EFFECTS OF ANTHROPOGENIC DISTURBANCE ON TREE COMMUNITY CHARACTERISTICS AND CARBON STOCK IN THE FORESTS OF AIZAWL DISTRICT, MIZORAM

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

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EFFECTS OF ANTHROPOGENIC DISTURBANCE ON TREE COMMUNITY CHARACTERISTICS AND CARBON STOCK IN THE FORESTS OF AIZAWL DISTRICT, MIZORAM

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SUPERVISOR'S CERTIFICATE

This is to certify that the Thesis entitled **"Effects of anthropogenic disturbance on tree community characteristics and carbon stock in the forests of Aizawl District, Mizoram"** submitted by **Elizabeth Nemhoihkim** for the degree of Doctor of Philosophy (Ph.D.) in **Environmental Science**, embodies the record of original investigation carried out by her under my guidance and supervision. This Thesis or any part thereof has not been submitted for any degree of any other University.

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DECLARATION

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I **Elizabeth Nemhoihkim**, hereby declare that the subject matter of this thesis is the record of work done by me, that the contents of this thesis did not form basis of the award of any previous degree to me or to do the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University/Institute.

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LIST OF ABBREVIATIONS

A:F	Abundance-to-Frequency ratio (Whitford index)
AGB	Aboveground biomass
ANOVA	Analysis of variance
BD	Bulk Density
BGB	Belowground biomass
C:N	Carbon-to-Nitrogen ratio
CR	Critically Endangered
D	Simpson’s dominance index
dbh	Diameter at breast height
DD	Data deficient
DI	Disturbance Index
Dmg	Margalef’s species richness index
EN	Endangered
EW	Extinct in the wild
EX	Extinct
FAO	Food and Agriculture Organization
g cm^{-3}	grams per cubic centermetre
gbh	Girth at breast height
H´	Shannon-Wiener index
HD	Highly disturbed
IDH	Intermediate Disturbance Hypothesis
IPCC	Intergovernmental Panel on Climate Change
ISFR	India State of Forest Report
IUCN	International Union for Conservation of Nature
IVI	Importance Value Index
J	Pielou’s evenness index
K	Available Potassium
kg ha^{-1}	Kilograms per hectare
LC	Least concern
$m2ha^{-1}$	Square metres per hectare
MD	Moderately disturbed
Mg ha^{-1}	Megagrams per hectare
NA	Not applicable
NE	Not evaluated

NGO	Non-Governmental Organization
NT	Near threatened
P	Available Phosphorus
REDD+	Reducing Emissions from Deforestation and Forest Degradation
S_E	Sorensen similarity index
SMC	Soil Moisture Content
SOC	Soil Organic Carbon
t ha^{-1}	Tonnes per hectare
TN	Total Nitrogen
UD	Undisturbed
VU	Vulnerable

Chapter 1

INTRODUCTION

1.1 Overview

Forests sustain about 80% of the total terrestrial biodiversity and are among the very dynamic ecosystems on earth. They also act as a storehouse for carbon and helps in mitigating climate change (FAO, 2020; Watson et al., 2000). According to Franklin et al. (2002), the structure and composition of a forest depend on biotic factors (living components) and the abiotic factors (climate, type of soil, topography). Over the last few decades, forest change due to anthropogenic activities has become a great concern (Bellasse and Luyssaert, 2014; Haq et al., 2022). Activities such as selective logging, agricultural expansion and urbanisation have caused alteration in species diversity, forest composition, and ecosystem functions like water cycle and nutrient cycle disruption (Kumar et al., 2024). When forests are disturbed, they shift their role from carbon sinks to carbon sources by releasing stored carbon into the atmosphere (Pan et al., 2013). Therefore, it is very important to understand the effect of anthropogenic disturbance on tree community characteristics and carbon stock in the forest (Luyssaert et al., 2008).

1.2 Forest ecosystem biodiversity

Forests are ecological systems with preponderance of trees. According to the Food and Agriculture Organization, a forest is an area larger than 0.5 ha that comprises trees taller than 5 m and canopy cover greater than 10% (FAO, 2020). This definition encompasses a broad range of forest types, from dense tropical rainforests to open woodland areas, each supporting unique assemblages of species. The forest is a type of vegetation predominantly occupied by plants with clear cut bole, for which diameter at breast height (dbh) can easily be measured.

Forest ecosystem is made up of multiple layers of vegetation. Tall trees form the upper canopy, and receives maximum sunlight, while smaller trees and shrubs occupy the middle layer and saplings and non-woody vegetation occupy the bottom which receives the least sunlight, and the forest floor is normally covered with litter

(Spies, 1998). All these layers create diverse microhabitats that support a wide variety of flora and fauna.

The term “biodiversity” was coined for the first time by an American scientist named Walter G. Rosen in 1985. The word biodiversity is derived from the Greek word “bios,” which means life, and the Latin word “diversitas,” which means variety. So, it means variety of life on earth. Biodiversity, often referred to as biological diversity, describes the variety of living organisms found at every level of life (Convention on Biological Diversity, 1992). Biodiversity has been categorized at three main levels: genetic, species and ecosystem levels (Noss, 1990). Genetic diversity means the range of genetic differences found within individuals or population of a species. This variation helps species adjust to changing environments and improves their chances of survival over time (Frankham et al., 2002). Population with greater genetic variety are usually better at withstanding stress such as disease or climate shifts, reducing the possibility of extinction. Species diversity describes the variety of individual species present in an area and the even distribution of individuals among them (Magurran, 2004). Ecosystems exhibiting a high level of species diversity have higher resilience towards ecological disturbance. Ecosystem diversity means the presence of different types of habitats and ecological systems within a region (Hunter and Gibbs, 2006). Forests, grasslands, wetlands and desert are examples, each of which supports different groups of plants and animals and provides distinct ecological services. All the three levels of biodiversity are interconnected which means a change at one level can affect the others. Together, these levels decide the overall health and strength of the natural environment.

The biodiversity hotspot is an area that holds large number of species including endemic species, making them global priorities for conservation (Myers et al., 2000). Norman Myers first introduced this concept in 1988 to highlight regions where protecting nature would have the greatest benefit for the earth’s biodiversity (Myers, 1988). For a region to be classified as a biodiversity hotspot, it must have minimum 1,500 endemic plant species and must have lost at least 70% of its initial vegetation (Myers et al., 2000). At present, there are 36 such hotspots around the world, occupying only about 2.4% of Earth’s land area but supporting more than half of all plant species and roughly 43% of vertebrate species that are unique to these areas.

These regions face serious anthropogenic pressures such as deforestation, farming expansion, urban growth, and climate change, making them vital targets for conservation and sustainable management (Brooks et al., 2002). It is essential to protect biodiversity hotspots to conserve diversity, to maintain ecosystem services and to regulate the global climate.

Trees are the main component of forest ecosystems. According to Gamfeldt et al. (2013), forests with a large variety of tree species are more productive and more resilient to disturbance. The environmental factors viz., temperature, elevation, rainfall, etc., species interactions, and past natural or anthropogenic disturbances all influence the diversity and composition of tree species (Poorter et al., 2015). In order to protect and manage forests, it is crucial to understand how tree diversity reacts to different environmental factors and anthropogenic activity (Xu et al., 2017). The management strategies should aim to preserve soil health, enhance carbon capture, and maintain the stability and recovery capacity of forest ecosystems (Adhikari and Hartemink, 2016).

