation in North East India. A recent study by Nath et al., (2019) reported that the four commonly used generic models developed by Chambers et al. (2001); Brown et al., (1989); Chave et al., (2005); Chave et al., (2014) overestimated biomass stocks by 300–591 kg tree^{-1} in the North-East Indian condition. Although, height is a valuable addition when estimating biomass, the diameter-only equation provides better biomass estimates than diameter-height allometry (Williams and Schreuder, 2000). Therefore, to get accurate site specific estimation, we followed the diameter-only allometric model best fit model suggested by Nath et al., (2019). Biomass of shrubs and tree saplings was estimated using allometric equation developed by Ali et al., (2015). For deadwood biomass estimation, we followed the methodology suggested by Cros and Lopez, (2009). Volume of the dead logs and stumps were first measured following the allometric equation developed by them. Stem length, diameter (mid), and decaying status of each fallen or standing deadwood piece were recorded in the field to estimate their volume. Then, the deadwood volume was multiplied by respective wood density values of different decaying status (freshly cut = 0.48 g cm^{-3}, moderately decomposed = 0.35 g cm^{-3}, highly decomposed = 0.25 g cm^{-3}, and burnt = 0.19 g cm^{-3}) to estimate the deadwood biomass. Liana (Hairiah et al., 2011) and banana (Addo-Fordjour and Rahmad, 2013) biomass was estimated using allometric equation developed for a similar ecological region. Biomass of the bamboo species was estimated using allometric equation developed by Singnar et al., (2017) for North East India. For litter and herb, all the standing biomass present in the quadrats was first measured in the field and 100^{-g} fresh samples were brought to the laboratory for dry biomass estimation. Tree belowground biomass was estimated applying different root to shoot ratio for different forest types (Mokany et al., 2006). Belowground biomass of bamboo, wild banana, shrub, small tree and liana was estimated using root to shoot ratio suggested by Cairns et al,.(1997), Ravindranath and Ostwald, (2008). Biomass in all the compartments was finally extrapolated and scaled to per hectare basis.

Table 7.1 Allometric equations used in this study.

Biomass component	Allometric equation	Reference
Tree	$AGB_{est} = 0.18D^{2.16} \times 1.32$	Nath et al. (2019)
Small tree	$AGB = 3.344 + (0.443 \times (\ln((DBH)^2)))$	Chaturvedi et al. (2012)
Liana	$AGB = \exp(-1.484 + 2.657 \times (\ln(DBH)))$	Schnitzer et al. (2006)
Shrub	$AGB = \exp(-3.5 + 1.65 \times \ln(CD) + 0.842 \times \ln(H)$	Ali et al. (2015)
Dead wood	$V = (L \times \pi \times D_m^2)/4$	Teissier du Cros and Lopez (2009)
Bamboo	$\ln(AGB) = \ln(\alpha) + \beta(\ln D^2) + \varepsilon$	Singnar et al. (2017)
Wild banana	$AGB = 0.0303 \times D^{2.1345}$	Hairiah et al. (2011)

7.2.7 Estimation of Biomass Carbon Stock

Carbon content in herb and litter biomass was analyzed following dry ashing method (Campbell and Plank, 1998) and then the value was multiplied with the respective dry biomass amount. Biomass carbon in rest of the plant components was estimated by multiplying the default value of 47% with the total biomass amount (IPCC, 2006). The total carbon stock in each major forest type was the sum of carbon stocks in all the biomass compartments and the soil organic carbon stock.

7.2.8 Soil Organic Carbon Stock Estimation

Soil carbon stock for each depth class was estimated by multiplying with corresponding values of fine bulk density and SOC content. SOC stock was calculated following the formula given by IPCC, (2003).

$$C\ storage = \sum_{\text{horizon}=1}^{\text{horizon}=\text{n}} (SOC \times Bulk\ Density \times Depth \times (1 - frag) \times 10)horizon$$

Where,

SOC = representative soil organic carbon stock, Mg C ha^{-1}.
SOC horizon = SOC stock for a constituent soil horizon, Mg C ha^{-1}.
[SOC] = concentration of soil organic carbon, g C (kg soil)$^{-1}$.
Bulk density = soil mass per sample volume, Mg soil m^{-3}.
Depth = horizon depth or thickness of soil layer, m.
Frag = % volume of coarse fragments/100, dimensionless.

7.2.9 Estimation of Carbon Sequestration

Carbon sequestration rate in each of the forest type was estimated following "stock difference" method based on the IPCC guidelines (IPCC, 2003, 2006). The stock difference method includes all process that brings about changes in a given pool. The carbon stock will be estimated for each pool at two points in time, namely t_1 and t_2**.** In this study the duration between the two points was two years (t_1 =2016 and t_2 = 2018). Thus, the estimated stock at t_2 was deducted from the estimated stock at t_1 and the difference was divided by the number of years between the two periods ($t_2 - t_1$). The "stock- difference" was estimated separately for each carbon pool and later summed for each forest type.

7.2.10 Acquisition of Environmental Data

The climatic variables such as mean annual temperature and mean annual rainfall were derived for all the plots from the World-Clim dataset using *sp* and *raster* packages in R 3.6.2 (Worldclim, 2019) and altitude was recorded in the field itself using a GPS.

7.3 Statistical Analysis

Descriptive statistical analyses were performed using SPSS-20.Pearson correlation analysis was carried out in SPSS and correlograms were prepared in PAST. PCA analysis was done in PAST to assess the plot level relationships between ecosystem variables and total carbon stocks. The effect of underlying factors on ecosystem carbon storage was analyzed by multiple linear regression models using forward wise selection method. Variance inflation factor (VIF) was used to check any multi collinearity in the independent variable and the Durbin Watson test was performed to measure auto correlation in residuals from regression analysis.

7.4 Results

7.4.1 Relationship between Species Diversity and Ecosystem Parameters

Species diversity (Shannon - Wienner diversity index) was correlated with 16 ecosystem variables to find out the factors which effects species diversity in the selected forests types of Mizoram. Correlations analysis between the species diversity and environmental parameters indicated that species diversity exhibited positive correlations with mean annual rainfall and altitude and negative correlation with temperature. However, these relationships were not significant except with rainfall. Among the soil parameters, pH ($r = 0.809^{**}$), soil organic carbon content ($r = 0.669^{**}$) and phosphorus ($r = 0.806^{**}$) had significant positive correlations with species diversity and rest of the soil parameters (soil moisture, bulk density, sand, silt, clay, TN, K) didn't correlate significantly. Bulk density, sand and potassium had negative correlation and soil moisture, silt, clay and total nitrogen had positive correlation with species diversity. Correlation analysis between the species diversity and plant structural attributes showed that tree basal area ($r = 0.895^{**}$) and density ($r = 0.798^{**}$) had significant positive correlations with species diversity and tree DBH didn't correlate significantly. The details of the correlations are highlighted in the correlogram (**Figure 7.1**) and r – values are presented in the **Table 7.2.**

To better understand the possible effects of ecosystem parameters on species diversity, simple linear regression analysis were also performed for the statistically significant correlations. It was found that density ($R^2 = 0.63$, $p = 0.00$) and basal area ($R^2 = 0.80$, $p = 0.00$) were the two plant structural attributes which had significant positive effects on species diversity. Out of the ten soil properties, soil moisture content ($R^2 = 0.44$, $p = 0.00$), pH ($R^2 = 0.66$, $p = 0.00$), soil organic carbon content ($R^2 = 0.45$, $p = 0.00$) and phosphorus ($R^2 = 0.65$, $p = 0.00$) had strong positive effect on species diversity. Among the environmental parameters, only rainfall had significant impact ($R^2 = 0.52$, $p = 0.02$) on species diversity (**Figure 7.2**).

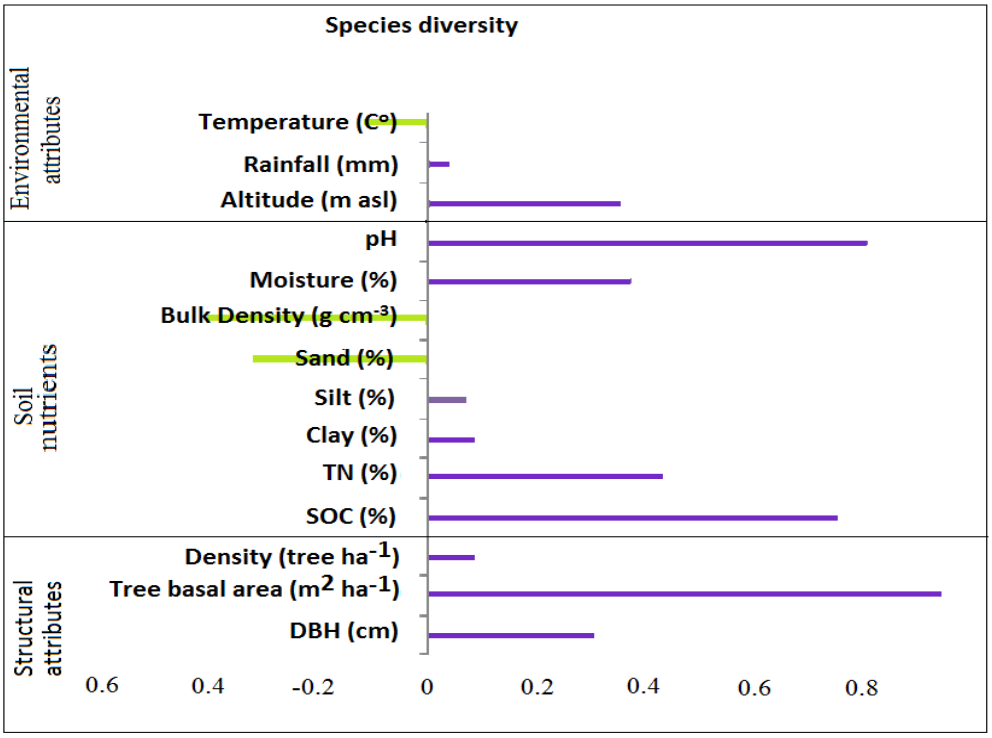
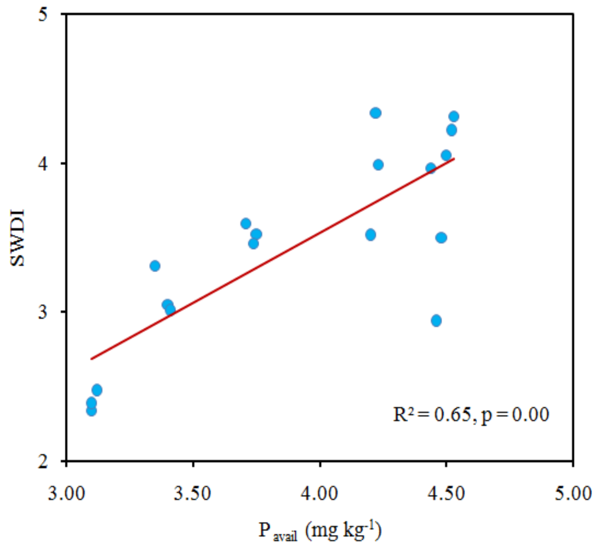


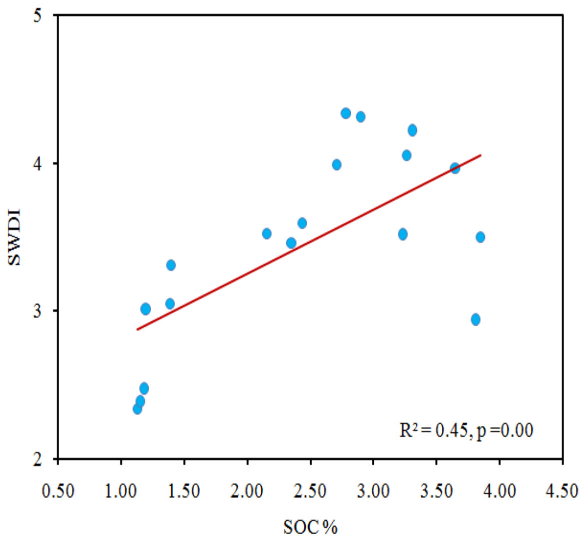
Figure 7.1 Correlation between species diversity (Shannon– Wiener's diversity index) and environmental attributes{ mean annual temperature (C^0), mean annual rainfall (mm) and altitude (m asl)}, soil nutrients { pH, moisture (%), bulk density (g cm-3), sand (%), silt (%), clay (%), total nitrogen (%), soil organic carbon content (%)}and structural attributes { tree basal area,tree density, mean tree DBH}.

Table 7.2 Correlation (r-values) between species diversity, soil nutrients, plant structural attributes and environmental attributes.

Sl No.	Variables	r - value
		Species diversity
1	Temperature (C^o)	-0.117
2	Rainfall (mm)	0.541*
3	Altitude (m asl)	0.055*
4	pH	0.809**
5	Moisture (%)	0.376
6	Bulk density (g cm^{-3})	-0.405
7	Sand (%)	-0.328
8	Silt (%)	0.071
9	Clay (%)	0.087
10	TN (%)	0.431
11	P_{avail}(mg kg^{-1})	0.806**
12	K^+(cmol$_c$ kg $^{-1}$)	-0.244
13	SOC (%)	0.669**
14	Density (tree ha^{-1})	0.798**
15	Tree basal area (m^2 ha^{-1})	0.895**
16	DBH (cm)	0.312

Note: r-values with asterisk represent asignificant relationship between the variables (*$p < 0.05$ level, **$p < 0.01$ level and other r-values exhibit relationships which are non-significant).





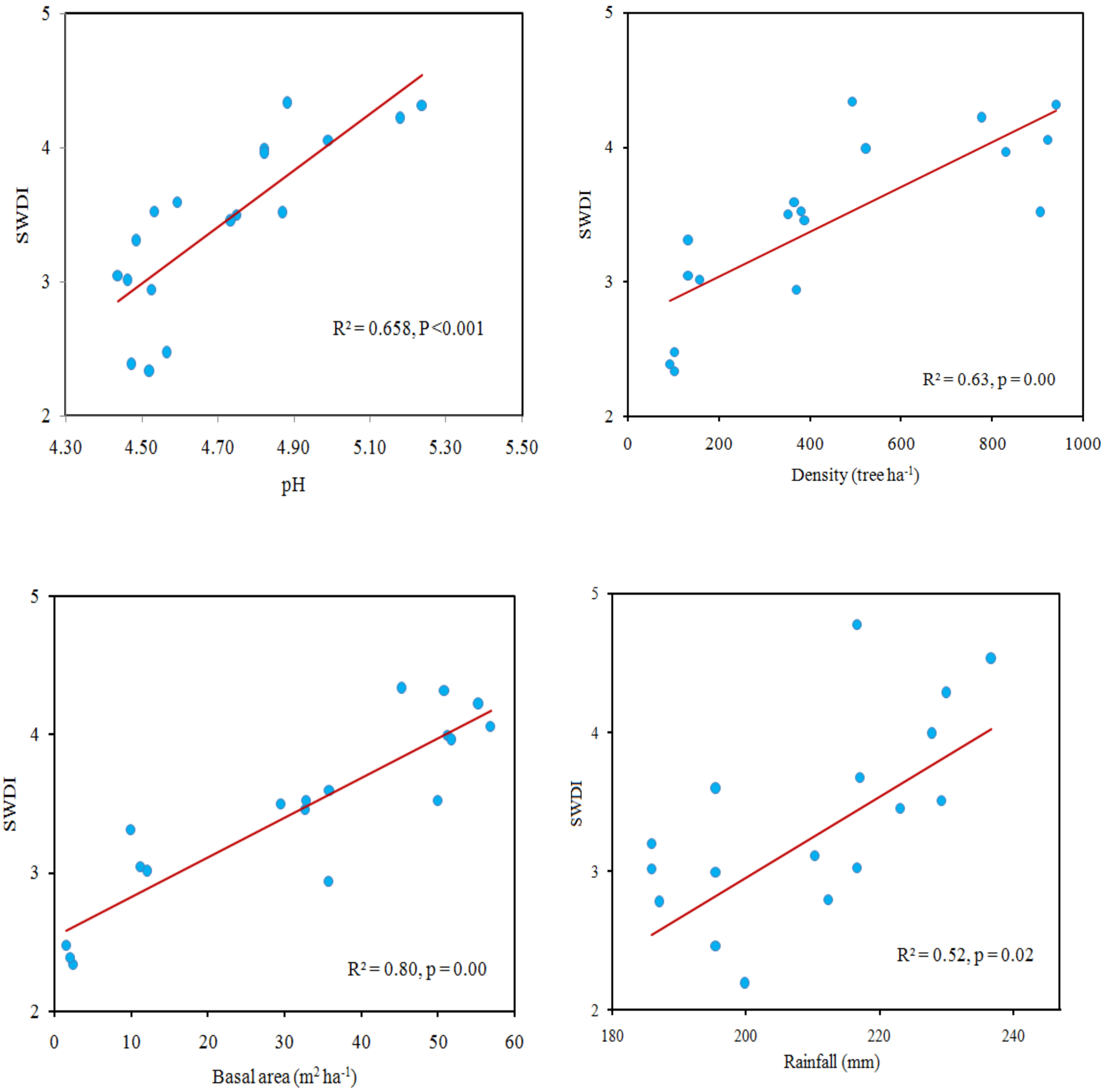


Figure 7.2 Effect of environmental factors (i.e. elevation, mean annual temperature, mean annual rainfall), soil nutrients (i.e. soil water content, pH, bulk density, soil texture, soil phosphorus availability, total nitrogen, available potassium, soil organic carbon content) and plant structural attributes (i.e. tree density, mean tree DBH, tree basal area) on species diversity in the selected forest types of Mizoram. SWDI= Shannon Weinner's Diversity Index.

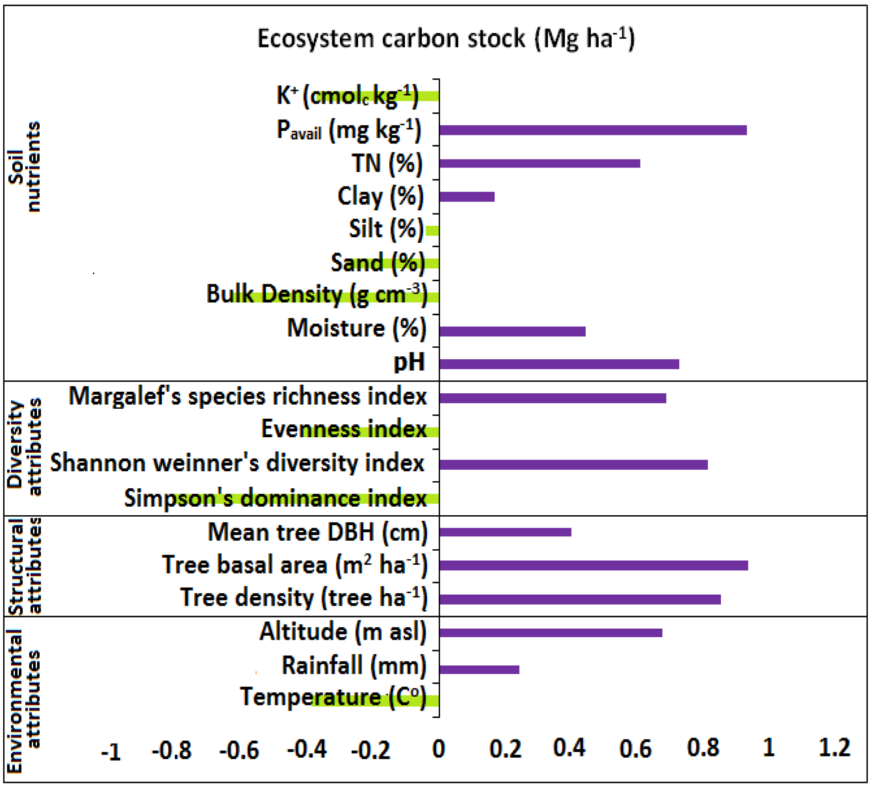


Figure 7.3 **C**orrelations between the ecosystem carbon stock andenvironmental variables, plant structural attributes, plant diversity indices, and soil properties.

Table 7.3 Correlation (r-values) between ecosystem carbon stock and soil nutrients, environmental, plant structural and diversity attributes.

Sl No.	Variables	r- value
		Ecosystem carbon stock (Mg ha^{-1})
1	Temperature (C^o)	-0.391
2	Rainfall (mm)	0.443*
3	Altitude (m asl)	0.675*
4	Tree density (trees ha^{-1})	0.853**
5	Tree basal area (m^2 ha^{-1})	0.933**
6	Mean tree DBH (cm)	0.399*
7	Simpson's dominance index	-0.814**
8	Shannon weinner's diversity index	0.815**
9	Evenness index	-0.413*
10	Margalef's species richness index	0.687**
11	pH	0.724**
12	Moisture (%)	0.441**
13	Bulk density (g cm^{-3})	-0.632**
14	Sand (%)	-0.284
15	Silt (%)	-0.040
16	Clay (%)	0.165
17	TN (%)	0.608**
18	P_{avail}(mg kg^{-1})	0.949**
19	K$^+$(cmol$_c$ kg $^{-1}$)	-0.422

Note: **Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at 0.05 level (2-tailed).

From the overall results of the correlation analysis followed by regression models it was observed that phosphorus, soil organic carbon content and pH were the most important soil parameters which effected species diversity the most. Among the plant structural attributes, density and basal area effected species diversity the most. However, environmental factors didn’t have significant impact on plant diversity in the studied forests.

7.4.2 Relationship between Carbon Storage and Ecosystem Variables

The linear relationship between the ecosystem carbon stocks and other ecosystem variables was determined by Pearson correlation coefficient. The correlogram presented in the **Figure 7.3** highlights significant positive correlation between ecosystem carbon stocks and density ($r = 0.853^{**}$), basal area ($r = 0.933^{**}$), mean tree DBH ($r = 0.399^{*}$), Shannon Weinner's diversity index ($r = 0.815^{**}$), Margalef's species richness index ($r = 0.687^{**}$), pH ($r = 0.724^{**}$), moisture ($r = 0.441^{**}$), total nitrogen ($r = 0.608^{**}$), phosphorus (0.949^{**}) and altitude ($r = 0.675^{*}$). Whereas, Simpson's dominance index ($r = -0.814^{**}$), Pielu’s Evenness index ($r = -0.413^{*}$) and bulk density ($r = -0.632^{**}$), had significant negative correlation with ecosystem carbon storage. However, temperature, rainfall and soil textural classes didn’t have any significant relations with ecosystem carbon stocks.

The principal components analysis (PCA) was performed to assess the plot level relationships between the ecosystem variables and total carbon stocks (**Figure 7.4**). It was found that the eigen values of the dominant axis were 7.96, 3.60, 2.59, 1.92, 1.03, 0.77, 0.53, 0.29, 0.14, 0.09 respectively and the corresponding percentage variances were 41.92, 18.96, 13.64, 10.11, 5.40, 4.04, 2.78, 1.52, 0.71 and 0.45. These values reflect variations in Shannon Weinner’s diversity index, Margalef's species richness index, Pielou’s evenness index, Simpson's dominance index, temperature, rainfall, altitude, density, basal area and mean DBH which together accounted for 99.5% variation in ecosystem carbon storage revealing that ecosystem carbon storage was influenced by plant diversity, structural attributes and environmental factors.

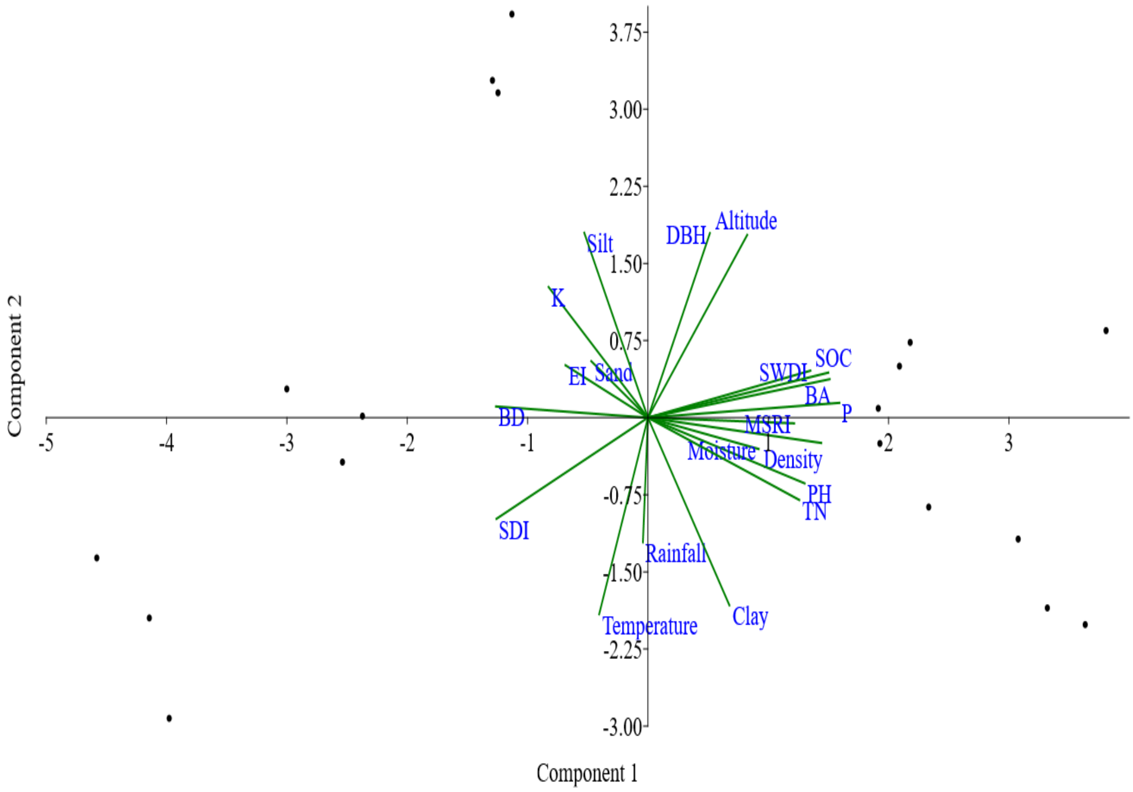


Figure 7.4 Principal components analysis of environmental factors (i.e. elevation, mean annual temperature, mean annual rainfall), soil nutrients (i.e. soil moisture content, pH, bulk density, soil texture, soil phosphorus, total nitrogen, potassium, soil organic carbon content) plant structural attributes (i.e. tree density, mean tree DBH, tree basal area) and diversity attributes (i.e. Simpson's dominance index, Shannon Weinner's diversity index, Evenness index, Margalef's species richness index) against total carbon storage at plot-level. Each dot represents a plot.

Multiple linear regression models using forward wise selection method were prepared to find out the causal relationships between ecosystem variables and total carbon stocks. The summary of the multiple-liner regression model was presented in the **Table 7.4**. Temperature, rainfall, altitude, tree density, basal area, DBH, species diversity, species dominance, species evenness, species richness, soil moisture, bulk density, sand, silt, clay, and total N content was used as predictor variables. After the forward wise selection method, only three variables basal area, altitude, and tree density were retained by the model and significant at a level of $p < 0.01$. The adjusted coefficient of determination (R^2) obtained from the model on the interaction between the three parameters was 0.948 which indicated that these variables collectively explain 94.8% of the variance in the ecosystem carbon stock of the selected forests. Therefore, from the Pearson correlations followed by multiple regression models it was observed that basal area, altitude, and tree density were the most significant ecosystem variables which influenced the total ecosystem carbon storage pattern the most in the selected forest types of Mizoram.

Table 7.4 Model summary of the multiple linear regressions considering ecosystem carbon stock as a dependant variable and temperature, rainfall, altitude, tree density, basal area, DBH, species diversity, species dominance, species evenness, species richness, soil moisture, bulk density, sand, silt, clay, and total N content was used as predictor variables.

Model		Unstandardized Coefficient		Standardized Coefficient	t	Sig.	Adjusted R square
		B	Std. Error	Beta			
1	(Constant)	68.478	14.201		4.822	0.000	0.881
	Tree basal area	5.032	0.384	0.942	13.103	0.000	
2	(Constant)	49.795	11.233		4.433	0.000	0.936
	Tree basal area	4.294	0.327	0.803	13.136	0.000	
	Altitude	0.039	0.009	0.273	4.456	0.000	
3	(Constant)	44.141	10.408		4.241	0.000	0.948
	Tree basal area	2.204	0.918	0.412	2.400	0.026	
	Altitude	0.052	0.010	0.359	5.447	0.000	
	Tree density	0.131	0.055	0.373	2.404	0.026	

7.6 Discussions

Forest ecosystem functioning is determined by environmental factors, diversity, plant structural attributes and edaphic factors (Poorter et al., 2015). The local scale variation in diversity can be the result of local processes including biotic (Hillebrand, 2005) and abiotic factors (Gronroos and Heino, 2012; Fotis et al., 2017). The overall impact of ecosystem factors on plant diversity is complex as it involves multiple of factors. Therefore, it is very essential to find out the most important factors that are crucial to a more thorough and useful understanding of the diversity and ecosystem factors relationship in the studied forests. Although, several studies have suggested that species diversity is mostly associated with the regional climatic and topographic conditions (Post et al., 1982; Hawkins et al., 2003; Lianf et al., 2016), from the present study results it can be substantiate that regional diversity is determined by the combined effects of environmental factors, edaphic factors and plant structural attributes. Findings of the present study highlight that the underlying ecosystem factors shaping the plant community composition, diversity and thus affecting the ecosystem carbon storage. In this study, it was observed that out of the sixteen ecosystem variables rainfall, tree density, basal area, soil moisture content, pH, soil organic carbon content and available phosphorus were the most significant factors which had positively affected species diversity in the studied forests of Mizoram.

The environmental factors showed both positive and negative impact on species diversity. Out of the three environmental factors, rainfall was found to be positively impacting species diversity the most than altitude and mean air temperature. The significant impact of mean annual rainfall and soil moisture content reveals that species diversity in the studied forests is highly related to the water availability then altitude and air temperature. Therefore, it indicates that dry conditions may negatively impact species diversity in the studied forests. In this study, altitude didn’t have any significant impact on species diversity even though, it was positively correlated. It indicates that altitude doesn’t have much influence on species diversity in the study area which may be due to the less variations in elevation across the different forest type. Many other studies have reported that an increase in species diversity may have an elevation limit above which diversity would become negatively correlated (Liu et al., 2018). For instance, the resources necessary for plant growth are limited at extremely high elevations because of strong winds and shallow soils (Zhang et al., 2013). The negative correlation between air temperature and species diversity shows the usual trend which has been already demonstrated in several previous studies. (Zhang et al., 2017; Bradly et al., 2019; Liu et al., 2021). According to many studies air temperature tends to be negatively correlated with diversity (Pace et al., 2019).

The significant positive effect of tree density and basal area on diversity corroborates with the findings of Palmer et al., 2000 and Steege et al., 2003. Stand basal area can significantly affect the diversity. However, whether the direction is positive or negative is determined by the site conditions (Park et al., 2019). In the present study the site conditions may have positively affected stand density and basal area which ultimately promoted species diversity. According to Wills et al., (1997) Strong density- and diversity-related effects help to maintain tree species diversity in Neo-tropical forests. Tree diversity components and density are positively related with total tree basal area (Sagar et al., 2003).