The FAO (2020) has defined biodiversity in forest ecosystem as a variety of life forms (both flora and fauna) found in freshwater and terrestrial environments, as well as ecological interactions that maintain the forest health and stability. It incorporates the diversity seen within a single species, between species, and throughout entire ecosystem (Brienen et al., 2015).

There are various ecological parameters and indices that calculate the tree community characteristics of a forest. Species richness helps in understanding the diversity of species in the forest, species evenness indicates the distribution of individuals among species and species dominance calculate the dominant species in the region (Dar and Sundarapandian, 2013; Gairola et al., 2011). The quantitative characteristics of trees viz., density, girth size, basal area, frequency, density, and abundance help in understanding the forest structure (Malik and Bhatt, 2016). The tree distribution pattern of a forest depends on factors like microclimatic conditions, soil characteristics, competition, and past natural or anthropogenic disturbances, resulting in clumped, random, or regular pattern of distribution (Haq et al., 2023; Shaheen et al., 2011). The Importance Value Index (IVI) is used to identify the most dominant and ecologically important species (Dar and Khuroo, 2020). The age and successional stage of the forest are very important for determining overall biodiversity and community structure (Kohl et al., 2015).

1.3 Soil characteristics

Soil is very essential in the process of nutrient cycling, and carbon storage (Lal, 2005). Soil directly influences tree growth, species composition, and the overall functioning of the forest (Adhikari and Hartemink, 2016). The soil has better structure, pore space and organic matter in undisturbed forest while the disturbed areas have poorer soil quality (Lal, 2005).

The physical properties of the soil include temperature, texture, structure, water holding capacity, porosity, bulk density, and moisture content (Osman, 2012). Bulk density is the dry weight of soil per unit volume (Daddow, 1983). Low bulk density value represents well-structured soil. The soil texture, which is determined on the concentration of sand, silt and clay, affects how much water and nutrients can be stored by the soil and how air moves through it (Dexter, 2004).

The chemical properties of soil include pH, cation exchange capacity, nutrient availability, and base saturation which strongly influences the growth and distribution of forest vegetation. Soil pH plays a major role in how nutrients dissolve, how microbes work, and how some elements become available or harmful to plants (Neina, 2019). Soil rich in organic carbon and nutrients usually support higher productivity. Phosphorus, potassium and nitrogen are the macronutrients that are easily accessible when the soil is slightly acidic to nearly neutral, that is pH between 6.0 to 7.0. Micronutrients such as iron, manganese, and zinc are more easily available when the soil is moderately acidic, with pH between 5.0 and 6.5. Trees in forest grow best in soils having pH between 5.5 and 7.0, though some species can survive in more acidic or more alkaline soil (Binkley and Fisher, 2019).

Organic matter in soil is formed when animal and plant materials decompose. It offers necessary nutrients, improves soil structure, and stores carbon (Bot and Benites, 2005). The carbon-to-nitrogen (C:N) ratio in the soil differs along the disturbance gradient with the undisturbed forest having the lower value when compared to the disturbed stands. A high C:N ratio indicates poor fertility of the soil (Manral et al., 2020).

The living component of the soil includes a wide variety of organisms, from bacteria and fungi to larger organisms like arthropods. These organisms help in cycling of nutrients, decomposition, and the overall operation of the ecosystem (Bardgett and Van Der Putten, 2014). Nitrogen-fixing microorganisms play an important role in nitrogen fixation, nitrification and denitrification, which help regulate the amount of nitrogen accessible to plants. The microbial activities in soil are extremely sensitive to soil conditions like shift in pH, temperature and moisture.

1.4 Forest carbon stock

Carbon stock refers to the amount of carbon contained in a carbon pool, meaning a reservoir or sink that has the potential to store carbon (IPCC, 2006). In forests, carbon is distributed across several pools, viz., aboveground biomass such as leaves, branch and stem, belowground biomass in the roots, deadwood, litter and soil (FAO, 2020). A forest's carbon storage capacity is determined by factors like the type, age, management practices and local microclimatic condition of the forest (Pan et al., 2011).

Aboveground biomass (AGB) refers to all the living parts of trees, shrubs, and herbs that grow above the ground and account for a high amount of carbon stored in a forest (Brown et al., 1989). In mature forests, tree trunks contribute the maximum biomass in tree trunks when compared to branches, twigs, and foliage (Chhabra et al., 2002). The AGB of trees is measured using allometric equations requiring the tree height and girth and the equation may be either species specific or applied to a forest type (Cairns et al., 1997).

Belowground biomass (BGB) refers to the living plant roots and stores a good amount of carbon in forest ecosystems (Sharma et al., 2010). The roots hold the plants firmly to the ground, supply water and essential nutrients to the plants, add carbon to the soil and act as a carbon pool (Korner, 2017). The BGB is calculated using root-to-shoot ratio or formula that links both AGB and BGB.

Deadwood, which acts as carbon sink, is home to a huge number of organisms. The number of dead trees and the rate of decomposition affect the quantity of carbon stored in the deadwood (Bellassen and Luyssaert, 2014). In addition, the layer of litter which is made up of freshly fallen leaves, bark, twigs and other plant remains forms another active carbon pool that connects vegetation and soil (Dar and Sundarapandian, 2013). The rate at which litter breakdown varies depend on climatic conditions, litter chemical quality, and soil organism activity. These processes influence the soil carbon buildup and help to regulate nutrient cycle within the forest ecosystem.

Soil organic carbon (SOC) is among the largest carbon reservoirs on land. Compared to carbon vegetation, SOC remains more stable and can be stored in the soil for several decades or even thousands of years, based on the physical and chemical characteristics of soil (Dar and Sundarapandian, 2013). The quantity of SOC is mainly influenced by factors such as climate, the type of vegetation, soil texture, drainage, and different land use or management practices.

1.5 Anthropogenic disturbance and its effects on forest ecosystems

Disturbance is defined as any event that disrupts ecosystem, community, or population structure and changes resource availability, substrate characteristics, or the natural environment (Pickett et al., 1985). Forest ecosystems are shaped by natural occurrences like forest fire, storms, insect outbreaks, etc., which produce a variety of habitats that are home to numerous species (Franklin et al., 2002). However, in recent years, anthropogenic disturbance has increased in frequency and severity than the forest can naturally recover (Haq et al., 2022). Long-lasting changes in forest structure and composition can result from activities like excessive deforestation or clearing of land for other land uses, while disturbance caused by activities like fuelwood collection by locals or selective logging may appear insignificant at first but have the potential to slowly change the forest as the activities increase (Sturtevant and Fortin, 2021).

Selective logging is basically the removal of only particular trees of economic importance as opposed to clear cutting which removes all the trees from an area. Despite being more controlled, this practice can damage the surrounding trees, compact the soil and change the microclimate (Putz et al., 2000). The degree of damage depends on the method of logging, the equipment utilized, and the number of trees being felled. Repeated logging over time can eventually deteriorate the forest health and affect the species composition (Asner et al., 2006).

Fuelwood gathering causes significant disturbance in areas where local communities are totally dependent on forest resources (Kumar et al., 2024). Collection of fuelwood, fodder, and other products from forest results in the removal of small trees, shrubs and herbs, which slowly changes the forest structure (Malik et al., 2016). Though each collection activity may not affect the forest, frequent collection may cause huge damage as it may slow down the process of natural regeneration, species alteration and reduction in the storage capacity of carbon. These activities are more prone to forests which are close to human settlements (Haq et al., 2019).

Livestock grazing in forests affects regeneration, ground vegetation, and soil quality (Shaheen et al., 2011). It causes damage as livestock feed on young plants, trampling the soil, and changing the quantity of nutrients from dung deposition. The extent of its impact depends on numbers of livestock, grazing time, and plant tolerance. Intense grazing can result in slow forest recovery by reducing the chance of survival of young trees thereby gradually changing forest composition and structure.