Out of the ten soil parameters pH, moisture content, silt, clay, total nitrogen, phosphorus and soil organic carbon content were found to be positively correlated with species diversity whereas, bulk density, sand and potassium were inversely correlated. The correlation matrix followed by simple linear regression models confirms that soil moisture, pH, soil organic carbon content and phosphorus had significant effect on species diversity. The positive impact of soil organic carbon on diversity can be corroborated with the findings of Tiessen et al., 1994 which demonstrates that high soil organic carbon can impose positive impact on species richness and productivity by increasing soil water-holding capacity and sustaining soil fertility. Other studies have found that soil organic carbon stock is highly related to plant functional traits and microbial community, which have large effects on plant diversity (De Deyn et al., 2008; Stein et al., 2014; Stark et al., 2017). Furthermore, soil organic carbon is positively correlated with pH and phosphorus (Dibar et al., 2020). Soil pH regulates the capacity for SOC storage and nutrient supplies and, thereby, regulates species diversity and primary productivity (Slessarev et al., 2016). High soil acidity can and increase SOC accumulation by inhibiting soil microbial activities and accelerating the leaching of dissolved organic carbon to sub-soils (Funakawa et al., 2014). The higher rate of soil acidity in the study area might have increased the soil organic carbon concentrations which subsequently lead to positive impact on species diversity. This indicates that species diversity is not only affected by soil organic carbon but also by the amount of pH and phosphorus in the soil. According to Wan et al. 2018, pH and soil organic carbon are amongst the important soil indicators for monitoring global plant diversity. Plant diversity may also be affected by nitrogen availability (Clark et al., 2007; Stein et al., 2014). But, in the present study nitrogen didn’t have any significant effect on species diversity even though, it was positively correlated. Some studies have also found that nitrogen enrichment reduces species richness (Clark and Tilman 2008; Ibisch et al., 2016).

Correlation matrices followed by PCA analysis highlights that ecosystem carbon storage is significantly influenced by plant diversity, structural attributes, environmental and edaphic factors. These results corroborates with the study results of Kothandaraman et al., (2020), Hofhansl et al., (2020) where they have found that carbon stocks are influenced by structural attributes, diversity attributes, environmental and edaphic factors. Diversity indices, temperature, rainfall, altitude, density, basal area and mean DBH together accounted for 99.5% variation in ecosystem carbon storage. All the structural attributes accounted in this study were positively correlated with ecosystem carbon storage. High tree densities enhance carbon storage due to greater canopy packing leading to more light harvesting and increased wood production (Morin, 2015). As biomass increases exponentially with tree diameter, high stand basal area and big-sized tree densities increase carbon storage (Poorter et al., 2015). The positive relationship between species diversity and carbon stocks could be attributed to local variation in stem density (Chisholm et al., 2013), large tree sizes (Silk et al., 2013) and dominance effects (Labriere et al., 2016).

Among the environmental factors, ecosystem carbon storage was significantly and positively correlated with mean annual rainfall and altitude and negatively correlated with mean annual temperature. Elevation influences carbon storage by affecting microclimate, which in turn influences stand attributes (Jucker et al., 2015; Fotis et al., 2017; Sharma et al., 2010). Carbon storage is also influenced by mean annual rainfall as high annual rainfall increases the length of the growing season, enhancing the growth of trees, leading to increased biomass (Toledo et al., 2012). On the other hand, high mean annual temperature often has a limiting effect on stand carbon stocks (Vayreda et al., 2012). Similar results were observed in other studies as well. Vayreda et al., (2012) found that species richness and structural richness variables are better predictors of carbon accumulation than climatic and local site variables in Western Mediterranean region. Poorter et al., (2015) observed that diversity attributes are strongly related to aboveground biomass at small spatial scales, whereas structural attributes are related to aboveground biomass at all spatial scales. They also concluded that rainfall is a major driver of aboveground biomass. Behera et al., (2017) reported a strong positive relationship of AGB with species richness and structural attributes in an Indian tropical deciduous forest. Poorter et al., (2015) showed that vegetation attributes were more frequently and significantly associated with biomass than environmental conditions. Liu et al., (2018) found that tree species richness enhances ecosystem-level carbon storage in the subtropical forests of China. Amara et al., (2019) reported a moderate linear relationship between tree species richness and AGBC in the Guinean savanna landscape, Africa. Li et al., (2019) observed that tree carbon storage was significantly positively related with diversity, structural attributes and precipitation.

Correlation only reveals the potential relationships between variables, which needs further analysis to establish causal relationships (Kothandaraman et al., 2020). Therefore, we performed multiple linear regressions modelling using forward wise selection method to identify the most important underlying factors which influence ecosystem carbon storage. Among the twelve significant predictor variables (i.e., density, basal area, mean tree DBH, Shannon Weinner's diversity index, Margalef's species richness index, Simpson's dominance index, Pielu's Evenness index, bulk density, pH, moisture content, total nitrogen, altitude) only three variables (i.e., basal area, tree density and altitude) appeared to be the most influential on ecosystem carbon storage. Therefore, results of this study showed that structural (density and basal area) and environmental attributes (altitude) had stronger effect than species diversity on forest carbon storage. The multiple linear regression models followed by forward-wise selection method reveals that the tree basal area accounts for the 88% variation in the ecosystem C stocks, while the inclusion of altitude and tree density along with the basal area accounts for 94% variation in ecosystem C stock. It is observed that structural attributes have more bearing on ecosystem carbon storage than functional or phylogenetic diversity, environmental factors and soil nutrients. Lauue et al., (2019) has opined that structural attributes may be as good or a better predictor of ecosystem functions than species richness and phylogenetic diversity. Stand level characteristics of forest structure drives productivity, energy and nutrient cycling, and biotic resistances at a large-scale. Species and structural diversity can also be inter-correlated, as species diversity increases structural diversity when species with different life strategies coexist. Species diversity can also promote tree size and canopy height heterogeneity as well while; structural diversity can be a proxy for species diversity. Thus, species diversity indirectly affects productivity via structural diversity.

CHAPTER-8

SUMMARY AND CONCLUSIONS

The global scientific community has realized that the issue of climate change and biodiversity loss is interrelated and these issues are needed to be tackled together instead of viewing it separately. The relationships between forest type, biodiversity and ecosystem services like carbon sequestration are highly relevant for forming forest policy and management plans. Mizoram being part of the Eastern Himalaya biodiversity hotspot region is rich in flora and fauna and also threatened with various types of anthropogenic activities. Hence, priority conservation areas need to be identified and protected in terms of both species diversity and carbon storage. However, lack of systematic studies covering all the major forest types of the state is the biggest hindering towards the achievement of these sustainable development goals.

Numerous studies have been carried out to estimate carbon storage patterns in the forests of North East India particularly in the forests of the Barak and Brahmaputra valleys (Nath et al., 2017; Gogoi et al., 2021). However, comprehensive studies to understand the plant biodiversity, C stock, and sequestration potential of the North East Indian forests and its relation to the environmental factors are limited. The varied topographical differences in the hilly state of Mizoram provide scope for understanding the effect of environmental driving factors and soil nutrients on plant diversity and ecosystem carbon stock of the different forest types in this region.Besides large variation in the environmental and topographical conditions, Mizoram has the highest forest cover (84.53 %) among all the Indian states in terms of percentage to the total geographical area (ISFR, 2021). However, it is not clear that whether or not forest cover increases carbon storage as compared to those Indian states which are having the highest forest cover. Moreover, it is very important to identify the richest forest types of the state in terms of both species diversity and carbon storage for future developmental strategies. Thus, a proper study to understand the plant diversity and carbon sequestration potential of major forest types of Mizoram and its relation to environmental factors and soil nutrients is of prime importance in the current scenario.

The present study was carried out selecting all the major forest types of Mizoram with the following major objectives:-

1. To investigate plant diversity, composition and vegetation structure of the study area.
2. To assess the variation in soil organic carbon stock and its influencing factors in selected forest types.
3. To estimate the variation in biomass, total carbon stock and carbon sequestration potential of the selected forest types.
4. To correlate the effect of environmental factors and soil nutrients on plant diversity and carbon storage pattern in the selected forest types.

Six major forest types were selected in four districts of Mizoram based on the forest classification described by Singh et al. in 2002. These are namely: - 1.tropical wet evergreen forest, 2. montane sub tropical forest, 3. temperate forest, bamboo forest, 5. quercus forest and 6. jhumland. The sampling sites of the tropical wet evergreen forest were selected in the Dampa Tiger Reserve; the sampling sites for the montane sub tropical forest were selected in the Riek Community Forest; for temperate forest sampling sites were selected in Phawngpui National Park; sampling sites for the quercus forest were selected in the Lengteng Wildlife Sanctuary; sampling sites for the bamboo forest and jhum lands were selected in Lengpui and Sakawrtuichhun area of Aizawl District respectively.

The first round of field survey was carried out in the year 2016 and the same was repeated after two years. In each forest type, three major permanent plots of 250 m × 250 m size were demarcated following ISRO-GBP/NCP-VCP protocol (Singh and Dadhwal, 2009) wherein, vegetation and biomass sampling were carried out. The major plots were selected in such a way that the effect of anthropogenic disturbance could be negligible. Reconnaissance surveys were carried out before selecting the sampling sites to find out homogeneous, least disturbed forest sites. The species diversity, composition and plant community structure was analysed following standard methods and biomass, carbon stock and carbon sequestration potential was estimated following non destructive methods.

The key conclusions of the present study are discussed hereunder:-

Species Diversity, Composition and Vegetation Structure of the Selected Forest Types of Mizoram:-

The study provides an account of the species diversity, composition and structure of the major forest types of Mizoram. The present study results reveal that the primary forests were richer in species diversity, composition and structure as compared to the secondary forests i.e., bamboo forests and jhum land. Species poor condition in the secondary forests was mainly associated with the past anthropogenic disturbances. However, fair regeneration in bamboo forests and good regeneration in jhum land indicates that these forests have the future potential to harbour regional species diversity as same as a neighbouring primary forests. Therefore, intensive management of the bamboo forest as well as in the jhum land is required to maintain substantial tree diversity in those land uses, which will also be helpful for mitigating climate change as well as for soil conservation in the state. Time to time harvesting of matured bamboo culms and increasing the jhum fallow age may be useful to achieve these goals.

Understanding species diversity and distribution patterns is important for helping managers to evaluate the complexity and resources of a particular forest. Tropical wet evergreen forest was found to be the richest in terms of species richness (131 tree species belonging to 89 genera and 42 families) and the lowest species richness was observed in the jhum land (21 species belonging to 20 genera and 14 families). *Castanopsis tribuloides* (Sm.) A.DC., *Calliandra umbrosa* (Wall.) Benth., *Mesua ferrea* L., *Helicia excelsa* (Roxb.) Blume, *Oroxylum indicum* (L.) Kurz, Quercus oblongata D. Don, *Engelhardtia spicata* Lechen ex Blume, *Quercus floribunda* Lindl. ex A. Camus, *Lithocarpus elegans* (Blume) Hatus. ex Soepadmo, *Quercus griffithii* Hook.f. & Thomson ex Miq. and *Quercus serrata* Murray were the dominant tree species in the primary forests and *Castanopsis tribuloides* (Sm.) A.DC., *Rhus chinensis* Mill., *Schima wallichii* Choisy, *Bischofia javanica* Blume, *Cassia fistula* L. and *Leea indica* (Burm. f.) Merr. were the dominant tree species in the secondary forests. Lauraceae, Miliaceae, Moraceae, Anacardiaceae, Euphorbiaceae, Fabaceae, Fagaceae, Lamiaceae, and Phyllanthaceae were the dominant families in the primary forests while; Euphorbiaceae, Lamiaceae, Malvaceae, Moraceae, Fabaceae, Fagaceae, Lamiaceae and Phyllanthaceae were the dominant families in the secondary forests.

These findings may be useful for prioritising selected forest types for future policy making in the state. Additionally, the study results may provide insight into forest management and ecological study that would be applicable to other similar forest types of NE India.

However, only the tree component was included for plant diversity assessment in the present study due to limited time and resources. Therefore, it is suggested to include herbs, shrubs, woody and non woody climbers and epiphytes in future studies for better understanding of species diversity and composition in the major forest types of Mizoram. Establishing permanent sampling plots in all the major forest types to study the forest dynamics in terms of species diversity, composition, structure, biomass accumulation, species recruitment etc. is a must needed step towards the sustainable management of the forests of Mizoram.

Variations in Soil Organic Carbon Storage and Its Influencing Factors in Different Forest Types of Mizoram

This study systematically demonstrates the differences in soil physical and chemical properties, carbon stability and SOC stock among the major forest types of Mizoram which will be helpful in the future management of natural carbon sink under land use and climate change scenario. Based on the objectives of the study and subsequent field analysis, this study concludes that temperate forests of Mizoram had the highest SOC stock and plays a vital role in carbon cycling and climate regulations. The percentage contribution of active carbon to TOC was highest in the temperate forests but slow and passive carbon was higher in montane sub tropical forests that indicate a dominant role of these forests in long-term carbon sequestration in the state. LULC significantly reduced the SOC stock of the major forests that become more pronounced when temperate forests were converted to jhum lands. The finding of this study also highlights that the conversion of primary forests to the secondary forests i.e., bamboo forests and jhum lands reduces carbon sink capacity and stability of the carbon pool varied with the soil depth. Additionally, soil organic carbon stock in the study area is significantly influenced by plant biomass, plant structural attributes, plant diversity and soil physical and chemical properties.

Variation in Biomass, Total Carbon Stock and Carbon Sequestration Potential of the Selected Forests of Mizoram:-

Quantifying biomass and carbon sequestration in different forest types of Mizoram has significant concern for improving nation's carbon accounting, to support the formulation of better climate policies and future projection of climate change. Also, it can contribute positively to the UNFCCC agenda of forest conservation, sustainable management of forests, and enhancement of forest carbon stocks in developing countries (REDD+) like India. This study results presents the baseline data on biomass, carbon stock and carbon sequestration potential of the major forest types of Mizoram which may be useful for regional level policy making to combat climate change in Mizoram.

From the present study it can be concluded that the primary forests demonstrate larger carbon sink capacity than the secondary forests. Our estimates showed lesser ecosystem carbon stock in jhum lands which is mainly associated with the younger age of the jhum lands and past disturbance history; however, with the increasing age, these forests can accumulate a greater amount of atmospheric carbon in plants and soils and act as terrestrial carbon sink. Component wise breakup of the carbon stock showed that the maximum carbon was stored in the soil followed by aboveground and belowground biomass components. The tropical wet evergreen forest possessed the highest amount of ecosystem carbon storage and also had the maximum carbon sequestration potential among all the selected forest types. Other selected primary forest types i.e., montane sub tropical forest, temperate forest and quercus forest also showed better carbon sick potential as compared to the secondary forests. Therefore, adequate emphasis must be taken for better management of the primary forests in order to have maximum carbon storage.

Artocarpus chama Buch.-Ham., *Aporosa octandra* (Buch.-Ham. ex D. Don) Vickery, *Duabanga grandiflora* (DC.) Walp. , *Ficus religiosa* L., *Magnolia champaca* (L.) Baill. ex Pierre, *Mesua ferrea* L., *Terminalia chebula* Retz., *Terminalia myriocarpa* Van Heurck & Müll. Arg., *Tectona grandis* L.f., *Gmelina arborea* Roxb., *Haldina cordifolia* (Roxb.) Ridsdale, *Phoebe hainesiana* Brandis, *Bombax ceiba* L. and *Helicia excelsa* (Roxb.) Blume were the dominant tree species in the primary forests in terms of carbon sequestration. Whereas, *Albizia procera* (Roxb.) Benth., *Callicarpa arborea* Roxb., *Macaranga indica* Wight, *Schima wallichii* Choisy, *Rhus chinensis* Mill. and *Trema orientalis* (L.) Blume possessed highest carbon sequestration in the secondary forests.

Present study results also suggested that land use change had significant impact on ecosystem carbon storage. Among all the primary forest types, the maximum loss in total ecosystem carbon sequestration rate was observed when tropical wet evergreen forests were converted to jhum lands. Therefore, it is also suggested to adapt maximum protection measures in those forest areas by the State Govt. However, organizing awareness programmes, providing alternative livelihood to the jhumiyas may be helpful towards the eradication of these problems. Governmental initiative must also be taken for successful implementation of the agroforestry models specially developed for North East India.

Impact of Underlying Factors Controlling Plant Diversity and Ecosystem Carbon Storage in Selected Forest Types of Mizoram

From the present study results it can be substantiate that species diversity in the study area is determined by the combined effects of environmental factors, edaphic factors and plant structural attributes. Findings of the present study highlight that the underlying ecosystem factors shaping the plant community composition, diversity and thus affecting the ecosystem carbon storage. Structural (density and basal area) and environmental attributes (altitude) had stronger effect than species diversity on forest carbon storage in the present study. It is further observed that structural attributes had more bearing on ecosystem carbon storage than functional or phylogenetic diversity, environmental factors and soil nutrients. Therefore, it is suggested to adopt necessary measures to enhance plant structural quality in the studied forests so as to achieve maximum carbon storage. However, it is recommended to include environmental factors, edaphic factors and plant structural attributes for predicting regional diversity; and both plant structural attributes and environmental factors for predicting ecosystem carbon storage in present and future changing climate and also in making conservation strategies related to carbon sink management in the study area. Additionally, establishing permanent plots with installation of adequate environmental data monitoring facilities in all the major forest types may be useful for better understanding of the long term effect of different ecosystem parameters on species diversity and forest carbon storage.

Appendix 1

1.1 Tropical wet evergreen forest.

Sl No	Species name	Family	Density (ha^{-1})	Relative frequency (%)	Relative density (%)	Relative abundance (%)	Importance value index	Regeneration status	Species rarity	Distribution pattern
1	*Acer laevigatum* Wall.	Sapindaceae	17	1.37	1.90	0.27	3.54	Good	Common	Contagious
2	*Adenanthera pavonina* L.	Fabaceae	2	0.55	0.19	1.09	1.83	Poor	Rare	Contagious
3	*Aglaia edulis* (Roxb.) Wall.	Meliaceae	2	0.55	0.19	1.09	1.83	Fair	Rare	Contagious
4	*Aglaia oligophylla* Miq.	Meliaceae	1	0.27	0.09	1.09	1.46	Fair	Very rare	Contagious
5	*Aglaia perviridis* Hiern	Meliaceae	2	0.55	0.19	1.09	1.83	Fair	Rare	Contagious
6	*Aglaia spectabilis* (Miq.) S.S.Jain & S.Bennet	Meliaceae	8	1.65	0.85	0.73	3.23	Fair	Rare	Random
7	*Albizia lebbeck* (L.) Benth.	Fabaceae	31	0.55	3.51	0.06	4.12	Good	Dominant	Contagious
8	*Albizia odoratissima* (L.f.) Benth.	Fabaceae	4	1.10	0.47	0.87	2.44	Fair	Rare	Random
9	*Alphonsea lutea* (Roxb.) Hook.f. & Thomson	Annonaceae	7	1.10	0.76	0.54	2.40	Fair	Rare	Contagious
10	*Antidesma bunius* (L.) Spreng.	Phyllanthaceae	3	1.10	0.38	1.09	2.57	Fair	Rare	Random
11	*Antidesma montanum* Blume	Phyllanthaceae	1	0.27	0.09	1.09	1.46	Fair	Very rare	Contagious
12	*Aphananthe cuspidata* (Blume) Planch.	Cannabaceae	3	0.55	0.28	0.73	1.56	Poor	Rare	Contagious
13	*Aporosa octandra* (Buch.-Ham. ex D.Don) Vickery	Phyllanthaceae	23	1.65	2.65	0.23	4.54	Fair	Dominant	Contagious
14	*Aquilaria malaccensis* Lam.	Thymeleaceae	6	0.55	0.66	0.31	1.52	Poor	Rare	Contagious
15	*Ardisia polycephala* Wall. ex A.DC.	Primulaceae	1	0.27	0.09	1.09	1.46	None	Very rare	Contagious

16	*Artocarpus chama* Buch.-Ham.	Moraceae	1	0.27	0.09	1.09	1.46	Fair	Very rare	Contagious
17	*Artocarpus lacucha* Buch.-Ham.	Moraceae	1	0.27	0.09	1.09	1.46	Good	Very rare	Contagious
18	*Baccaurea ramiflora* Lour.	Phyllanthaceae	4	0.82	0.47	0.65	1.95	Fair	Rare	Contagious
19	*Balakata baccata* (Roxb.) Esser	Euphorbiaceae	2	0.27	0.19	0.54	1.01	Fair	Rare	Contagious
20	*Calliandra umbrosa* (Wall.) Benth.	Fabaceae	51	2.47	5.78	0.16	8.42	Fair	Dominant	Contagious
21	*Carallia brachiata* (Lour.) Merr.	Rhizophoraceae	1	0.27	0.09	1.09	1.46	Fair	Very rare	Contagious
22	*Castanopsis indica* (Roxb. ex Lindl.) A.DC.	Fagaceae	2	0.55	0.19	1.09	1.83	Fair	Rare	Contagious
23	*Castanopsis lanceifolia* (Oerst.) Hickel & A.Camus	Fagaceae	13	1.37	1.42	0.36	3.16	Good	Common	Contagious
24	*Castanopsis tribuloides* (Sm.) A.DC.	Fagaceae	131	2.75	14.88	0.07	17.70	Good	Dominant	Contagious
25	*Celtis timorensis* Span.	Cannabaceae	6	0.82	0.66	0.47	1.95	Good	Rare	Contagious
26	*Chrysophyllum roxburghii* G.Don	Sapotaceae	1	0.27	0.09	1.09	1.46	Good	Very rare	Contagious
27	*Chukrasia tabularis* A.Juss.	Meliaceae	1	0.27	0.09	1.09	1.46	Fair	Very rare	Contagious
28	*Cinnamomum cassia* (L.) J.Presl	Lauraceae	2	0.55	0.19	1.09	1.83	Good	Rare	Contagious
29	*Cinnamomum glanduliferum* (Wall.) Meisn.	Lauraceae	1	0.27	0.09	1.09	1.46	Fair	Very rare	Contagious
30	*Colona floribunda* (Kurz) Craib	Malvaceae	7	0.55	0.76	0.27	1.58	Fair	Rare	Contagious
31	*Cordia dichotoma* G.Forst.	Boraginaceae	1	0.27	0.09	1.09	1.46	Good	Very rare	Contagious
32	*Derris robusta* (DC.) Benth.	Fabaceae	8	0.55	0.85	0.24	1.64	Fair	Rare	Contagious
33	*Dillenia indica* L.	Dilliniaceae	1	0.27	0.09	1.09	1.46	Good	Very rare	Contagious
34	*Dimocarpus longan* Lour.	Sapindaceae	3	1.10	0.38	1.09	2.57	Fair	Rare	Random
35	*Diospyros glandulosa* Lace	Ebenaceae	3	0.55	0.28	0.73	1.56	Fair	Rare	Contagious
36	*Diospyros lanceolata* Poir.	Ebenaceae	3	0.82	0.38	0.82	2.02	Good	Rare	Random
37	*Diospyros pilosiuscula* G.Don	Ebenaceae	10	1.92	1.14	0.63	3.70	Good	Rare	Random

38	*Diospyros stricta* Roxb.	Ebenaceae	10	1.65	1.14	0.54	3.33	Good	Rare	Random
39	*Dipterocarpus retusus* Blume	Dipterocarpaceae	4	1.10	0.47	0.87	2.44	Fair	Rare	Random
40	*Drimycarpus racemosus* (Roxb.) Hook.f. ex Marchand.	Anacardiaceae	2	0.55	0.19	1.09	1.83	None	Rare	Contagious
41	*Drypetes indica* (Müll.Arg.) Pax & K.Hoffm.	Putranjivaceae	15	1.37	1.71	0.30	3.38	Good	Common	Contagious
42	*Duabanga grandiflora* (DC.) Walp.	Lythraceae	1	0.27	0.09	1.09	1.46	Good	Very rare	Contagious
43	*Dysoxylum excelsum* Blume	Meliaceae	1	0.27	0.09	1.09	1.46	Good	Very rare	Contagious
44	*Elaeocarpus rugosus* Roxb. ex G.Don	Elaeocarpaceae	3	0.82	0.28	1.09	2.20	Good	Rare	Random
45	*Erythrina stricta* Roxb.	Fabaceae	1	0.27	0.09	1.09	1.46	Fair	Very rare	Contagious
46	*Eurya cerasifolia* (D.Don) Kobuski	Pentaphylacaceae	1	0.27	0.09	1.09	1.46	Fair	Very rare	Contagious
47	*Ficus altissima* Blume	Moraceae	2	0.55	0.19	1.09	1.83	Good	Rare	Contagious
48	*Ficus glaberrima* Blume	Moraceae	3	0.27	0.28	0.36	0.92	Poor	Rare	Contagious
49	*Ficus hispida* L.f.	Moraceae	1	0.27	0.09	1.09	1.46	Good	Very rare	Contagious
50	*Ficus racemosa* L.	Moraceae	3	0.55	0.28	0.73	1.56	Good	Rare	Contagious
51	*Ficus religiosa* L.	Moraceae	6	0.82	0.66	0.47	1.95	Fair	Rare	Contagious
52	*Ficus retusa* L.	Moraceae	1	0.27	0.09	1.09	1.46	Fair	Very rare	Contagious
53	*Ficus semicordata* Buch.-Ham. ex Sm.	Moraceae	1	0.27	0.09	1.09	1.46	Fair	Very rare	Contagious
54	*Firmiana simplex* (L.) W.Wight	Malvaceae	6	1.10	0.66	0.62	2.38	Fair	Rare	Random
55	*Garcinia cowa* Roxb. ex Choisy	Clusiaceae	3	1.10	0.38	1.09	2.57	Good	Rare	Random
56	*Garcinia microstigma* Kurz	Clusiaceae	2	0.27	0.19	0.54	1.01	Fair	Rare	Contagious
57	*Garcinia sopsopia* (Buch.-Ham.) Mabb.	Clusiaceae	6	1.10	0.66	0.62	2.38	Fair	Rare	Random
58	*Garuga floribunda* Decne.	Burseraceae	1	0.27	0.09	1.09	1.46	None	Very rare	Contagious
59	*Glochidion heyneanum* (Wight & Arn.) Wight	Phyllanthaceae	3	0.82	0.28	1.09	2.20	Poor	Rare	Random

60	*Gmelina arborea* Roxb.	Lamiaceae	3	0.55	0.38	0.54	1.47	Poor	Rare	Contagious
61	*Gmelina oblongifolia* Roxb.	Lamiaceae	2	0.27	0.19	0.54	1.01	Fair	Rare	Contagious
62	*Gynocardia odorata* R.Br.	Achariaceae	1	0.27	0.09	1.09	1.46	Fair	Very rare	Contagious
63	*Haldina cordifolia* (Roxb.) Ridsdale	Rubiaceae	5	0.55	0.57	0.36	1.48	Good	Rare	Contagious
64	*Heritiera papilio* Bedd.	Malvaceae	32	3.02	3.60	0.31	6.94	Fair	Dominant	Random
65	*Heteropanax fragrans* (Roxb.) Seem.	Araliaceae	2	0.55	0.19	1.09	1.83	None	Rare	Contagious
66	*Homalium ceylanicum* (Gardner) Benth.	Salicaceae	3	1.10	0.38	1.09	2.57	Poor	Rare	Random
67	*Hyptianthera stricta* (Roxb. ex Schult.) Wight & Arn.	Rubiaceae	21	2.20	2.37	0.35	4.92	Fair	Dominant	Random
68	*Ixora cauliflora* Montrouz.	Rubiaceae	5	0.55	0.57	0.36	1.48	Fair	Rare	Contagious
69	*Knema cinerea* Warb.	Myristicaceae	3	0.55	0.28	0.73	1.56	Poor	Rare	Contagious
70	*Knema linifolia* (Roxb.) Warb.	Myristicaceae	3	0.55	0.28	0.73	1.56	Poor	Rare	Contagious
71	*Lagerstroemia speciosa* (L.) Pers.	Lythraceae	3	0.27	0.28	0.36	0.92	Fair	Rare	Contagious
72	*Lannea coromandelica* (Houtt.) Merr.	Anacardiaceae	2	0.55	0.19	1.09	1.83	Fair	Rare	Contagious
73	*Leea indica* (Burm. f.) Merr.	Vitaceae	7	1.92	0.76	0.95	3.63	Fair	Rare	Random
74	*Licuala peltata* Roxb. ex Buch.-Ham.	Arecaceae	1	0.27	0.09	1.09	1.46	Fair	Very rare	Contagious
75	*Lindera nacusua* (D. Don) Merr.	Lauraceae	11	1.10	1.23	0.33	2.67	Fair	Common	Contagious
76	*Lithocarpus chittagongus* (King ex Hook.f.) Merr.	Fagaceae	3	0.27	0.28	0.36	0.92	Fair	Rare	Contagious
77	*Lithocarpus obscurus* C.C.Huang & Y.T.Chang	Fagaceae	6	0.27	0.66	0.16	1.09	Poor	Rare	Contagious
78	*Litsea monopetala* (Roxb.) Pers.	Lauraceae	29	2.47	3.32	0.28	6.07	Good	Dominant	Random
79	*Litsea salicifolia* (J. Roxb. ex Nees) Hook. f.	Lauraceae	1	0.27	0.09	1.09	1.46	Good	Very rare	Contagious

80	*Litsea semecarpifolia* (Wall. ex Nees) Hook.f.	Lauraceae	2	0.27	0.19	0.54	1.01	Good	Rare	Contagious
81	*Macaranga indica* Wight	Euphorbiaceae	4	0.82	0.47	0.65	1.95	Good	Rare	Contagious
82	*Machilus parviflora* Meisn.	Lauraceae	23	0.55	2.65	0.08	3.28	Good	Dominant	Contagious
83	*Macropanax dispermus* (Blume) Kuntze	Araliaceae	3	0.27	0.38	0.27	0.93	Good	Rare	Contagious
84	*Macropanax undulatus* (Wall. ex G.Don) Seem.	Araliaceae	1	0.27	0.09	1.09	1.46	None	Very rare	Contagious
85	*Magnolia baillonii* Pierre	Magnoliaceae	2	0.27	0.19	0.54	1.01	Fair	Rare	Contagious
86	*Magnolia champaca* (L.) Baill. ex Pierre	Magnoliaceae	10	1.92	1.14	0.63	3.70	Fair	Rare	Random
87	*Magnolia oblonga* (Wall. ex Hook.f. & Thomson) Figlar	Magnoliaceae	1	0.27	0.09	1.09	1.46	Fair	Very rare	Contagious
88	*Magnolia pleiocarpa* (Dandy) Figlar & Noot.	Magnoliaceae	1	0.27	0.09	1.09	1.46	None	Very rare	Contagious
89	*Mallotus philippensis* (Lam.) Müll.Arg.	Euphorbiaceae	13	0.82	1.52	0.20	2.54	Poor	Common	Contagious
90	*Mammea sanguinea* (Jum. & H.Perrier) Kosterm.	Calophyllaceae	1	0.27	0.09	1.09	1.46	Good	Very rare	Contagious
91	*Mesua ferrea* L.	Calophyllaceae	45	2.47	5.12	0.18	7.77	Poor	Dominant	Contagious
92	*Meyna spinosa* Roxb. ex Link	Rubiaceae	3	0.82	0.28	1.09	2.20	Good	Rare	Random
93	*Micromelum minutum* Wight & Arn.	Rutaceae	8	0.82	0.85	0.36	2.04	Good	Rare	Contagious
94	*Mitragyna rotundifolia* (Roxb.) Kuntze	Rubiaceae	1	0.27	0.09	1.09	1.46	Fair	Very rare	Contagious
95	*Parkia timoriana* (DC.) Merr.	Fabaceae	1	0.27	0.09	1.09	1.46	Fair	Very rare	Contagious
96	*Phoebe hainesiana* Brandis	Lauraceae	3	0.82	0.28	1.09	2.20	None	Rare	Random
97	*Polyalthia jenkinsii* (Hook.f. & Thomson) Hook.f. & Thomson	Annonaceae	7	1.10	0.76	0.54	2.40	Good	Rare	Contagious
98	*Polyalthia simiarum* (Hu)Bân	Annonaceae	5	0.55	0.57	0.36	1.48	Good	Rare	Contagious