Clearing of forest land for farming, settlements, or infrastructure often results in the permanent disappearance of forest cover (Rashid et al., 2017). Such activities completely transform natural forest ecosystems, switching them to different land uses and causing sharp and sometimes irreversible losses in biodiversity and carbon storage. In addition, settlements located inside or near forests cause several types of disturbance through the collection of forest products, disposal of waste and spread of non-native species. When multiple disturbance factors occur together, their combined effects are usually greater than the individual impacts.

The disturbances normally lead to changes in the balance among the tree species, diversity tends to drop, and the overall forest structure becomes simpler (Malik et al., 2016). Studies from various regions show that as the level of disturbance rises, both tree density and basal area decline (Haq et al., 2019). Cutting down valuable tree species changes the way the remaining trees compete for space and resources. When trees of economic importance are removed from a forest, the balance among the remaining species gets interrupted as pioneer species or species that can tolerate disturbance begin to dominate the area.

The type, frequency and intensity of disturbance determine its impact on tree diversity (Kaushal and Baishya, 2021). The intermediate disturbance hypothesis states that mild disturbance can enhance diversity by creating a mix environmental condition that permits the co-existence of species with different ecological requirements (Mishra et al., 2004). However, the forest that is severely or frequently disturbed experience drop in diversity of species. The loss of rare or endemic species is especially concerning because they have limited ranges and have difficulty recovering once harmed. Such changes in diversity can have impact on an ecosystem's stability and resilience, lowering the ability of the forest to withstand future disturbance or environmental changes. According to Vieira et al. (2005), disturbed forests frequently exhibit an uneven distribution of tree sizes with very few or no big trees while the untouched forests generally consist of balanced number of both young and mature trees.

The physical and chemical properties of soil can be altered by anthropogenic disturbance, which may cause long-term effect on the forest ecosystem (Wani et al., 2015). When trees are removed due to anthropogenic activities, important nutrients are lost, affecting the soil's natural recycling of nutrients. Soil organic matter declines as disturbance increases either because of less litter or warmer and drier environments which accelerate decomposition. These changes can also affect soil pH, moisture content, bulk density, soil organic carbon and nutrient balance, all of which affect both mature plants and seedlings. Nutrients like potassium, nitrogen and phosphorus are carried away by rain when surface soil is directly exposed as a result of less vegetation cover. The degree of disturbance, soil type, climate and the rate at which plant regrows all determine the soil recovery rate.

The quantity of carbon stored in forests can be significantly impacted by anthropogenic activities (Haq et al., 2022). According to Sharma et al. (2010), forests that experience disturbance often store less carbon compared to those that are undisturbed. The type of disturbance and the level of disturbance determine the amount of carbon lost. Total deforestation and land conversion are the main causes for reduction in the carbon storage capacity of the forest. Following a disturbance, many of the remaining trees eventually die, thereby releasing more carbon into the atmosphere. The widened canopy gap also influences the local environment by changing light intensity, temperature, and soil moisture levels. Such changes fasten the rate of the decay of organic matter and gradually lower the amount of carbon stored in the soil (Wani et al., 2015). When a canopy gap appears, it often allows sunlight to reach the forest floor, encouraging the growth of small plants and young trees which absorb carbon as they grow, helping to recover part of the carbon that was lost earlier. The overall carbon balance, however, depends on how much carbon is lost compared to what is regained, and this changes with the forest type, the kind of disturbance, and the time since it took place.

1.6 Importance of sustainable forest management

Sustainable practice of forest management has become an essential strategy for maintaining the balance between the ecological, economic, and social roles of forests, especially as human pressures on these ecosystems continue to rise (Kumar and Singh, 2020). It includes the careful and responsible use of forests so that their biodiversity and ability to regenerate are preserved. The aim is to make sure that forests continue to fulfil the requirements of the present as well as future generations without harming other ecosystems (FAO, 2020). Combining local knowledge with scientific understanding to develop practical and long-lasting strategies is the key to effective forest management.

The way a forest is managed has a significant impact on its health and vitality (Kumar et al., 2024). The collection of forest resources for timber, fuelwood, medicine, etc. should be practiced in such a way that natural recovery capacity of the forest is not exceeded. For example, selective logging using good machinery minimises damage when done sustainably (Putz et al., 2000). To avoid overexploitation of the resources, it is important to regulate the gathering of forest products. Similarly, controlling livestock grazing through proper rotation of grazing areas can minimise the damage of the forest.

Climate change is greatly influenced by how well the forests are maintained for carbon storage. Today, forests management not only focuses on conservation or for timber production in a sustainable manner, but it also focuses on the role of forest in capturing and storing (Bellassen and Luyssaert, 2014). Reducing Emissions from Deforestation and Forest Degradation (REDD+) is one such program that reflects this shift by urging countries to rehabilitate and protect their forests. The developing countries can receive financial aid from these efforts for reducing deforestation and improving forest management practices. However, the long-term success of these projects is dependent on having reliable tools to monitor carbon storage, strong governance, and transparent systems that ensure benefit to the locals while protecting their rights.

Protected or reserved forests are crucial to protect forests from disruptions caused by humans as these forests protect biodiversity and continue storing carbon when human activities are restricted or discontinued (Kumar et al., 2024). In many places, these areas still undergo land encroachment, illegal timber extraction, and lack of management capacity. Community based management practices which include the involvement of local people in decision making, have proven to be effective in strengthening conservation results while also supporting the local livelihoods.

1.7 Significance and scope of the study

The present research is focused on the effects of anthropogenic disturbances on tree community attributes and the forest carbon stock in Aizawl District, Mizoram. The aforesaid study is of paramount significance, as it is obvious from available literature that there is paucity of information on the aforesaid research topic particularly for the state of Mizoram. Mizoram, which falls under the biodiversity hotspot of Indo-Burma, has very high forest cover spanning over 17,820 sq. km., or 84.53% of the geographic area of the state (ISFR, 2021). In past few decades, there has been tremendous increase in human population, leading to overexploitation of forest biological resources in terms of high dependency on shifting cultivation (jhum), fuelwood collection, selective logging and livestock grazing which has led to the degradation of mature forests and disturbance in natural forest dynamics, and finally resulting in reduced forest cover. Such disturbances impact the species composition of tree communities and influence the forest’s ability to store carbon, however, systematic studies on the response of tree communities to varying intensities of human disturbance are rare in Mizoram and northeast part of India. Most studies are confined either with tree diversity or carbon estimations taken separately, without considering the effects along the disturbance gradients, which resulted in major gaps in the knowledge regarding anthropogenic pressure on the forest structure and species composition and its effects on carbon dynamics. In view of the above, it is assumed that the outcome of present investigation may help in formulating appropriate strategies for biodiversity conservation at a large, despite filling the gaps in knowledge.

The research aims to provide insights on how forest ecosystem responds along a gradient of anthropogenic disturbance from a lesser studied region. It evaluates the characteristics of tree community (species frequency, density, composition, basal area, size class distribution and Importance Value Index), soil organic carbon, aboveground and belowground biomass all together to understand how anthropogenic activities impact biodiversity and carbon storage. This study gives essential baseline data on tree community, forest structure and carbon storage along a disturbance gradient, thereby providing better understanding on how anthropogenic activities affect and alter the forest ecosystem.