99	*Premna racemosa* Wall. ex Schauer	Lamiaceae	4	0.82	0.47	0.65	1.95	Fair	Rare	Contagious
100	*Protium serratum* (Wall. ex Colebr.) Engl.	Burseraceae	1	0.27	0.09	1.09	1.46	Good	Very rare	Contagious
101	*Prunus ceylanica* (Wight) Miq.	Rosaceae	1	0.27	0.09	1.09	1.46	Poor	Very rare	Contagious
102	*Pterospermum semisagittatum* Buch.-Ham. ex Roxb.	Malvaceae	1	0.27	0.09	1.09	1.46	Good	Very rare	Contagious
103	*Pterygota alata* (Roxb.) R. Br.	Malvaceae	2	0.55	0.19	1.09	1.83	Fair	Rare	Contagious
104	*Quercus floribunda* Lindl. ex A.Camus	Fagaceae	3	1.10	0.38	1.09	2.57	Good	Rare	Random
105	*Sapindus mukorossi* Gaertn.	Sapindaceae	2	0.27	0.19	0.54	1.01	Fair	Rare	Contagious
106	*Saraca indica* L.	Fabaceae	33	1.65	3.79	0.16	5.60	Fair	Dominant	Contagious
107	*Schima wallichii* Choisy	Theaceae	23	1.92	2.56	0.28	4.76	Good	Dominant	Contagious
108	*Spondias pinnata* (L. f.) Kurz	Anacardiaceae	1	0.27	0.09	1.09	1.46	Fair	Very rare	Contagious
109	*Sterculia villosa* Roxb.	Malvaceae	1	0.27	0.09	1.09	1.46	None	Very rare	Contagious
110	*Stereospermum chelonoides* (L.f.) DC.	Bignoniaceae	5	0.82	0.57	0.54	1.94	Good	Rare	Contagious
111	*Stereospermum tetragonum* DC.	Bignoniaceae	2	0.27	0.19	0.54	1.01	Fair	Rare	Contagious
112	*Syzygium claviflorum* (Roxb.) Wall. ex A.M.Cowan & Cowan	Myrtaceae	1	0.27	0.09	1.09	1.46	Fair	Very rare	Contagious
113	*Syzygium cumini* (L.) Skeels	Myrtaceae	2	0.27	0.19	0.54	1.01	None	Rare	Contagious
114	*Syzygium grande* (Wight) Walp.	Myrtaceae	16	2.47	1.80	0.52	4.79	Poor	Common	Random
115	*Syzygium kurzii* (Duthie) N.P.Balakr.	Myrtaceae	1	0.27	0.09	1.09	1.46	Fair	Very rare	Contagious
116	*Syzygium praetermissum* (Gage) N.P.Balakr.	Myrtaceae	4	1.37	0.47	1.09	2.94	Fair	Rare	Random
117	*Tectona grandis* L.f.	Lamiaceae	28	2.75	3.22	0.32	6.29	None	Dominant	Random
118	*Terminalia bellirica* (Gaertn.) Roxb.	Combretaceae	3	0.82	0.28	1.09	2.20	Good	Rare	Random
119	*Terminalia chebula* Retz.	Combretaceae	3	0.82	0.28	1.09	2.20	Good	Rare	Random

120	*Terminalia crenulata* Roth	Combretaceae	3	0.55	0.38	0.54	1.47	Poor	Rare	Contagious
121	*Terminalia myriocarpa* Van Heurck & Müll. Arg.	Combretaceae	3	0.55	0.28	0.73	1.56	Good	Rare	Contagious
122	*Terminalia tomentosa* Wight & Arn.	Combretaceae	2	0.55	0.19	1.09	1.83	Fair	Rare	Contagious
123	*Tetrameles nudiflora* R. Br.	Tetramelaceae	4	0.55	0.47	0.44	1.46	None	Rare	Contagious
124	*Toona ciliata* M.Roem.	Meliaceae	1	0.27	0.09	1.09	1.46	Good	Very rare	Contagious
125	*Vitex negundo* L.	Lamiaceae	10	1.37	1.14	0.45	2.96	Fair	Rare	Contagious
126	*Vitex peduncularis* Wall. ex Schauer	Lamiaceae	1	0.27	0.09	1.09	1.46	Fair	Very rare	Contagious
127	*Vitex quinata* (Lour.) F.N.Williams	Lamiaceae	6	1.10	0.66	0.62	2.38	Fair	Rare	Random
128	*Walsura robusta* Roxb.	Meliaceae	10	0.82	1.14	0.27	2.23	None	Rare	Contagious
129	*Wrightia arborea* (Dennst.) Mabb.	Meliaceae	4	1.10	0.47	0.87	2.44	None	Rare	Random
130	*Xantolis tomentosa* (Roxb.) Raf.	Sapotaceae	1	0.27	0.09	1.09	1.46	None	Very rare	Contagious
131	*Xylia xylocarpa* (Roxb.) Taub.	Fabaceae	1	0.27	0.09	1.09	1.46	None	Very rare	Contagious

1.2 Montane sub tropical forest.

Sl No	Species name	Family	Density (ha^{-1})	Relative frequency (%)	Relative density (%)	Relative abundance (%)	Importance value index	Regeneration status	Species rarity	Distribution pattern
1	*Acrocarpus fraxinifolius* Arn.	Fabaceae	2	0.73	0.26	1.48	2.47	Poor	Rare	Contagious
2	*Acronychia pedunculata* (L.) Miq.	Rutaceae	12	2.18	1.82	0.64	4.64	Poor	Common	Regular
3	*Aglaia edulis* (Roxb.) Wall.	Meliaceae	3	0.73	0.39	0.99	2.11	Poor	Rare	Contagious
4	*Aglaia spectabilis* (Miq.) S.S.Jain & S.Bennet	Meliaceae	3	1.09	0.52	1.11	2.72	Poor	Rare	Regular
5	*Alangium chinense* (Lour.) Harms	Cornaceae	1	0.36	0.13	1.48	1.98	None	Very rare	Contagious
6	*Albizia lucidior* (Steud.) I.C.Nielsen	Fabaceae	2	0.36	0.26	0.74	1.37	Fair	Rare	Contagious
7	*Albizia richardiana* (Voigt) King & Prain	Fabaceae	1	0.36	0.13	1.48	1.98	Fair	Very rare	Contagious
8	*Alphonsea lutea* (Roxb.) Hook.f. & Thomson	Annonaceae	2	0.73	0.26	1.48	2.47	Good	Rare	Contagious
9	*Alphonsea ventricosa* (Roxb.) Hook.f. & Thomson	Annonaceae	2	0.73	0.26	1.48	2.47	Fair	Rare	Contagious
10	*Alseodaphne petiolaris* Hook.f.	Lauraceae	2	0.73	0.26	1.48	2.47	Fair	Rare	Contagious
11	*Anogeissus acuminata* (Roxb. ex DC.) Wall. ex Guillem. & Perr.	Combretaceae	3	0.73	0.39	0.99	2.11	Good	Rare	Contagious
12	*Aquilaria malaccensis* Lam.	Thymelaeaceae	2	0.73	0.26	1.48	2.47	None	Rare	Contagious
13	*Archidendron bigeminum* (L.) I.C.Nielsen	Fabaceae	2	0.73	0.26	1.48	2.47	Poor	Rare	Contagious
14	*Artocarpus heterophyllus* Lam.	Moraceae	5	0.73	0.78	0.49	2.00	None	Rare	Contagious
15	*Artocarpus lacucha* Buch.-Ham.	Moraceae	3	0.73	0.39	0.99	2.11	Good	Rare	Contagious
16	*Atalantia simplicifolia* (Roxb.) Engl.	Rutaceae	2	0.73	0.26	1.48	2.47	Fair	Rare	Contagious

17	*Baccaurea ramiflora* Lour.	Phyllanthaceae	5	1.09	0.78	0.74	2.61	Fair	Rare	Contagious
18	*Balakata baccata* (Roxb.) Esser	Euphorbiaceae	4	1.45	0.65	1.19	3.29	Good	Rare	Regular
19	*Betula cylindrostachya* Lindl. ex Wall.	Betulaceae	1	0.36	0.13	1.48	1.98	Good	Very rare	Contagious
20	*Bombax ceiba* L.	Malvaceae	5	0.73	0.78	0.49	2.00	Good	Rare	Contagious
21	*Bombax insigne* Wall.	Malvaceae	6	1.09	0.91	0.64	2.64	Fair	Rare	Contagious
22	*Bridelia tomentosa* Blume	Phyllanthaceae	1	0.36	0.13	1.48	1.98	Good	Very rare	Contagious
23	*Bruinsmia polysperma* (C.B.Clarke) Steenis	Styracaceae	4	1.45	0.65	1.19	3.29	Fair	Rare	Regular
24	*Calliandra umbrosa* (Wall.) Benth.	Fabaceae	3	0.73	0.39	0.99	2.11	Good	Rare	Contagious
25	*Callicarpa arborea* Roxb.	Lamiaceae	8	1.09	1.17	0.49	2.76	Good	Rare	Contagious
26	*Calophyllum polyanthum* Wall. ex Planch. & Triana	Clusiaceae	2	0.73	0.26	1.48	2.47	Good	Rare	Contagious
27	*Canarium bengalense* Roxb.	Burseraceae	3	0.36	0.39	0.49	1.25	Good	Rare	Contagious
28	*Castanopsis indica* (Roxb. ex Lindl.) A.DC.	Fagaceae	14	1.09	2.21	0.26	3.57	Good	Common	Contagious
29	*Castanopsis tribuloides* (Sm.) A.DC.	Fagaceae	9	1.45	1.43	0.54	3.43	Good	Common	Contagious
30	*Choerospondias axillaris* (Roxb.) B.L.Burtt & A.W.Hill	Anacardiaceae	3	0.73	0.39	0.99	2.11	Fair	Rare	Contagious
31	*Cinnamomum glanduliferum* (Wall.) Meisn.	Lauraceae	8	1.45	1.17	0.66	3.29	Fair	Rare	Contagious
32	*Cinnamomum tamala* (Buch.-Ham.) T.Nees & Eberm.	Lauraceae	2	0.36	0.26	0.74	1.37	Fair	Rare	Contagious
33	*Cinnamomum verum* J.Presl	Lauraceae	6	1.45	0.91	0.85	3.21	Fair	Rare	Regular
34	*Colona floribunda* (Kurz) Craib	Malvaceae	4	0.36	0.65	0.30	1.31	Good	Rare	Contagious
35	*Croton lissophyllus* Radcl.-Sm. & Govaerts ex Esser	Euphorbiaceae	1	0.36	0.13	1.48	1.98	Fair	Very rare	Contagious

36	*Croton wallichii* Müll.Arg.	Euphorbiaceae	1	0.36	0.13	1.48	1.98	None	Very rare	Contagious
37	*Cryptocarya amygdalina* Nees	Lauraceae	5	0.73	0.78	0.49	2.00	Poor	Rare	Contagious
38	*Dalbergia pinnata* (Lour.) Prain	Fabaceae	2	0.36	0.26	0.74	1.37	Fair	Rare	Contagious
39	*Dalbergia stipulacea* Roxb.	Fabaceae	1	0.36	0.13	1.48	1.98	Good	Very rare	Contagious
40	*Diospyros glandulosa* Lace	Ebenaceae	3	1.09	0.52	1.11	2.72	Good	Rare	Regular
41	*Diospyros lanceifolia* Roxb.	Ebenaceae	3	1.09	0.52	1.11	2.72	Fair	Rare	Regular
42	*Drimycarpus racemosus* (Roxb.) Hook.f. ex Marchand.	Anacardiaceae	6	1.45	0.91	0.85	3.21	Good	Rare	Regular
43	*Duabanga grandiflora* (DC.) Walp.	Lythraceae	3	1.45	0.52	1.48	3.46	Good	Rare	Regular
44	*Dysoxylum excelsum* Blume	Meliaceae	3	1.09	0.39	1.48	2.97	Good	Rare	Regular
45	*Elaeocarpus floribundus* Blume	Elaeocarpaceae	1	0.36	0.13	1.48	1.98	Good	Very rare	Contagious
46	*Elaeocarpus rugosus* Roxb. ex G.Don	Elaeocarpaceae	5	1.09	0.78	0.74	2.61	Good	Rare	Contagious
47	*Elaeocarpus tuberculatus* Roxb.	Elaeocarpaceae	6	1.45	0.91	0.85	3.21	Good	Rare	Regular
48	*Engelhardtia spicata* Lechen ex Blume	Juglandaceae	20	2.18	3.13	0.37	5.68	Good	Doninant	Contagious
49	*Eriobotrya bengalensis* var. angustifolia Cardot	Rosaceae	13	2.18	2.08	0.56	4.82	Good	Common	Regular
50	*Eurya acuminata* DC.	Pentaphylacaceae	1	0.36	0.13	1.48	1.98	Good	Very rare	Contagious
51	*Ficus benghalensis* L.	Moraceae	1	0.36	0.13	1.48	1.98	Fair	Very rare	Contagious
52	*Ficus religiosa* L.	Moraceae	13	1.82	2.08	0.46	4.37	Fair	Common	Contagious
53	*Ficus semicordata* Buch.-Ham. ex Sm.	Moraceae	2	0.73	0.26	1.48	2.47	Good	Rare	Contagious
54	*Fraxinus floribunda* Wall.	Oleaceae	2	0.73	0.26	1.48	2.47	Fair	Rare	Contagious
55	*Garcinia cowa* Roxb. ex Choisy	Clusiaceae	3	0.36	0.39	0.49	1.25	None	Rare	Contagious
56	*Garcinia xanthochymus* Hook.f. ex	Clusiaceae	2	0.73	0.26	1.48	2.47	Good	Rare	Contagious

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57	*Glochidion sphaerogynum* (Müll.Arg.) Kurz	Phyllanthaceae	1	0.36	0.13	1.48	1.98	Good	Very rare	Contagious
58	*Gynocardia odorata* R.Br.	Achariaceae	7	2.18	1.04	1.11	4.34	None	Rare	Regular
59	*Helicia excelsa* (Roxb.) Blume	Proteaceae	30	2.18	4.69	0.25	7.12	Good	Doninant	Contagious
60	*Heteropanax fragrans* (Roxb.) Seem.	Araliaceae	3	0.36	0.39	0.49	1.25	Good	Rare	Contagious
61	*Holigarna caustica* (Dennst.) Oken	Anacardiaceae	2	0.73	0.26	1.48	2.47	Fair	Rare	Contagious
62	*Homalium ceylanicum* (Gardner) Benth.	Salicaceae	1	0.36	0.13	1.48	1.98	Fair	Very rare	Contagious
63	*Ilex godajam* Colebr. ex Hook.f.	Aquifoliaceae	3	1.09	0.39	1.48	2.97	Fair	Rare	Contagious
64	*Lindera pulcherrima* (Nees) Hook. f.	Lauraceae	4	1.45	0.65	1.19	3.29	Fair	Rare	Regular
65	*Lithocarpus dealbatus* (Hook.f. & Thomson ex Miq.) Rehder	Fagaceae	11	0.73	1.69	0.23	2.65	Good	Common	Contagious
66	*Lithocarpus pachyphyllus* (Kurz) Rehder	Fagaceae	2	0.73	0.26	1.48	2.47	Good	Rare	Contagious
67	*Lithocarpus xylocarpus* (Kurz) Markgr.	Fagaceae	3	0.36	0.39	0.49	1.25	Good	Rare	Contagious
68	*Litsea salicifolia* (J. Roxb. ex Nees) Hook. f.	Lauraceae	4	0.73	0.65	0.59	1.97	Good	Rare	Contagious
69	*Macaranga denticulata* (Blume) Müll.Arg.	Euphorbiaceae	12	1.09	1.82	0.32	3.23	Good	Common	Contagious
70	*Macaranga peltata* (Roxb.) Müll.Arg.	Euphorbiaceae	12	0.73	1.82	0.21	2.76	Good	Common	Contagious
71	*Machilus glaucescens* (Nees) H.W.	Lauraceae	2	0.73	0.26	1.48	2.47	Good	Rare	Contagious
72	*Magnolia champaca* (L.) Baill. ex Pierre	Magnoliaceae	3	0.36	0.39	0.49	1.25	Good	Rare	Contagious
73	*Magnolia hodgsonii* (Hook.f. & Thomson) H.Keng	Magnoliaceae	3	0.36	0.39	0.49	1.25	Fair	Rare	Contagious
74	*Magnolia oblonga* (Wall. ex Hook.f. & Thomson) Figlar	Magnoliaceae	1	0.36	0.13	1.48	1.98	Good	Very rare	Contagious
75	*Mallotus philippensis* (Lam.) Müll.Arg.	Euphorbiaceae	6	1.09	0.91	0.64	2.64	Fair	Rare	Contagious

76	*Mangifera sylvatica* Roxb.	Anacardiaceae	1	0.36	0.13	1.48	1.98	None	Very rare	Contagious
77	*Mesua ferrea* L.	Calophyllaceae	30	1.82	4.69	0.21	6.71	Good	Doninant	Contagious
78	*Neolamarckia cadamba* (Roxb.) Bosser	Rubiaceae	1	0.36	0.13	1.48	1.98	None	Very rare	Contagious
79	*Neonauclea purpurea* (Roxb.) Merr.	Rubiaceae	3	0.73	0.39	0.99	2.11	Poor	Rare	Contagious
80	*Olea dioica* Roxb.	Oleaceae	15	2.18	2.34	0.49	5.02	Good	Common	Contagious
81	*Olea salicifolia* Wall. ex G.Don	Oleaceae	5	0.73	0.78	0.49	2.00	Good	Rare	Contagious
82	*Oreocnide integrifolia* (Gaudich.) Miq.	Urticaceae	1	0.36	0.13	1.48	1.98	Poor	Very rare	Contagious
83	*Oroxylum indicum* (L.) Kurz	Bignoniaceae	58	1.82	9.11	0.11	11.04	Good	Doninant	Contagious
84	*Ostodes paniculata* Blume	Euphorbiaceae	1	0.36	0.13	1.48	1.98	Poor	Very rare	Contagious
85	*Pandanus odorifer* (Forssk.) Kuntze	Pandanaceae	3	0.73	0.52	0.74	1.99	Poor	Rare	Contagious
86	*Prunus undulata* Buch.-Ham. ex D.Don	Rosaceae	1	0.36	0.13	1.48	1.98	Fair	Very rare	Contagious
87	*Pterospermum lanceifolium* Roxb.	Malvaceae	1	0.36	0.13	1.48	1.98	Poor	Very rare	Contagious
88	*Quercus glauca* Thunb.	Fagaceae	13	2.18	1.95	0.59	4.73	Good	Common	Regular
89	*Quercus oblongata* D.Don	Fagaceae	47	2.55	7.29	0.19	10.02	Good	Doninant	Contagious
90	*Rhus chinensis* Mill.	Anacardiaceae	10	1.09	1.56	0.37	3.02	Good	Common	Contagious
91	*Schima wallichii* Choisy	Theaceae	21	2.18	3.26	0.36	5.79	Good	Doninant	Contagious
92	*Sterculia villosa* Roxb.	Malvaceae	4	1.09	0.65	0.89	2.63	Good	Rare	Contagious
93	*Stereospermum tetragonum* DC.	Bignoniaceae	2	0.73	0.26	1.48	2.47	Fair	Rare	Contagious
94	*Styrax serrulatus* Roxb.	Styracaceae	6	1.45	0.91	0.85	3.21	Fair	Rare	Regular
95	*Symplocos racemosa* Roxb.	Symplocaceae	3	0.36	0.39	0.49	1.25	Good	Rare	Contagious
96	*Syzygium claviflorum* (Roxb.) Wall. ex A.M.Cowan & Cowan	Myrtaceae	19	1.82	2.99	0.32	5.14	Fair	Doninant	Contagious
97	*Syzygium cumini* (L.) Skeels	Myrtaceae	7	1.82	1.04	0.93	3.79	Good	Rare	Regular

98	*Tarennoidea wallichii* (Hook.f.) Tirveng. & Sastre	Rubiaceae	3	1.09	0.52	1.11	2.72	None	Rare	Regular
99	*Terminalia myriocarpa* Van Heurck & Müll. Arg.	Combretaceae	3	0.36	0.52	0.37	1.26	Good	Rare	Contagious
100	*Toona ciliata* M.Roem.	Meliaceae	6	0.36	0.91	0.21	1.49	Good	Rare	Contagious
101	*Toxicodendron succedaneum* (L.) Kuntze	Anacardiaceae	7	1.82	1.04	0.93	3.79	Good	Rare	Regular
102	*Trema orientalis* (L.) Bl.	Cannabaceae	16	1.09	2.47	0.23	3.80	Good	Common	Contagious
103	*Triadica cochinchinensis* Lour.	Euphorbiaceae	21	2.55	3.26	0.42	6.22	Poor	Doninant	Contagious
104	*Vernicia montana* Lour.	Euphorbiaceae	3	0.73	0.52	0.74	1.99	Poor	Rare	Contagious
105	*Vitex quinata* (Lour.) F.N.Williams	Lamiaceae	3	0.73	0.52	0.74	1.99	Good	Rare	Contagious
106	*Wendlandia budleioides* Wall. ex Wight & Arn.	Rutaceae	1	0.36	0.13	1.48	1.98	Good	Very rare	Contagious

1.3 Temperate forest

Sl No	Species name	Family	Density (ha^{-1})	Relative frequency (%)	Relative density (%)	Relative abundance (%)	Importance value index	Regeneration status	Species rarity	Distribution pattern
1	*Ailanthus integrifolia* Lam.	Simaroubaceae	5	1.61	0.97	1.63	4.21	Poor	Rare	Contagious
2	*Albizia chinensis* (Osbeck) Merr.	Fabaceae	3	0.54	0.48	1.09	2.11	Fair	Rare	Contagious
3	*Alseodaphne petiolaris* Hook.f.	Lauraceae	3	1.08	0.64	1.63	3.35	Fair	Rare	Contagious
4	*Anogeissus acuminata* (Roxb. ex DC.) Wall. ex Guillem. & Perr.	Combretaceae	15	1.61	2.90	0.54	5.05	Good	Common	Contagious
5	*Antidesma bunius* (L.) Spreng.	Phyllanthaceae	3	1.61	0.64	2.44	4.70	Fair	Rare	Random
6	*Aphananthe cuspidata* (Blume) Planch.	Cannabaceae	3	1.08	0.64	1.63	3.35	Fair	Rare	Contagious
7	*Archidendron bigeminum* (L.) I.C.Nielsen	Fabaceae	2	0.54	0.32	1.63	2.49	Fair	Rare	Contagious
8	*Balakata baccata* (Roxb.) Esser	Euphorbiaceae	3	1.08	0.64	1.63	3.35	Good	Rare	Contagious
9	*Betula alnoides* Buch.-Ham. ex D.Don	Betulaceae	4	1.08	0.81	1.30	3.18	Fair	Rare	Contagious
10	*Boehmeria rugulosa* Wedd.	Urticaceae	3	0.54	0.48	1.09	2.11	Poor	Rare	Contagious
11	*Bruinsmia polysperma* (C.B.Clarke) Steenis	Styracaceae	10	2.15	1.93	1.09	5.17	Poor	Common	Contagious
12	*Buddleja macrostachya* Benth.	Scrophulariaceae	1	0.54	0.16	3.26	3.95	Poor	Very rare	Contagious
13	*Callicarpa arborea* Roxb.	Lamiaceae	2	0.54	0.32	1.63	2.49	Good	Rare	Contagious
14	*Carallia brachiata* (Lour.) Merr.	Rhizophoraceae	1	0.54	0.16	3.26	3.95	Good	Very rare	Contagious
15	*Castanopsis indica* (Roxb. ex Lindl.) A.DC.	Fagaceae	4	0.54	0.81	0.65	1.99	Good	Rare	Contagious
16	*Castanopsis tribuloides* (Sm.) A.DC.	Fagaceae	30	4.84	5.80	0.81	11.45	Good	Dominant	Random
17	*Cephalotaxus mannii* Hook. f.	Taxaceae	1	0.54	0.16	3.26	3.95	Poor	Very rare	Contagious

18	*Chukrasia tabularis* A.Juss.	Meliaceae	4	1.08	0.81	1.30	3.18	Good	Rare	Contagious
19	*Cinnamomum glaucescens* (Nees) Hand.-Mazz.	Lauraceae	4	1.61	0.81	1.95	4.37	Fair	Rare	Contagious
20	*Cinnamomum tamala* (Buch.-Ham.) T.Nees & Eberm.	Lauraceae	4	0.54	0.81	0.65	1.99	None	Rare	Contagious
21	*Cinnamomum verum* J.Presl	Lauraceae	9	2.69	1.77	1.48	5.94	Poor	Common	Random
22	*Derris robusta (*DC.) Benth.	Fabaceae	12	2.69	2.25	1.16	6.11	Good	Common	Contagious
23	*Drimycarpus racemosus* (Roxb.) Hook.f. ex Marchand.	Anacardiaceae	10	1.61	1.93	0.81	4.36	Good	Common	Contagious
24	*Duabanga grandiflora* (DC.) Walp.	Lythraceae	19	3.23	3.70	0.85	7.78	None	Dominant	Contagious
25	*Dysoxylum alliaceum* (Blume) Blume	Meliaceae	1	0.54	0.16	3.26	3.95	Good	Very rare	Contagious
26	*Dysoxylum excelsum* Blume	Meliaceae	3	0.54	0.64	0.81	2.00	Good	Rare	Contagious
27	*Elaeocarpus rugosus* Roxb. ex G.Don	Elaeocarpaceae	7	2.15	1.29	1.63	5.07	Fair	Rare	Contagious
28	*Elaeocarpus tectorius* (Lour.) Poir.	Elaeocarpaceae	1	0.54	0.16	3.26	3.95	Fair	Very rare	Contagious
29	*Elaeocarpus tuberculatus* Roxb.	Elaeocarpaceae	1	0.54	0.16	3.26	3.95	Fair	Very rare	Contagious
30	*Engelhardtia spicata* Lechen ex Blume	Juglandaceae	28	4.30	5.31	0.79	10.40	Fair	Dominant	Contagious
31	*Ficus religiosa* L.	Moraceae	9	2.15	1.77	1.18	5.11	None	Common	Contagious
32	*Ficus tinctoria* G.Forst.	Moraceae	2	0.54	0.32	1.63	2.49	None	Rare	Contagious
33	*Glochidion heyneanum* (Wight & Arn.) Wight	Phyllanthaceae	1	0.54	0.16	3.26	3.95	Poor	Very rare	Contagious
34	*Gmelina arborea* Roxb.	Lamiaceae	6	1.61	1.13	1.40	4.14	Good	Rare	Contagious
35	*Helicia excelsa* (Roxb.) Blume	Proteaceae	23	2.69	4.35	0.60	7.64	Good	Dominant	Contagious
36	*Helicia robusta* (Roxb.) R.Br. ex Blume	Proteaceae	11	2.69	2.09	1.25	6.03	Fair	Common	Contagious
37	*Kydia calycina* Roxb.	Malvaceae	3	1.08	0.48	2.17	3.73	Fair	Rare	Contagious

38	*Lithocarpus elegans* (Blume) Hatus. ex Soepadmo	Fagaceae	3	1.61	0.64	2.44	4.70	Good	Rare	Random
39	*Lithocarpus polystachyus* (Wall. ex A.DC.) Rehder	Fagaceae	8	0.54	1.61	0.33	2.47	Good	Rare	Contagious
40	*Lithocarpus thomsonii* (Miq.) Rehder	Fagaceae	8	2.15	1.45	1.45	5.05	Good	Rare	Contagious
41	*Litsea semecarpifolia* (Wall. ex Nees) Hook.f.	Lauraceae	5	0.54	0.97	0.54	2.05	Good	Rare	Contagious
42	*Macaranga indica* Wight	Euphorbiaceae	4	1.61	0.81	1.95	4.37	Good	Rare	Contagious
43	*Macropanax undulatus* (Wall. ex G.Don) Seem.	Araliaceae	8	1.61	1.45	1.09	4.15	Fair	Rare	Contagious
44	*Magnolia champaca* (L.) Baill. ex Pierre	Magnoliaceae	9	2.15	1.77	1.18	5.11	Good	Common	Contagious
45	*Magnolia oblonga* (Wall. ex Hook.f. & Thomson) Figlar	Magnoliaceae	2	0.54	0.32	1.63	2.49	Fair	Rare	Contagious
46	*Mahonia napaulensis* DC.	Berberidaceae	3	1.08	0.48	2.17	3.73	None	Rare	Contagious
47	*Mallotus macrostachyus* (Miq.) Müll.Arg.	Euphorbiaceae	3	0.54	0.48	1.09	2.11	Poor	Rare	Contagious
48	*Nageia nagi* (Thunb.) Kuntze	Podocarpaceae	2	0.54	0.32	1.63	2.49	Poor	Rare	Contagious
49	*Neolitsea umbrosa* (Nees) Gamble	Lauraceae	7	1.08	1.29	0.81	3.18	Good	Rare	Contagious
50	*Ocotea lancifolia* (Schott) Mez	Lauraceae	4	1.61	0.81	1.95	4.37	Fair	Rare	Contagious
51	*Olea dioica* Roxb.	Oleaceae	4	1.08	0.81	1.30	3.18	Good	Rare	Contagious
52	*Olea salicifolia* Wall. ex G.Don	Oleaceae	4	0.54	0.81	0.65	1.99	Good	Rare	Contagious
53	*Ostodes paniculata* Blume	Euphorbiaceae	4	0.54	0.81	0.65	1.99	Good	Rare	Contagious
54	*Pinus roxburghii* Sarg.	Pinaceae	16	1.08	3.06	0.34	4.48	Good	Common	Contagious
55	*Quercus floribunda* Lindl. ex A.Camus	Fagaceae	51	3.23	9.82	0.32	13.37	Good	Dominant	Contagious
56	*Quercus helferiana* A.DC.	Fagaceae	8	1.61	1.45	1.09	4.15	Fair	Rare	Contagious

57	*Quercus lancifolia* Schltdl. & Cham.	Fagaceae	11	0.54	2.09	0.25	2.88	Good	Common	Contagious
58	*Quercus oblongata* D.Don	Fagaceae	18	2.69	3.38	0.78	6.85	Good	Dominant	Contagious
59	*Rhododendron arboreum* Sm.	Ericaceae	30	3.76	5.80	0.63	10.19	Good	Dominant	Contagious
60	*Rhus chinensis* Mill.	Anacardiaceae	12	3.23	2.25	1.40	6.88	Good	Common	Random
61	*Saurauia punduana* Wall.	Actinidiaceae	3	0.54	0.64	0.81	2.00	Poor	Rare	Contagious
62	*Schima wallichii* Choisy	Theaceae	9	2.69	1.77	1.48	5.94	Good	Common	Random
63	*Styrax serrulatus* Roxb.	Styracaceae	5	1.61	0.97	1.63	4.21	Poor	Rare	Contagious
64	*Syzygium cumini* (L.) Skeels	Myrtaceae	4	1.08	0.81	1.30	3.18	Good	Rare	Contagious
65	*Terminalia myriocarpa* Van Heurck & Müll. Arg.	Combretaceae	4	1.08	0.81	1.30	3.18	Good	Rare	Contagious
66	*Toona ciliata* M.Roem.	Meliaceae	4	1.61	0.81	1.95	4.37	Good	Rare	Contagious
67	*Trema orientalis* (L.) Blume	Cannabaceae	7	1.08	1.29	0.81	3.18	Good	Rare	Contagious
68	*Vitex peduncularis* Wall. ex Schauer	Lamiaceae	5	1.08	0.97	1.09	3.13	Fair	Rare	Contagious
69	*Wendlandia budleioides* Wall. ex Wight & Arn.	Rubiaceae	5	1.08	0.97	1.09	3.13	Poor	Rare	Contagious
70	*Xantolis hookeri*	Sapotaceae	2	0.54	0.32	1.63	2.49	Poor	Rare	Contagious
71	*Ailanthus integrifolia* Lam.	Simaroubaceae	5	1.61	0.97	1.63	4.21	Poor	Rare	Contagious