The research took place in Aizawl district, where the sites were selected based on varying levels of disturbance, from undisturbed to moderately disturbed and highly disturbed forest stands. Overall, this research fills the knowledge gap in examining the effects of anthropogenic disturbances on tree community characteristics and carbon stock in the forests of Mizoram. This study will help in guiding future research and help in strengthening broader regional environmental awareness leading to formulation of appropriate management strategies.

1.8 Objectives

The objectives of the present research work envisage the followings:

1. To study tree community characteristics in the selected forest stands along disturbance gradient.
2. To determine the biomass and carbon stock in the vegetation and soil.
3. To assess the effects of disturbance on diversity-distribution of trees and carbon stock of the forests in Aizawl district of Mizoram.

Chapter 2

REVIEW OF LITERATURE

2.1 International

Forests are one of earth's most important ecosystems that cover about 31% of the surface area at global level and provide food and shelter for a variety of flora and fauna (FAO, 2020). These ecosystems are believed to contain more than 80% of all terrestrial biodiversity. Forests keep the environment healthy and help in maintaining the equilibrium of natural systems (FAO, 2020). Many researchers estimated that there are nearly 73,000 species globally, though many still remain unknown to science or are yet to be recorded (Cazzolla Gatti et al., 2022). Earlier global assessments listed about 60,065 recognized species (Beech et al., 2017).

The pattern of tree diversity is shaped by factors like climate, past events and ecological processes that took place in the area and are known to differ from one place to another. Among all the forest types, tropical forests are recorded to have the highest diversity of trees (Cazzolla Gatti et al., 2022). The stratification of vertical canopy structure of the forests offers various microhabitats for a wide variety of flora and fauna, such as canopy trees, understorey vegetation, and ground flora (Jucker et al., 2015). This forest structure governs the light penetration, moisture, and the nutrient cycle process, resulting in some changes in the environmental conditions which supports the coexistence of species.

The forest ecosystems support a wide variety of services, ranging from provisional services where the forests provide tangible products, food and medicinal products, to regulating services like climate regulation, water purification and nutrient cycling, to cultural services like recreation and aesthetic benefits (Brockerhoff et al., 2017). The framework for ecosystem services has shifted in the last 20 years to reflect forests as multifunctional systems that offer provisioning, regulating, cultural, and sustaining functions. Over the past two decades, the ecosystem services framework has evolved to recognize forests as multifunctional systems delivering provisioning, regulating, cultural, and supporting services (Ellison et. al., 2017). Other than these ecological roles, forests also provide cultural services including the intangible benefits derived by humans like recreation, aesthetic and spiritual value (Daniel et al., 2012). Human activities, mainly uncontrolled logging and resource extraction, conservation of forest land into agricultural lands or settlement areas, became the leading drivers of change in forest ecosystems around the world, leading to change in the species composition, tree diversity, and ecosystem processes. The tree diversity is substantially affected by both natural and anthropogenic disturbances (Gibson et al., 2011).

Selective logging is one of the most common anthropogenic disturbances affecting forests and long-term studies on such forests have shown that the removal of commercially valuable tree species affects forest structure, species composition, and patterns of natural regeneration (Putz et al., 2012). After conducting field experiments in logged forests across Southeast Asia, Edward et al. (2019) argued that forest structure maintenance and connectivity largely supporting the persistence of biodiversity. Their study highlighted that when logging intensity exceeds, roughly 40% of basal area loss and biodiversity declines.

Forest fragmentation involves forest patches created due to land use conversion, surrounded by modified landscapes. The smaller fragments often contain fewer tree species because of limited space, stronger edge effect, and further distance from the seed sources in surrounding forests, prohibiting natural regeneration to take place (Laurance et al., 2011). The biodiversity of tropical forests is threatened by agricultural expansion along the edge of the forests, and this conversion may not only result in loss of tree species but will also favor the growth of pioneer or disturbance tolerant species (Arroyo-Rodriguez et al., 2020).

The concept of different magnitudes of disturbance on forests, from undisturbed (UD) to moderately disturbed (MD) to highly disturbed (HD), gives an outline for understanding the ecological responses to anthropogenic pressure (Chazdon, 2017). The undisturbed stand are primary forests having complex structure and have not undergone through anthropogenic pressure, the moderately disturbed stand falls in the middle i.e., it experiences intermediate level of disturbance, while the highly disturbed stand are forests with simpler structure dominated by pioneer species (Poorter et al., 2021; Malik et al., 2016; Kumar et al., 2024). According to research done by many researchers around the world tree species composition and density decreased with increase in the level of anthropogenic disturbance, indicating the vulnerability of forest ecosystems to human activities (Bentsi-Enchill et al., 2022; Muhati et al.,2018; Eshaghi et al., 2018).

Anthropogenic disturbance can influence the regeneration patterns of the forest ecosystem around the world. In Nepal's community forests, Pandey (2021) identified grazing and trampling as the most significant disturbances for inhibiting seedling growth, with areas having higher trampling intensity showing lower numbers of seedlings and saplings. A study done in the endangered *Abies ziyuanensis* forests of China showed that the areas affected by human activities exhibited a greater diversity of shrub and herb species probably due to more light penetration on the forest floor as a result of widened canopy gap (Zhang et. Al., 2024).

Forest soil is an integral constituent of the terrestrial ecosystem, providing support for plant life, and regulating biogeochemical processes (O' Connor et al., 2005). Anthropogenic activities may have significant impacts on soil physical, chemical, and biological properties which occur by the removal of vegetation from the forest floor, exposing the soil surface to erosion, changing organic matter inputs, and altering the decomposition process. Extensive logging, especially mechanical logging, tends to compact the soil, and raise the bulk density from typical forest values of 0.8 to 1.2 g cm^{-3} to 1.3 to 1.6 g cm^{-3}, while decreasing porosity and weakening the soil structure (Alamgir et al., 2016). These physical changes reduce root penetration, lower water infiltration, and increase the risk of erosion and surface water runoff for a long time after the occurrence of disturbance (Mukul et al., 2016).

Soil organic carbon is an important carbon sink, supporting nutrient cycling and overall soil health. In the forests of Bangladesh, Saimun et al. (2021) recorded the soil carbon stock at 77.1 t ha^{-1}. It was also found that soil carbon was positively correlated to soil moisture, bulk density, pH, and silt content. Fine-textured and denser soils help to slow down the rate of decomposition of organic matter, whereas moist soil reduces oxidation and microbial breakdown of organic matter. A well-balanced pH in the soil, which promotes the growth of microorganisms, supports the gradual buildup and stable retention of carbon in the soil. In contrast, the negative correlation with temperature means that at higher temperatures, organic matter decomposes faster.

Geographical distribution of soil carbon shows strong edge effects and fragmentation impacts. Cardelus et al. (2013), demonstrated that the size of Ethiopian church forests significantly impacts the physical and chemical properties of the soil. With reduction in the size of the area, there was a sharp decline in carbon and nutrients from the interior to the periphery of the forests constraining the biological and physical nutrient cycling processes by the reduced soil water content.

Bol and Tokuchi (2018) noted that in the tropical evergreen forests of Myanmar, soils in old growth and undisturbed areas were much richer in carbon, nitrogen, and available phosphorus, and had a lighter texture compared to the soil in the disturbed areas. The decline in soil quality in the disturbed areas was due to anthropogenic activities like logging, agriculture, and urbanization. Anthropogenic disturbance in Iran's Zagros forests reduced the soil organic matter, soil organic carbon, and nitrogen content, indicating that the intensity of disturbance is directly related to soil nutrient loss (Eshaghi et al., 2018).

Anthropogenic disturbances result in decline of forest carbon stocks by directly removing biomass and disrupting natural carbon cycling processes. Deforestation and forest degradation together account for about 10% to 15% of global greenhouse gas emissions, emphasizing how forest disturbance affects the climate (Houghton and Nassikas, 2017). Forests are considered as the largest system for storing carbon on land. Forests around the world hold around 861 gigatons of carbon (Pan et al., 2011; Friedlingstein et al., 2020). Although tropical forests cover only about 10% of the earth's land surface, they hold over 50% of the total forest carbon worldwide (Saatchi et al., 2011). The capacity of a forest to store carbon depends on the forest type, with mature tropical forests generally containing between 150 and 250 Mg ha^{-1} in aboveground biomass alone which is much higher than other forest types (Martin et al., 2013).

The carbon contained in forest is the outcome of numerous ongoing processes like growth of trees, production of biomass, organic material decomposition, etc. The study in the forests of Bangladesh showed that forest structures which are characterized by high tree density and tree diameters, exhibited a positive correlation with tree carbon (Saimun et al., 2021). So, it can be said that trees with high density tend to store more carbon. Regions subjected to increased human disturbance reported reduced carbon levels, although the study revealed a temporary rise in soil carbon.

The structure of forest is highly affected by human induced disturbance. This was proved in the study conducted by Bentsi-Enchill et al. (2022), where the areas that was left untouched showed higher tree density, height and basal area, and carbon stock compared to those under stress. The basal area and height of tree were found to be closely associated with carbon stock, suggesting that these play a major role in determining the amount of carbon storage capacity of the forest. The clearing of large trees in disturbed sites was highlighted as a serious factor contributing to the decline in carbon storage.

Bentsi-Enchill et al. (2020) investigated the potential for carbon storage along the disturbance gradient in Ghana's protected forests where the area which was mildly disturbed seemed to store the maximum carbon when compared to undisturbed or highly disturbed areas. Anthropogenic activities like farming, hunting, logging, and manufacture of charcoal reduced the quantity of carbon stored in the forest. Forest structure is highly sensitive to human disturbance. Research conducted by Amankwah et al. (2024) found the Boabeng Fiema Monkey Sanctuary losing around 40,236 Mg carbon and Kogyae Strict Nature Reserve losing about 272,109 Mg carbon as a result of human interference.

The total biomass in Nepal's forest was maximum in protected areas, reaching about 960.4 Mg ha^{-1} and minimum in disturbed forest with 449.1 Mg ha^{-1} as recorded by Gautam and Mandal in 2016, indicating that undisturbed forests have a higher ability to capture and store carbon. Species diversity, stand structure, and carbon storage capacity are inversely related to disturbance intensity. In Ethiopian forests, anthropogenic disturbance resulted to a decline of 36.8% in aboveground biomass in highly disturbed compared to least disturbed forest (Gebeyehu et al., 2019). This is supported by a study that took place in Ghana's protected areas which highlighted that anthropogenic activities caused carbon losses exceeding 40,000 and 2,72,000 Mg carbon (Amankwah et al., 2024). Structure of the stands and the age of the forests are important factors, and the past disturbance is often the primary driver that causes carbon levels to change.

The carbon distributed among different parts of a forest changes as the forest grows and manages over time. The total carbon retained in the lower subtropical broadleaved evergreen forest in China was recorded by Sun and Guan (2014) to be between 125.23 and 154.05 t ha^{-1}. They found that while maximum carbon was concentrated in middle-aged trees and mature forests, over half of it (about 56.55%) was stored in the soil of young forests. As the forest advanced to middle age and mature stages, the arbor layer (tree canopy) became the main carbon reservoir. In younger stands, most of the carbon was found in the understorey vegetation, whereas in older forests, coarse wood debris became dominant, holding around 51.26% of carbon. These findings show that as forests grow older, the way carbon is stored gradually changes from being present mostly in the soil and understorey vegetation in the early years to being concentrated in tree trunks and fallen wood material later on. Wannasingha et al. (2023) in their research on Thailand's community reserved forests, found that the areas which were managed well stored more carbon than the areas that were poorly managed.

Studies of forests along disturbance gradient help in understanding how the ecosystem responds to increased stress. According to Bentsi-Enchill et al. (2022), species diversity, basal area, tree height, stand density, and carbon stock tend to decline with increasing disturbance in the Atewa Range Forest Reserve of Ghana. Yohannes et al. (2015) and Muhati et al. (2018) found that for a quick and effective estimate of the potential of a forest to store carbon, the height and basal area of the trees would be necessary.

In the tropical forests of Africa, trees contribute over 75% of the total biomass, indicating the need to protect these forests (Lung and Espira, 2015). In the *Quercus mongolica* forests of China, Ma et al. (2025) reported that factors like tree diversity, density, and stand structure determined about 66.4% of the change in carbon storage. The tree density had a direct impact on the stability of the forest stand and an indirect impact on tree diversity and structural patterns of the forest. These components are closely linked, working together to shape how much carbon the forest can store and howresilient it is to change.

In the tropical montane forests of Mexico, the primary forest stored the most carbon compared to the secondary forest stands (Aceves and Toledo-Garibaldi, 2025).

In Phnom Kulen National Park of Cambodia, Sovann et al. (2025) found that human-driven alterations in land cover brought about marked declines in several ecological components. These included reductions in soil water content, plant diversity, leaf traits, forest structure, aboveground biomass, deadwood, leaf area index, and the capacity of the canopy to absorb sunlight. The effect of disturbance differs from region to region depending on the type of forest, the climate, and the actions that people practice in that forest. The large trees have higher value than small trees because the stem density, diameter and the wood density of large trees affect over 75% of the difference in biomass (Lung and Espira, 2015). In the Central temperate forest of Europe, Silva Pedro et al. (2015) noted that an increased diversity of tree species mitigated the adverse effects of disturbances on carbon uptake and storage. A varied assortment of species acts as natural buffer, allowing the forests to recover while preserving their functional significance.

Deadwood and coarse woody debris form significant carbon reserves in many forests, especially in old growth stands where large trees leave behind extensive woody material after dying (Woodall et al., 2015). The wood density, microclimatic conditions, and decomposer organisms are some factors which determine the rate at which deadwood breaks down. The rate of decomposition is faster in the tropical forests in comparison to the temperate forests. In undisturbed forest ecosystems, deadwood can store about 10% to 20% of the carbon within the forest (Russell et al., 2015).

Forests serve as vital carbon sinks, but their ability to store carbon is increasingly being reservoirs, yet their capacity to store carbon is being increasingly weakened by anthropogenic disturbances (Saimun et al., 2021). When human pressure on the forest is extreme, it results in change of the natural structure of the forest and reduction of biodiversity (Machado et al., 2025). The most significant anthropogenic disturbance influencing the biomass and carbon storage in Nepal's forests was lopping, which is basically the removal of branches for fodder and fuel (Pandey, 2021). The forests in Thailand that was managed properly had higher basal area, tree density, species richness, and evenness compared to those forests managed with less attention (Wannasingha et al., 2023). The study proposed that offering an alternative source of income to those who depend on forests may reduce stress and maintain forest ecosystems. It is necessary to have a clear understanding on how anthropogenic activities affect the tree community characteristics, soil parameters and carbon stock of a forest in order to come up with an effective management and conservation technique.

2.2 National

India supports high diversity because of its wide geographical area, diverse landscapes, and multiple biogeographic zones. Its forests contain about 7,428 tree species that belong to numerous families and genera. The botanical surveys are still recording new species proving that not all the floral diversity in India has been documented (Singh et al., 2015).