1.4 Quercus forest.

Sl No	Species name	Family	Density (ha^{-1})	Relative frequency (%)	Relative density (%)	Relative abundance (%)	Importance value index	Regeneration status	Species rarity	Distribution pattern
1	*Albizia chinensis* (Osbeck) Merr.	Fabaceae	3	1.34	0.88	1.89	4.12	Good	Rare	Contagious
2	*Albizia odoratissima* (L.f.) Benth.	Fabaceae	2	1.34	0.44	3.79	5.57	Poor	Rare	Contagious
3	*Alseodaphne petiolaris* Hook.f.	Lauraceae	1	0.67	0.22	3.79	4.68	Poor	Very rare	Contagious
4	*Alstonia scholaris* (L.) R. Br.	Apocynaceae	6	2.01	1.55	1.62	5.18	Good	Rare	Contagious
5	*Antidesma bunius* (L.) Spreng.	Phyllanthaceae	3	1.34	0.88	1.89	4.12	Good	Rare	Contagious
6	*Aporosa octandra* (Buch.-Ham. ex D.Don) Vickery	Phyllanthaceae	13	2.01	3.31	0.76	6.08	Good	Common	Contagious
7	*Artocarpus lacucha* Buch.-Ham.	Moraceae	4	1.34	1.10	1.51	3.96	Good	Rare	Contagious
8	*Betula alnoides Buch.-Ham. ex D.Don*	Betulaceae	2	0.67	0.44	1.89	3.01	None	Rare	Contagious
9	*Bischofia javanica* Blume	Phyllanthaceae	4	1.34	1.10	1.51	3.96	Fair	Rare	Contagious
10	*Calophyllum amblyphyllum* A.C.Sm. & S.P.Darwin	Clusiaceae	3	2.01	0.66	3.79	6.46	Fair	Rare	Random
11	*Castanopsis echinocarpa* Miq.	Fagaceae	1	0.67	0.22	3.79	4.68	Good	Very rare	Contagious
12	*Castanopsis tribuloides* (Sm.) A.DC.	Fagaceae	9	1.34	2.43	0.69	4.46	Good	Common	Contagious
13	*Cinnamomum bejolghota* (Buch.-Ham.) Sweet	Lauraceae	4	0.67	1.10	0.76	2.53	None	Rare	Contagious
14	*Derris robusta* (DC.) Benth.	Fabaceae	3	1.34	0.66	2.52	4.53	Good	Rare	Contagious
15	*Diospyros lanceifolia* Roxb.	Ebenaceae	5	1.34	1.32	1.26	3.93	Good	Rare	Contagious
16	*Duabanga grandiflora* (DC.) Walp.	Lythraceae	5	2.68	1.32	2.52	6.53	Good	Rare	Random

17	*Elaeocarpus lanceifolius* Roxb.	Elaeocarpaceae	3	2.01	0.66	3.79	6.46	Good	Rare	Random
18	*Ficus religiosa* L.	Moraceae	9	3.36	2.43	1.72	7.50	Fair	Common	Random
19	*Ficus semicordata* Buch.-Ham. ex Sm.	Moraceae	2	1.34	0.44	3.79	5.57	Fair	Rare	Contagious
20	*Glochidion lanceolarium* (Roxb.) Voigt	Phyllanthaceae	8	3.36	1.99	2.10	7.45	Fair	Rare	Random
21	*Gmelina arborea* Roxb.	Lamiaceae	3	1.34	0.66	2.52	4.53	Good	Rare	Contagious
22	*Gmelina oblongifolia* Roxb.	Lamiaceae	3	2.01	0.66	3.79	6.46	Good	Rare	Random
23	*Helicia excelsa* (Roxb.) Blume	Proteaceae	4	2.01	1.10	2.27	5.39	Good	Rare	Contagious
24	*Juglans regia* L.	Juglandaceae	3	1.34	0.66	2.52	4.53	None	Rare	Contagious
25	*Lithocarpus dealbatus* (Hook.f. & Thomson ex Miq.) Rehder	Fagaceae	3	0.67	0.66	1.26	2.60	Good	Rare	Contagious
26	*Lithocarpus elegans* (Blume) Hatus. ex Soepadmo	Fagaceae	29	3.36	7.73	0.54	11.62	Good	Dominant	Contagious
27	*Lithocarpus obscurus* C.C.Huang & Y.T.Chang	Fagaceae	14	3.36	3.75	1.11	8.22	Good	Common	Contagious
28	*Lithocarpus pachyphyllus* (Kurz) Rehder	Fagaceae	4	2.01	1.10	2.27	5.39	Good	Rare	Contagious
29	*Lithocarpus xylocarpus* (Kurz) Markgr.	Fagaceae	8	2.68	2.21	1.51	6.41	Good	Rare	Contagious
30	*Litsea monopetala* (Roxb.) Pers.	Lauraceae	9	2.01	2.43	1.03	5.47	Good	Common	Contagious
31	*Litsea salicifolia* (J. Roxb. ex Nees) Hook. f.	Lauraceae	3	1.34	0.88	1.89	4.12	Good	Rare	Contagious
32	*Machilus parviflora* Meisn.	Lauraceae	5	2.68	1.32	2.52	6.53	Good	Rare	Random
33	*Mesua ferrea* L.	Calophyllaceae	18	2.68	4.64	0.72	8.04	Good	Dominant	Contagious
34	*Olea dioica* Roxb.	Oleaceae	5	0.67	1.32	0.63	2.63	Good	Rare	Contagious
35	*Persea odoratissima* (Nees) Kosterm.	Lauraceae	6	2.68	1.55	2.16	6.39	Good	Rare	Random
36	*Phoebe angustifolia* Meisn.	Lauraceae	8	2.68	1.99	1.68	6.35	Good	Rare	Contagious

37	*Phyllanthus emblica* L.	Phyllanthaceae	8	3.36	1.99	2.10	7.45	Good	Rare	Random
38	*Quercus floribunda* Lindl. ex A.Camus	Fagaceae	16	2.68	4.19	0.80	7.68	Good	Common	Contagious
39	*Quercus glauca* Thunb.	Fagaceae	8	2.01	1.99	1.26	5.26	Good	Rare	Contagious
40	*Quercus griffithii* Hook.f. & Thomson ex Miq.	Fagaceae	40	4.03	10.60	0.47	15.10	Good	Dominant	Contagious
41	*Quercus helferiana* A.DC.	Fagaceae	12	3.36	3.09	1.35	7.80	Good	Common	Contagious
42	*Quercus semiserrata* Roxb.	Fagaceae	15	2.68	3.97	0.84	7.50	Good	Common	Contagious
43	*Quercus serrata* Murray	Fagaceae	28	2.68	7.51	0.45	10.64	Good	Dominant	Contagious
44	*Rhododendron arboreum* Sm.	Ericaceae	13	2.68	3.53	0.95	7.16	Fair	Common	Contagious
45	*Rhus chinensis* Mill.	Anacardiaceae	7	3.36	1.77	2.37	7.49	Good	Rare	Random
46	*Schima wallichii* Choisy	Theaceae	12	2.68	3.09	1.08	6.86	Good	Common	Contagious
47	*Syzygium graveolens* (F.M.Bailey) Craven & Biffin	Myrtaceae	3	1.34	0.88	1.89	4.12	Poor	Rare	Contagious
48	*Terminalia chebula* Retz.	Combretaceae	3	0.67	0.66	1.26	2.60	Good	Rare	Contagious
49	*Toona ciliata* M.Roem.	Meliaceae	1	0.67	0.22	3.79	4.68	Good	Very rare	Contagious
50	*Vitex quinata* (Lour.) F.N.Williams	Lamiaceae	1	0.67	0.22	3.79	4.68	Fair	Very rare	Contagious
51	*Ziziphus incurva* Roxb.	Rhamnaceae	2	1.34	0.44	3.79	5.57	Poor	Rare	Contagious

1.5 Bamboo forest.

Sl No	Species name	Family	Density (ha^{-1})	Relative frequency (%)	Relative density (%)	Relative abundance (%)	Importance value index	Regeneration status	Species rarity	Distribution pattern
1	*Albizia procera* (Roxb.) Benth.	Fabaceae	4	2.94	2.96	3.04	8.94	Fair	Rare	Contagious
2	*Artocarpus chama* Buch.-Ham.	Moraceae	2	1.96	1.18	5.07	8.21	None	Rare	Contagious
3	*Bombax ceiba* L.	Malvaceae	6	4.90	4.14	3.62	12.66	Poor	Rare	Random
4	*Callicarpa arborea* Roxb.	Lamiaceae	9	4.90	6.51	2.30	13.71	Fair	Common	Random
5	*Castanopsis indica* (Roxb. ex Lindl.) A.DC.	Fagaceae	5	2.94	3.55	2.53	9.02	Good	Rare	Contagious
6	*Castanopsis tribuloides* (Sm.) A.DC.	Fagaceae	10	4.90	7.10	2.11	14.11	Good	Common	Contagious
7	*Ceiba pentandra* (L.) Gaertn.	Malvaceae	4	3.92	2.96	4.05	10.93	None	Rare	Random
8	*Duabanga grandiflora* (DC.) Walp.	Lythraceae	7	4.90	4.73	3.17	12.80	None	Rare	Random
9	*Ficus hispida* L.f.	Moraceae	3	3.92	2.37	5.07	11.36	None	Rare	Random
10	*Gmelina arborea* Roxb.	Lamiaceae	7	3.92	4.73	2.53	11.19	Fair	Rare	Contagious
11	*Grevillea robusta* A.Cunn. ex R.Br.	Proteaceae	2	1.96	1.18	5.07	8.21	None	Rare	Contagious
12	*Haldina cordifolia* (Roxb.) Ridsdale	Rubiaceae	2	1.96	1.18	5.07	8.21	None	Rare	Contagious
13	*Hydnocarpus kurzii* (King) Warb.	Achariaceae	3	2.94	1.78	5.07	9.78	None	Rare	Random
14	*Litsea monopetala* (Roxb.) Pers.	Lauraceae	2	0.98	1.18	2.53	4.70	Fair	Rare	Contagious
15	*Macaranga denticulata* (Blume) Müll.Arg.	Euphorbiaceae	3	3.92	2.37	5.07	11.36	Good	Rare	Random
16	*Macaranga peltata* (Roxb.) Müll.Arg.	Euphorbiaceae	4	2.94	2.96	3.04	8.94	Good	Rare	Contagious
17	*Magnolia champaca* (L.) Baill. ex Pierre	Magnoliaceae	6	3.92	4.14	2.90	10.96	Poor	Rare	Random
18	*Mallotus floribundus* (Blume) Müll.Arg.	Euphorbiaceae	3	3.92	2.37	5.07	11.36	None	Rare	Random

19	*Mesua ferrea* L.	Calophyllaceae	10	4.90	7.10	2.11	14.11	Good	Common	Contagious
20	*Phyllanthus emblica* L.	Phyllanthaceae	5	1.96	3.55	1.69	7.20	Fair	Rare	Contagious
21	*Pterospermum acerifolium* (L.) Willd.	Malvaceae	2	1.96	1.18	5.07	8.21	None	Rare	Contagious
22	*Rhus chinensis* Mill.	Anacardiaceae	10	4.90	7.10	2.11	14.11	None	Common	Contagious
23	*Schima wallichii* Choisy	Theaceae	9	4.90	6.51	2.30	13.71	Good	Rare	Random
24	*Syzygium cumin*i (L.) Skeels	Myrtaceae	8	5.88	5.33	3.38	14.59	None	Rare	Random
25	*Tectona grandis* L.f.	Lamiaceae	3	2.94	1.78	5.07	9.78	None	Rare	Random
26	*Terminalia myriocarpa* Van Heurck & Müll. Arg.	Combretaceae	3	1.96	1.78	3.38	7.11	None	Rare	Contagious
27	*Toona ciliata* M.Roem.	Meliaceae	3	3.92	2.37	5.07	11.36	Poor	Rare	Random
28	*Trema orientalis* (L.) Blume	Cannabaceae	8	4.90	5.92	2.53	13.35	Good	Common	Random

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Sl No	Species name	Family	Density (ha^{-1})	Relative frequency (%)	Relative density (%)	Relative abundance (%)	Importance value index	Regeneration status	Species rarity	Distribution pattern
1	*Albizia procera* (Roxb.) Benth.	Fabaceae	3	3	5.00	2.52	7.22	14.74	Good	Rare
2	*Artocarpus heterophyllus* Lam.	Moraceae	3	3	2.50	2.52	3.61	8.63	None	Rare
3	*Bauhinia variegata* L.	Fabaceae	6	5	5.00	5.04	3.61	13.65	Good	Rare
4	*Bischofia javanica* Blume	Phyllanthaceae	1	1	2.50	0.84	10.82	14.16	Poor	Very rare
5	*Bombax ceiba* L.	Malvaceae	3	3	5.00	2.52	7.22	14.74	Fair	Rare
6	*Callicarpa arborea* Roxb.	Lamiaceae	15	13	10.00	12.61	2.89	25.49	Fair	Common
7	*Cassia fistula* L.	Fabaceae	1	1	2.50	0.84	10.82	14.16	Poor	Very rare
8	*Castanopsis indica* (Roxb. ex Lindl.) A.DC.	Fagaceae	4	3	2.50	3.36	2.71	8.57	Good	Rare
9	*Castanopsis tribuloides* (Sm.) A.DC.	Fagaceae	10	8	7.50	8.40	3.25	19.15	Good	Rare
10	*Duabanga grandiflora* (DC.) Walp.	Lythraceae	7	6	5.00	5.88	3.09	13.97	None	Rare
11	*Erythrina variegata* L.	Fabaceae	4	3	2.50	3.36	2.71	8.57	Poor	Rare
12	*Leea indica* (Burm. f.) Merr.	Vitaceae	1	1	2.50	0.84	10.82	14.16	Fair	Very rare
13	*Macaranga indica* Wight	Euphorbiaceae	9	8	7.50	7.56	3.61	18.67	Good	Rare
14	*Phoebe hainesiana* Brandis	Lauraceae	3	3	2.50	2.52	3.61	8.63	None	Rare
15	*Phyllanthus emblica* L.	Phyllanthaceae	3	3	2.50	2.52	3.61	8.63	Poor	Rare
16	*Pterospermum acerifolium* (L.) Willd.	Malvaceae	6	5	2.50	5.04	1.80	9.35	Poor	Rare

17	*Rhus chinensis* Mill.	Anacardiaceae	12	10	10.00	10.08	3.61	23.69	Good	Common
18	*Schima wallichii* Choisy	Theaceae	11	9	7.50	9.24	2.95	19.70	Good	Common
19	*Tectona grandis* L.f.	Lamiaceae	2	2	2.50	1.68	5.41	9.59	Fair	Rare
20	*Toona ciliata* M.Roem.	Meliaceae	4	3	2.50	3.36	2.71	8.57	Good	Rare
21	*Trema orientalis* (L.) Blume	Cannabaceae	11	9	10.00	9.24	3.94	23.18	Good	Common

Appendix 2 Family-wise distribution of tree species richness (S), genera (G) and density (D) (ha^{-1}) of the selected six forest types of Mizoram (Includes only the tree species of DBH >10 cm).