In Indian forests, the diversity of trees varies according to the level of disturbance thereby disrupting the natural balance of the forest. According to Sagar et al. (2003), the mean stem density and basal area varied from 419 stems ha^{-1} and 13.78 m^2 ha^{-1} in the least disturbed stand to 35 stems ha^{-1} and 1.30 m^2 ha^{-1} in the most disturbed stand. Such a trend has been documented by many researchers (Sharma et al., 2023; Sagar et al., 2003; Mansingh, 2025).

As disturbance increased, the distribution pattern of more than 50% of the tree species found in the dry tropical forests of Vindhyan hill range appeared to change and there was shift in species like *Boswellia serrata, Holarrhena antidysenterica,* and *Lannea coromandelica* from a clumped to a uniform distribution, whereas *Butea monosperma, Cassia fistula,* and *Elaeondendron glaucum* changed from a uniform to a clumped pattern of distribution, implying that each species reach differently to the change caused due to disturbance (Sagar et al., 2003).

The studies conducted in the tropical rainforests of the Eastern, Northeastern, and Central Himalayan regions reported that forests with intermediate level of disturbance showed the highest diversity (Buragohain et al., 2023; Kaushal et al., 2021; Gogoi and Sahoo, 2018). About 62% of tree species exhibited regeneration in the undisturbed forest, which reduced to 50% in moderately disturbed forest and to about 25% in highly disturbed forest stand, indicating that disturbance reduces the capacity of the forest to recover from the damage and to maintain its diversity. In eastern

Himalayan rainforests, increased disturbance elevates the growth of invasive species which try to replace the native species (Gogoi and Sahoo, 2018).

India's forest soils are not uniform and are shaped by variations in parent material, climate, vegetation, and topography across the country. The major types of soil found in India are laterite soil, red and yellow soil, alluvial soil, black soil and mountain soil (Bhattacharyya et al., 2016). When anthropogenic pressure is too high, it affects the physical, chemical and biological characteristics of the forest soil and this degradation in soil quality can affect the growth and distribution of tree species (Alamgir et al., 2016).

Soil is one of the fundamental components of forest ecosystem and helps in regulating nutrient availability and water movement for the growth of plants (Sandra et al., 2025). With increase in anthropogenic disturbance, the bulk density of the soil also increases, meaning that the soil is more compact in disturbed areas. This lowers the infiltration of water and degrades the soil quality. The quantity of nutrients like nitrogen, potassium and phosphorus of a particular area drops as the disturbance level increases, making the soil less fertile (Mehta et al., 2008). The amount of carbon stored in the forest soils depend largely on the type of forest, the climate, elevation, past disturbance and past management practices it underwent (Kothandaraman et al., 2020; Ramachandran et al., 2007). A study on soil chemistry by Das (2021) and Sharma et al. (2017) mentioned the importance of maintaining the quality of the soil so as to improve the forest productivity and carbon storage capacity.

The forests are the major carbon pools in terrestrial ecosystem and play a huge role in maintaining carbon balance on earth. According to FSI report (2021), India's forests store about 7.2 billion tonnes of carbon. The stand density and species diversity influence the biomass and carbon stock of the forest (Kaushal and Baishya, 2021; Kaushal et al., 2021). A study done by Shankar et al. (2025) in a forest of India revealed that the organic carbon content in soil was about 27 to 30% of the total forest carbon pool, indicating that even when maximum amount of carbon is stored in vegetation, soil carbon still play an important role in the overall carbon balance. According to Buragohain et al. (2023), forests that are unharmed or untouched by humans store more carbon than the forests that are undergoing disturbance. In the northeastern Himalayas, the total carbon stock was recorded in areas with moderate disturbance when compared to highly disturbed forest, indicating that mild disturbance can enhance species richness, species diversity and increase productivity of the area (Buragohain et al., 2023; Pawar et al., 2014).

Natural forest stands in the Western Ghats were found to store roughly 381.69 Mg ha^{-1} of carbon, compared to 73.92 Mg ha^{-1} in rubber plantations and 21.19 Mg ha^{-1} in coconut plantations (Kumar and Balasubramanian, 2024). While species richness peaked at mid-elevations, the aboveground carbon gradually decreased with increase in altitude, due to the changes in soil, temperature, and rainfall that differs along the altitudinal gradient. The protected forests in the Himalayas store huge amount of carbon compared to the unprotected forest, signifying that proper forest management can improve the forest carbon storage by more than 44% (Maren and Sharma, 2021).

The biomass in the tropical dry deciduous forests of Mahendragiri Hills ranged from 129.05 to 255.87 Mg ha^{-1} (Khadanga and Jayakumar, 2020) and the undisturbed forest held the maximum carbon (Haq et al., 2022). The forest areas which are closer to human settlements experience more disturbance so there is a need to implement proper management strategies near human habitations, where efforts to protect resources frequently collide with the demands to use them.

In India, anthropogenic activities such as tree cutting, gathering of firewoods, cattle grazing, agricultural developments etc., are responsible for changing the structure and composition of forests (Kamimura et al., 2025). These activities disrupt the water balance of the forest ecosystem, light interception, soil and nutrient flow (Shankar et al., 2025)

Biomass and carbon storage in the Central Himalayan forests of India depend on the tree stands structure and species diversity (Kaushal and Baishya, 2021). The studies on tree diversity, regeneration, and disturbance in the Central Himalaya are important for conservation and managing the forests (Kaushal et al., 2021).

2.3 Regional

Northeastern part of India falls in the Indo-Burma biodiversity hotspot and comprise of rich floral diversity. The forests in this region undergo indigenous land use and conservation practices adopted for years by the locals residing in the region (Khan et al., 1997). These forests are among the most diverse in the world and have supported several rare and native species. Tree diversity in the Northeast varies greatly with each type of forest and with differing management practices.

Tree diversity varies greatly with each forest type and with differing management practices. In Meghalaya, for instance, subtropical broadleaved forests were found to have around 117 species. Under nearly the same conditions, pine forests supported only about 15 species. Also, the subtropical broadleaved forest has about 1,294 trees per hectare compared to 894 trees in pine forest. A survey that took place in the tropical moist deciduous forest of Kamrup Metropolitan District of Assam recorded 39 tree species in total, with an average density of nearly 1,008 stems per hectare (Kalita and Yumna, 2024). A study in the Dibru-Saikhowa biosphere reserve of Assam recorded species richness based on the degree of disturbance (Joshi, 2020). Measures of biodiversity were also much higher in areas with minimal disturbance.

Tree density and basal area are important measures of forest structure, and they often change noticeably when disturbance occurs (Mishra et al., 2004; Joshi, 2020). Within the forests of southern Assam, undisturbed forests supported about 708 stems per hectare, while disturbed forests had only around 443 stems per hectare. The basal area also dropped sharply from 42.01 to 18.44 m^2 ha^{-1} in disturbed sites (Borah et al., 2013).

Mishra et al. (2004) discovered that that species richness was highest in forests with moderate disturbance, followed by severely disturbed and undisturbed forest stands. This demonstrates that a moderate level of disturbance can increase number of species, but when disturbance gets too severe the species number decreases. According to Nautiyal and Manish (2024) who studied the forests in Arunachal Pradesh and Deb et al., (2020) who studied the forests in Tripura, along varying degree of disturbance, the tree community characteristics values were poorer in disturbed areas when compared to undisturbed forest areas. In the subtropical evergreen forest of Nagaland, edge effect was prominent. It was observed that overall biomass was higher in the core zone than in the buffer zone. Ao et al. (2023) reported that the total carbon stock at the core and buffer zone was estimated to be 224 Mg ha^{-1} and 173 Mg ha^{-1}, respectively, which shows that around 30% less carbon is stored in edge areas.

Soil characteristics are influenced by human activity and often reflect the overall condition of an ecosystem. The soil organic carbon tends to decrease along the disturbance gradient (Deb et al., 2020; Gogoi et al., 2017). The pine plantation in Manipur contained 30.6 Mg ha^{-1} of organic carbon while the mixed pine forest stored only 6.6 Mg ha^{-1}. This disparity in the amount stored was related to a slower decomposition rate with pine litter (Monsang et al., 2023). A comparative study of disturbed and undisturbed forests in Assam showed that soil parameters were distinct and the degraded sites had neutral to slightly acidic pH, whereas the soils from the control forests ranged from being acidic to strongly acidic as confirmed by Bhuyan and Sharma (2017).

Carbon storage is a vital role of forest ecosystems, varying under different types of forests and management practices. The tropical forests are known to store the maximum carbon compared to the other types of forests in the northeastern region and the forests that were disturbed with poor management practices stored less carbon in comparison to the forests that were undisturbed with better forest management practices (Chaudhury et al., 2022, Das and Deb, 2022). The sacred groves of Meghalaya and Manipur which are preserved for generation by locals stored huge amounts of carbon (Mir et al., 2021; Waikhom et al., 2018).

It is important to find out the regeneration pattern and population structure of the flora in order to understand the development of the forest and the way it responds to varying levels of disturbance. Mishra et al. (2004), in their study recorded that the dominant species varied along the disturbance gradient. In the undisturbed stand, tree species were the most dominant, while in the moderately disturbed stand, shrubs were maximum compared to other forest stands and herbs dominated the highly disturbed stand. Research on population structure under disturbed conditions showed many tree species with poor regeneration, which may threaten their long-term persistence (Borah et al. 2013).

With the increase in disturbance, the composition of species also undergoes some change. In undisturbed or stable forest stands, species like *Cynometra polyandra, Mesua ferrea,* and *Palaquium polyanthum* were most common and they contributed more to the overall carbon stock. Such species were barely present or were absent from the highly disturbed forest stand. Here species such as *Schima wallichii* and *Holarrhena pubescens* were more commonly available (Borah et al., 2019). Mishra et al. (2004) in their study found that both disturbed and undisturbed forest stands had species such as *Aporusa dioica, Exbucklandia populnea, Rhododendron arboreum,* and *Symplocos racemosa*, demonstrating their capacity to endure environmental changes while species like *Daphniphyllum himalayense, Engelhardtia spicata,* and *Machilus bombycine* were not available in disturbed regions, suggesting that they are more sensitive to disturbance.

Forests are not just means of livelihood to the indigenous people residing in and around but also hold spiritual and cultural importance to them. Sacred groves and age-old cultural traditions tie the locals to forest, and this helped in sustaining conservational efforts through many generations (Mir et al., 2021). These practices have helped sustain biodiversity while still meeting local needs in the form of food, medicine, and timber, while spiritual and social values remain a significant part of their lives.

Low-intensity disturbances to forests, which include fuelwood collection, selective tree cutting, and grazing by cattle, generally have little impact on plant diversity. However, with increasing disturbance, considerable loss of biodiversity and alterations in the community structure of the forest take place, which eventually hamper tree regeneration and encourage the growth of short-lived herbaceous plants and heliophytic shrubs (Mishra et al., 2004). The degradation of tropical forests due to anthropogenic activities is among the main reasons for decline of global biodiversity (Mishra et al., 2004). Due to the rise in anthropogenic disturbance, it is important to understand how natural communities and their structural features respond to the gradual loss of biodiversity brought about by human disturbances.

2.4 Mizoram

Mizoram, which is located in the Northeast part of India, is about 21,081 sq. km in size, with forests covering nearly 84% of its area. This makes the state an essential part of the Indo-Burma biodiversity hotspot. Mizoram has an elevation ranging between 30 and 2,000 m, which directly or indirectly support a diverse range of flora, including tropical wet evergreen forests, subtropical forests and bamboo-dominated forests (ISFR, 2021). However, intensive shifting cultivation that is practiced by more than 70% of locals resulted in anthropogenic pressure, changing forest structure, soil fertility, and carbon storage capacity.

A study in the Reiek Community Reserve of Mizoram by Devi et al. (2018) recorded 125 species of trees having a diameter of 10 cm and above, which belonged to 90 genera and 46 families. The forest was found to have a tree density of about 2145 individuals ha^{-1}, with a basal area of 64.76 m^2 ha^{-1}. The values of diversity indices were recorded as high (Shannon index 4.37 and evenness 0.89), showing that the forest community was rich and well balanced. Some of the dominant and commonly used species such as *Albizia richardiana, Engelhardtia roxburghiana, Ficus religiosa, Neolamarckia cadamba, Pterospermum lanceifolium, Schima wallichii* and *Terminalia myriocarpa* were seen as vulnerable.

According to Lamare et al. (2024), a larger number of tree species are found in Mizoram's tropical forests than in the subtropical forests. Based on Importance Value Index (IVI), *Castanopsis tribuloides, Schima wallichii, Aporosa octandra*, and *Wendlandia budleioides* were the most dominant species in tropical forests, based on Importance Value Index (IVI), while *Ilex godajam, Saprosma ternatum,* and *Diospyros racemosa* were the dominant species in the subtropical forest. The total tree basal area and density of tropical forests came to 1610 individuals ha^{-1} and 25.02 m^2 ha^{-1}, and subtropical forests came at 1380 individuals ha^{-1} and 24.20 m^2 ha^{-1}, respectively. Forest type, rainfall distribution pattern, altitude, soil characteristics, and past land-use history are some of the elements that contribute to this change.

According to Singh et al. (2015), Plant diversity along the disturbance gradient indicated the maximum number of species in the mildly disturbed forest stands (Singh et al., 2015). Mishra (2012) reported that fuelwood collection and timber extraction resulted in a drastic decline in the number of trees of a subtropical forest in Mizoram. The study also revealed significant modifications in the soil, forest floor, and microclimate.

Disturbance can affect the soil quality of a forest. According to Madhurima and Mishra (2023) the increased bulk density of the soil from 0.90 to 1.22 g cm^{-3}, lowered the ability of the soil to retain water due to soil compaction and the moisture content of the soil decreased from 30.71% to 18.5% across the disturbance gradient. There was seasonal influence noticed as well. The peak nutrient availability during the post-monsoon season was due to the increased litter decomposition (Sunar et al., 2017). Loss of vegetation and washing away nutrients are the main causes for depletion of soil carbon in disturbed forest (Mishra, 2012; Madhurima and Mishra, 2023; Sunar, 2017; Lalthakimi et al., 2023).

Forest carbon stocks in Mizoram show wide variation across different forest types and disturbance levels. Total tree biomass ranges between 144 and 314 Mg ha^{-1}, with corresponding carbon stocks from 68 to 148 Mg ha^{-1} across various forest stands (Ao et al., 2023; Hrahsel et al., 2019; Lamare et al., 2024). These differences are influenced by stand age, species composition, forest structure, and the history of disturbance in each area. In simple words, tropical forests tend to store more carbon than subtropical forests due to higher productivity and faster biomass accumulation. But the subtropical forests also have the capacity to store similar or even higher carbon content if maintained and conserved well (Lamare et al., 2024).