Family	TWEF			MSTF			TF			QF			BF			JL		
	S	G	D	S	G	D	S	G	D	S	G	D	S	G	D	S	G	D
Achariaceae	1	1	1	1	1	7							1	1	3			
Actinidiaceae							1	1	3									
Anacardiaceae	3	2	4	6	6	28	2	2	22	1	1	7	1	1	10	1	1	10
Annonaceae	3	2	18	2	1	3												
Apocynaceae										1	1	6						
Aquifoliaceae				1	1	3												
Araliaceae	3	2	6	1	1		1	1	8									
Arecaceae	1	1	1			3												
Berberidaceae							1	1	3									
Betulaceae				1	1	1	1	1	4	1	1	2						
Bignoniaceae	2	1	7	2	2	60												
Boraginaceae	1	1	1															
Burseraceae	2	2	2	1	1	3												
Calophyllaceae	2	2	46	1	1	30				1	1	18	1	1	9			
Cannabaceae	2	2	9	1	1	16	2	2	10				1	1	8	1	1	9
Clusiaceae	3	1	11	3	2	6				1	1	3						
Combretaceae	5	1	13	2	2	6	2	2	19	1	1	3	1	1	3			
Cornaceae				1	1	1												

Dilliniaceae	1	1	1															
Dipterocarpaceae	1	1	4															
Ebenaceae	4	1	26	2	1	7				1	1	5						
Elaeocarpaceae	1	1	3	3	1	12	3	1	8	1	1	3						
Ericaceae							1	1	30	1	1	13						
Euphorbiaceae	3	3	19	10	7	60	4	4	14				3	2	11	1	1	8
Fabaceae	9	8	131	7	5	11	3	3	16	3	2	8	1	1	4	4	4	12
Fagaceae	6	3	157	7	3	97	9	3	140	13	3	187	2	1	15	2	1	12
Juglandaceae				1	1	20	1	1	28	1	1	3						
Lamiaceae	7	4	55	2	2	11	3	3	13	3	2	6	3	3	17	2	2	14
Lauraceae	8	5	71	8	6	32	7	5	37	8	6	36	1	1	2	1	1	3
Lythraceae	2	2	4	1	1	3	1	1	19	1	1	5	1	1	7	1	1	6
Magnoliaceae	4	1	13	3	1	6	2	1	11				1	1	6			
Malvaceae	6	6	47	5	4	20	1	1	3				3	3	14	2	2	8
Meliaceae	9	6	28	4	3	14	4	3	13	1	1	1	1	1	3	1	1	3
Moraceae	9	2	17	5	2	23	2	1	11	3	2	15	2	2	5	1	1	3
Myristicaceae	2	1	6															
Myrtaceae	5	1	23	2	1	24	1	1	4	1	1	3	1	1	8			
Oleaceae				3	2	22	2	1	8	1	1	5						
Pandanaceae				1	1	3												
Pentaphylacaceae	1	1	1	1	1	1												
Phyllanthaceae	5	4	31	3	3	7	2	2	4	4	5	34	1	1	5	2	2	4
Pinaceae							1	1	16									

Podocarpaceae							1	1	2									
Primulaceae	1	1	1															
Proteaceae				1	1	27	2	1	30	1	1	4	1	1	2			
Putranjivaceae	1	1	15															
Rhamnaceae										1	1	2						
Rhizophoraceae	1	1	1				1	1	1									
Rosaceae	1	1	1	2	2	14												
Rubiaceae	5	5	31	3	3	7	1	1	5				1	1	2			
Rutaceae	1	1	8	3	3	14												
Salicaceae	1	1	3	1	1	1												
Sapindaceae	3	3	22															
Sapotaceae	2	2	2				1	1	2									
Scrophulariaceae							1	1	1									
Simaroubaceae							1	1	5									
Styracaceae				2	2	10	2	2	14									
Symplocaceae				1	1	3												
Taxaceae							1	1	1									
Tetramelaceae	1	1	4															
Theaceae	1	1	23	1	1	20	1	1	9	1	1	11	1	1	8	1	1	7
Thymelaeaceae	1	1	6	1	1	2												
Urticaceae				1	1	1	1	1	3									
Vitaceae	1	1	7													1	1	1
Total:	**131**	**89**	**880**	**107**	**82**	**639**	**70**	**55**	**517**	**51**	**37**	**377**	**28**	**26**	**140**	**21**	**20**	**99**

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LIST OF RESEARCH PUBLICATION(S)

(A). Paper Published in Peer Reviewed International Journals:-

1. Ahirwal, J., Gogoi, A. and Sahoo, U. K. (2022). Stability of soil organic carbon pools affected by land use and land cover changes in forests of eastern Himalayan region, India. *Catena.* (**ELSEVIER**)- Communicated.

2. Gogoi, A., Ahirwal, J. and Sahoo, U. K. (2022). Evaluation of ecosystem carbon storage in major forest types of Eastern Himalaya: Implications for carbon sink management. *Journal of Environmental Management,* **302:** 113972. (**ELSEVIER**).

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10. Kenye, A, Sahoo, U. K., Singh, S. L., Gogoi, A. (2018). Soil organic carbon stock of different land uses of Mizoram, Northeast India. *AIMS Geosciences*, **5 (1):** 25–40.

(B). Paper Published in National Journals.

1. Kenye, A. Sahoo, U. K., Singh, S. L. and Gogoi, A. (2019). Effect of Four Land uses on Soil Edaphic Properties and Soil Organic Carbon Stock in Mizoram, North-East India. *Indian Forester,* **145 (12):** 1139-1146.

PAPER PRESENTED IN CONFERENCE/SEMINAR/SYMPOSIUM:-

1 7th international Science Congress-2017. Organized by International Science Community Association & Collage of Science and Technology, Royal University of Bhutan, Bhutan.

2. International Conference on Harnessing the Sub-Himalayan Diversity for Human Welfare-2015. Organized by Dibrugarh University, Dibrugarh, Assam.

3. International Conference on Chemistry and Environment Sustainability (ICCES-1019). Organized by Department of Chemistry, Mizoram University, Aizawl, Mizoram.

4. International Symposium on Oak Forest- 2019. Organized by GIZ and Sikkim Forest Department, Gangtok, Sikkim.

5. National Seminar on Biodiversity, Conservation and Utilization of Natural Resources With Reference to North-East India (BCUNRNEI)-2017. Organized by Department of Botany, Mizoram University, Aizawl, Mizoram.

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1. International Workshop and Training on Hydro-Meteorological Monitoring and Watershed Management- 2017. Organized by Mizoram University, University of Minnesota and Mississippi Watershed Management Organization.

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ABSTRACT

VARIATION IN BIOMASS, CARBON STOCK AND CARBON SEQUESTRATION POTENTIAL OF SELECTED FORESTS OF MIZORAM

THESIS SUBMITTED IN FULFILMENT OF THE DEGREE AWARD
OF
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DEPARTMENT OF FORESTRY,
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ABSTRACT

The global scientific community has realized that the issue of climate change and biodiversity loss is interrelated and these issues are needed to be tackled together instead of viewing it separately. The relationships between forest type, biodiversity and ecosystem services like carbon sequestration are highly relevant for forming forest policy and management plans. Mizoram being part of the Eastern Himalaya biodiversity hotspot region is rich in flora and fauna and also threatened with various types of anthropogenic activities. Hence, priority conservation areas need to be identified and protected in terms of both species diversity and carbon storage. However, lack of systematic studies covering all the major forest types of the state is the biggest hindering towards the achievement of these sustainable development goals. Numerous studies have been carried out to estimate carbon storage patterns in the forests of North East India particularly in the forests of the Barak and Brahmaputra valleys (Nath et al., 2017; Gogoi et al., 2021). However, comprehensive studies to understand the plant biodiversity, C stock, and sequestration potential of the North East Indian forests and its relation to the environmental factors are limited. The varied topographical differences in the hilly state of Mizoram provide scope for understanding the effect of environmental driving factors and soil nutrients on plant diversity and ecosystem carbon stock of the different forest types in this region. Besides large variation in the environmental and topographical conditions, Mizoram has the highest forest cover (84.53 %) among all the Indian states in terms of percentage to the total geographical area (ISFR, 2021). However, it is not clear that whether or not forest cover increases carbon storage as compared to those Indian states which are having the highest forest cover. Moreover, it is very important to identify the richest forest types of the state in terms of both species diversity and carbon storage for future developmental strategies. Thus, a proper study to understand the plant diversity and carbon sequestration potential of major forest types of Mizoram and its relation to environmental factors and soil nutrients is of prime importance in the current scenario.

The present study was carried out selecting all the major forest types of Mizoram with the following major objectives:-

1. To investigate plant diversity, composition and vegetation structure of the study area.
2. To assess the variation in soil organic carbon stock and its influencing factors in selected forest types.
3. To estimate the variation in biomass, total carbon stock and carbon sequestration potential of the selected forest types.
4. To correlate the effect of environmental factors and soil nutrients on plant diversity and carbon storage pattern in the selected forest types.

Six major forest types were selected in four districts of Mizoram based on the forest classification described by Singh et al. in 2002. These are namely: - 1. tropical wet evergreen forest, 2. montane subtropical forest, 3. temperate forest, bamboo forest, 5. *Quercus* forest and 6. Jhum land. The sampling sites of the tropical wet evergreen forest were selected in the Dampa Tiger Reserve; the sampling sites for the montane sub-tropical forest were selected in the Riek Community Forest; for temperate forest sampling sites were selected in Phawngpui National Park; sampling sites for the Quercus forest were selected in the Lengteng Wildlife Sanctuary; sampling sites for the bamboo forest and jhum lands were selected in Lengpui and Sakawrtuichhun area of Aizawl District respectively.

The first round of field survey was carried out in the year 2016 and the same was repeated after two years. In each forest type, three major permanent plots of 250 m × 250 m size were demarcated following ISRO-GBP/NCP-VCP protocol (Singh and Dadhwal, 2009) wherein, vegetation and biomass sampling were carried out. The major plots were selected in such a way that the effect of anthropogenic disturbance could be negligible. Reconnaissance surveys were carried out before selecting the sampling sites to find out homogeneous, least disturbed forest sites. The species diversity, composition and plant community structure was analysed following standard methods and biomass, carbon stock and carbon sequestration potential was estimated following non-destructive methods.

The study provides an account of the species diversity, composition and structure of the major forest types of Mizoram. The present study results reveal that the primary forests were richer in species diversity, composition and structure as compared to the secondary forests i.e., bamboo forests and jhum land. Species poor condition in the secondary forests was mainly associated with the past anthropogenic disturbances. However, fair regeneration in bamboo forests and good regeneration in jhum land indicates that these forests have the future potential to harbour regional species diversity as same as a neighbouring primary forest. Therefore, intensive management of the bamboo forests as well as in the jhum land is required to maintain substantial tree diversity in those land uses, which will also be helpful for mitigating climate change as well as for soil conservation in the state. Time to time harvesting of matured bamboo culms and increasing the jhum fallow age may be useful to achieve these goals. Understanding species diversity and distribution patterns is important for helping managers to evaluate the complexity and resources of a particular forest. Tropical wet evergreen forest was found to be the richest in terms of species richness (131 tree species belonging to 89 genera and 42 families) and the lowest species richness was observed in the jhum land (21 species belonging to 20 genera and 14 families). *Castanopsis tribuloides* (Sm.) A.DC., *Calliandra umbrosa* (Wall.) Benth., *Mesua ferrea* L., *Helicia excelsa* (Roxb.) Blume, *Oroxylum indicum* (L.) Kurz, *Quercus oblongata* D. Don, *Engelhardtia spicata* Lechen ex Blume, *Quercus floribunda* Lindl. ex A. Camus, *Lithocarpus elegans* (Blume) Hatus. ex Soepadmo, *Quercus griffithii* Hook.f. & Thomson ex Miq. and *Quercus serrata* Murray are the dominant tree species in the primary forests and *Castanopsis tribuloides* (Sm.) A.DC., Rhus chinensis Mill., *Schima wallichii Choisy*, *Bischofia javanica* Blume, *Cassia fistula* L. and *Leea indica* (Burm. f.) Merr. were the dominant tree species in the secondary forests. Lauraceae, Miliaceae, Moraceae, Anacardiaceae, Euphorbiaceae, Fabaceae, Fagaceae, Lamiaceae, and Phyllanthaceae were the dominant families in the primary forests while; 135 Euphorbiaceae, Lamiaceae, Malvaceae, Moraceae, Fabaceae, Fagaceae, Lamiaceae and Phyllanthaceae were the dominant families in the secondary forests. These findings may be useful for prioritising selected forest types for future policy making in the state. Additionally, the study results may provide insight into forest management and ecological study that would be applicable to other similar forest types of NE India. However, only the tree component was included for plant diversity assessment in the present study due to limited time and resources. Therefore, it is suggested to include herbs, shrubs, woody and non woody climbers and epiphytes in future studies for better understanding of species diversity and composition in the major forest types of Mizoram. Establishing permanent sampling plots in all the major forest types to study the forest dynamics in terms of species diversity, composition, structure, biomass accumulation, species recruitment etc. is a must needed step towards the sustainable management of the forests of Mizoram.

This study also systematically demonstrates the differences in soil physical and chemical properties, carbon stability and SOC stock among the major forest types of Mizoram which will be helpful in the future management of natural carbon sink under land use and climate change scenario. Based on the objectives of the study and subsequent field analysis, this study concludes that temperate forests of Mizoram had the highest SOC stock and plays a vital role in carbon cycling and climate regulations. The percentage contribution of active carbon to TOC was highest in the temperate forests but slow and passive carbon was higher in montane sub-tropical forests that indicate a dominant role of these forests in long-term carbon sequestration in the state. LULC significantly reduced the SOC stock of the major forests that become more pronounced when temperate forests were converted to jhum lands. The finding of this study also highlights that the conversion of primary forests to the secondary forests i.e., bamboo forests and jhum lands reduces carbon sink capacity and stability of the carbon pool varied with the soil depth. Additionally, soil organic carbon stock 136 in the study area is significantly influenced by plant biomass, plant structural attributes, plant diversity and soil physical and chemical properties.

Quantifying biomass and carbon sequestration in different forest types of Mizoram has significant concern for improving nation's carbon accounting, to support the formulation of better climate policies and future projection of climate change. Also, it can contribute positively to the UNFCCC agenda of forest conservation, sustainable management of forests, and enhancement of forest carbon stocks in developing countries (REDD+) like India. This study results presents the baseline data on biomass, carbon stock and carbon sequestration potential of the major forest types of Mizoram which may be useful for regional level policy making to combat climate change in Mizoram. From the present study it can be concluded that the primary forests demonstrate larger carbon sink capacity than the secondary forests. Our estimates showed lesser ecosystem carbon stock in jhum lands which is mainly associated with the younger age of the jhum lands and past disturbance history; however, with the increasing age, these forests can accumulate a greater amount of atmospheric carbon in plants and soils and act as terrestrial carbon sink. Component wise breakup of the carbon stock showed that the maximum carbon was stored in the soil followed by aboveground and belowground biomass components. The tropical wet evergreen forest possessed the highest amount of ecosystem carbon storage and also had the maximum carbon sequestration potential among all the selected forest types. Other selected primary forest types i.e., montane sub-tropical forest, temperate forest and *Quercus* forest also showed better carbon sick potential as compared to the secondary forests. Therefore, adequate emphasis must be taken for better management of the primary forests in order to have maximum carbon storage. Present study results also suggested that land use change had significant impact on ecosystem carbon storage. Among all the primary forest types, the maximum loss in total ecosystem carbon sequestration rate was observed when tropical wet evergreen forests were 137 converted to jhum lands. Therefore, it is also suggested to adapt maximum protection measures in those forest areas by the State Govt. However, organizing awareness programmes, providing alternative livelihood to the jhumiyas may be helpful towards the eradication of these problems. Governmental initiative must also be taken for successful implementation of the agroforestry models specially developed for North East India.

Artocarpus chama Buch.-Ham., *Aporosa octandra* (Buch.-Ham. ex D. Don) Vickery, *Duabanga grandiflora* (D C.)Walp. , *Ficus religiosa* L., *Magnolia champaca* (L.) Baill.ex Pierre, *Mesua ferrea* L., *Terminalia chebula* Retz., *Terminalia myriocarpa* Van Heurck & Müll. Arg., *Tectona grandis* L.f., *Gmelina arborea* Roxb., *Haldina cordifolia* (Roxb.) Ridsdale, *Phoebe hainesiana* Brandis, *Bombax ceiba* L. and *Helicia excelsa* (Roxb.) Blume were the dominant tree species in the primary forests in terms of carbon sequestration. Whereas, *Albizia procera* (Roxb.) Benth., *Callicarpa arborea* Roxb., *Macaranga indica* Wight, *Schima wallichii* Choisy, *Rhus chinensis* Mill. and *Trema orientalis* (L.) Blume possessed highest carbon sequestration in the secondary forests.

From the present study results it can be substantiate that species diversity is determined by the combined effects of environmental factors, edaphic factors and plant structural attributes. Findings of the present study highlight that the underlying ecosystem factors shaping the plant community composition, diversity and thus affecting the ecosystem carbon storage. Structural (density and basal area) and environmental attributes (altitude) had stronger effect than species diversity on forest carbon storage in the present study. It is further observed that structural attributes had more bearing on ecosystem carbon storage than functional or phylogenetic diversity, environmental factors and soil nutrients. Therefore, it is suggested to adopt necessary measures to enhance plant structural quality in the studied forests so as to achieve maximum carbon storage. However, it is recommended to include environmental factors, edaphic factors and plant structural attributes for predicting regional diversity; and both plant structural attributes and environmental factors for predicting ecosystem carbon storage in present and future changing climate and also in making conservation strategies related to carbon sink management in the study area. Additionally, establishing permanent plots with installation of adequate environmental data monitoring facilities in all the major forest types may be useful for better understanding of the long term effect of different ecosystem parameters on species diversity and forest carbon storage.