Studies carried out in the Gmelina arborea dominated forests of Mamit district, Mizoram, reported that the aboveground biomass ranged between 66 and 108 Mg ha^{-1}. The highest biomass was found in stands with larger trees. This clearly shows that tree size and age affect the forest's carbon storage potential (Hauchhum, 2017). Likewise, in a tropical forest in Aizawl district, the total carbon stock was reported to be 468 t ha^{-1}, showing the strong potential of these forests to store carbon (Sharma et al., 2018). The Lalsavunga Park of Mizoram is covered by subtropical forest and the overall tree biomass and carbon of 314 Mg ha^{-1} and 148 Mg ha^{-1}, respectively (Ao et al., 2023). The trees with smaller and middle girth ranged between 10 to 90 cm, stored more carbon in this region.

Shifting cultivation is the main human-related disturbance in Mizoram, affecting around 60 to 70 percent of the area. Traditional fallow period, which once lasted from 15 to 20 years, has now shortened to around 5 to 7 years because of increasing population pressure (Gogoi et al., 2022). This shortening of the cycle slows down forest regeneration and gradually weakens the ecosystem in several ways. Hauchhum and Singson (2020) observed that there were significant changes in species composition at different stages of fallow age. Diversity and basal areas were noted to increase with an increased length in the fallow period and showed signs of forest regeneration. Short duration fallows were dominated by pioneer species like *Castanopsis tribuloides* while older fallows supported late successional species like *Albezia chinensis* as longer fallow time allows the soil nutrients to build up and canopy copver to increase with time, developing suitable environmental conditions for climax species tolerant of shade. In contrast, shorter fallow periods face higher disturbance and nutrient loss, which restricts regeneration and favors the dominance of fast-growing pioneer species.

It can be depicted that a study that focuses on how different degrees of anthropogenic disturbance affect the tree community characteristics and carbon storage capacity would not only guide the policymakers in framing effective laws to preserve the forests, but it would also help in promoting sustainable forest management in the biodiversity rich region that is undergoing tremendous pressure due to anthropogenic activities.

Chapter 3

METHODOLOGY

3.1 Study area

Mizoram is a hilly region that officially became the 23rd state of India in 1987 and harbours a total geographical area of 21,08,700 ha. The term “Mizo” refers to the native people of the region, and the term “ram” means land. So, Mizoram translates to “land of the Mizos”. It was formerly known as the Lushai Hills during the British rule in India. It is a landlocked state in the northeast part of the country that is bounded to the east and south by Myanmar, west by Bangladesh, northwest by Tripura, northeast by Manipur, and to the north by Assam. The state of Mizoram comprises 11 districts, viz., Aizawl, Champhai, Mamit, Saitual, Lunglei, Kolasib, Lawngtlai, Khawzawl, Siaha, Serchhip and Hnahthial. The 2011 census showed that Mizoram had a total population of 1,091,014, with 538,675 females and 552,339 males. The estimated population of Mizoram has risen to almost 12,00,000 as of 2022-2023, a slight increase since the last official census, according to Niti Aayog (2025).

The state comprises 21 prominent hill ranges or peaks of varying elevations, interlaced with lowlands. The hills in the state have an average elevation of 900 m, with elevations reaching about 1000 m (3,300 ft) in the western region, which increases gradually to 1,300 m (4,300 ft) in the eastern region, and some regions feature higher ranges that exceed altitudes of 2000 m (6,600 ft.).

Most of Mizoram’s waterways begin in the central region of the state and flow towards the north or south, driven by the north-south orientated ridges. The rivers Chhimtuipui (and its tributaries viz., Tuichang, Tuipui, Mat and Tiau), drain the southern hills, while the rivers Tlawng (and its tributaries viz., Tut and Teirei), Tuirial, Tuivawl, Tuivai and Langkaih drain the northern regions which join the Barak river of Assam eventually. The rivers Chhimtuipui and Tiau create the natural border with Myanmar in the south and east, while the Khawthlangtuipui (and its tributaries viz., Phairuang, Tuichawng and Kawrpui) form the western boundaries with Bangladesh and Tripura.

Aizawl, the state capital, lies in the north-central part of Mizoram (23°25′N and 24°15′N latitudes, and 92°40′E and 93°05′E longitudes). As per Government of Mizoram (2021), the area is characterised by its rough topography, i.e., steep hills, confined valleys, and preponderance of streams. The region is also a part of the Indo-Burma biodiversity hotspot. The district's elevation ranges from 300 m to 2,157 m, with most forested areas located between 600 m and 1,800 m. The study was carried out in Hmuifang and its adjoining areas in the Aizawl district, owing to its similarity to other forests in the region in terms of its important ecological, climatic, and vegetational attributes.

3.1.1 Climate

The study site has a moderate climate throughout the year. The Köppen-Geiger climate classification designates Mizoram's climate, including the Aizawl district, as humid subtropical with monsoon influences (Sharma et al., 2018). The area is directly influenced by the southwest monsoon and experiences pre-monsoon rains from March to May and southwest monsoon from June to October. The temperature ranges from 7° C to 21° C during the coolest months i.e., November to February, to between 20° C and 29° C in the warmest months i.e., June to August. The area experiences three seasons viz., pre-monsoon (February to May), monsoon (June to September), and post-monsoon (October to January).

3.1.2 Forest and vegetation

Situated within the Indo-Burma hotspot, Mizoram boasts a high percentage of forest cover among all Indian states with a total forest cover of 85.34% of its total area (FSI, 2023). The forest cover of Northeast Indian has been documented by many botanists and foresters like Rao and Panigrahi (1961) and Champion and Seth (1968), yet studies specifically on Mizoram forests are very limited (Deb and Dutta, 1987; Lalramnghinglova, 1997). Singh et al. (2002) discussed the state's forest types based on rainfall, altitude and dominant species classification, viz., tropical wet evergreen and semi-evergreen forest, montane subtropical forest, temperate forest, bamboo forest, *Quercus* forest and jhumland.

Tropical wet and semi evergreen forests make up a major part of the state's forest and are found below 900 m altitude and has an average temperature of 21° C and average rainfall between 2,000 and 2,500 mm per year. The tropical wet evergreen forests tend to occur in the western and southern part while tropical semi evergreen forests are in the central, northwestern and northern part of Mizoram. In such forests, tall-boled trees occupy the top canopy, middle and lower canopy are evergreen, thick and diverse, and the third canopy is occupied by the shrubs and smallest trees. Common species found here are*, Emblica officinalis, Gmelina arborea*, *Michelia champaca, Schima wallichii, Syzygium cumini,* etc. Montane subtropical forests are typically found in cooler regions where precipitation is less. These forests are found in areas having elevation between 900 and 1,500 m. Species like *Castanopsis purpurella, Pinus kesiya, Prunus cerasoides, Quercus semiserrata,* etc are found here. Temperate forests occur at elevations higher than 1,600 m and cover areas like Lengteng, Pharpak and Phawngpui. These areas are dominated by like *Betula alnoides, Elaeocarpus serratus, Michelia champaca, Myrica esculenta, Litsea salicifolia, Lithocarpus dealbata,* etc. Bamboo forests typically occur in subtropical and tropical regions below 1,600 m in elevation. These forests are results of shifting cultivation as bamboos are the first to colonise in jhum fields that are abandoned (Deb and Dutta, 1987). *Melocanna baccifera* is the most dominant species found here. Other species may include *Bambusa tulda, Dendrocalamus hamiltonii, Schizostachyum dulloa*, etc. Quercus forests often mix with temperate and subtropical forest areas and supports species like *Quercus griffithiana* and *Lithocarpus dealbata*. Jhumlands are found all over the state, these are categorised into active, historical and deserted jhumlands.

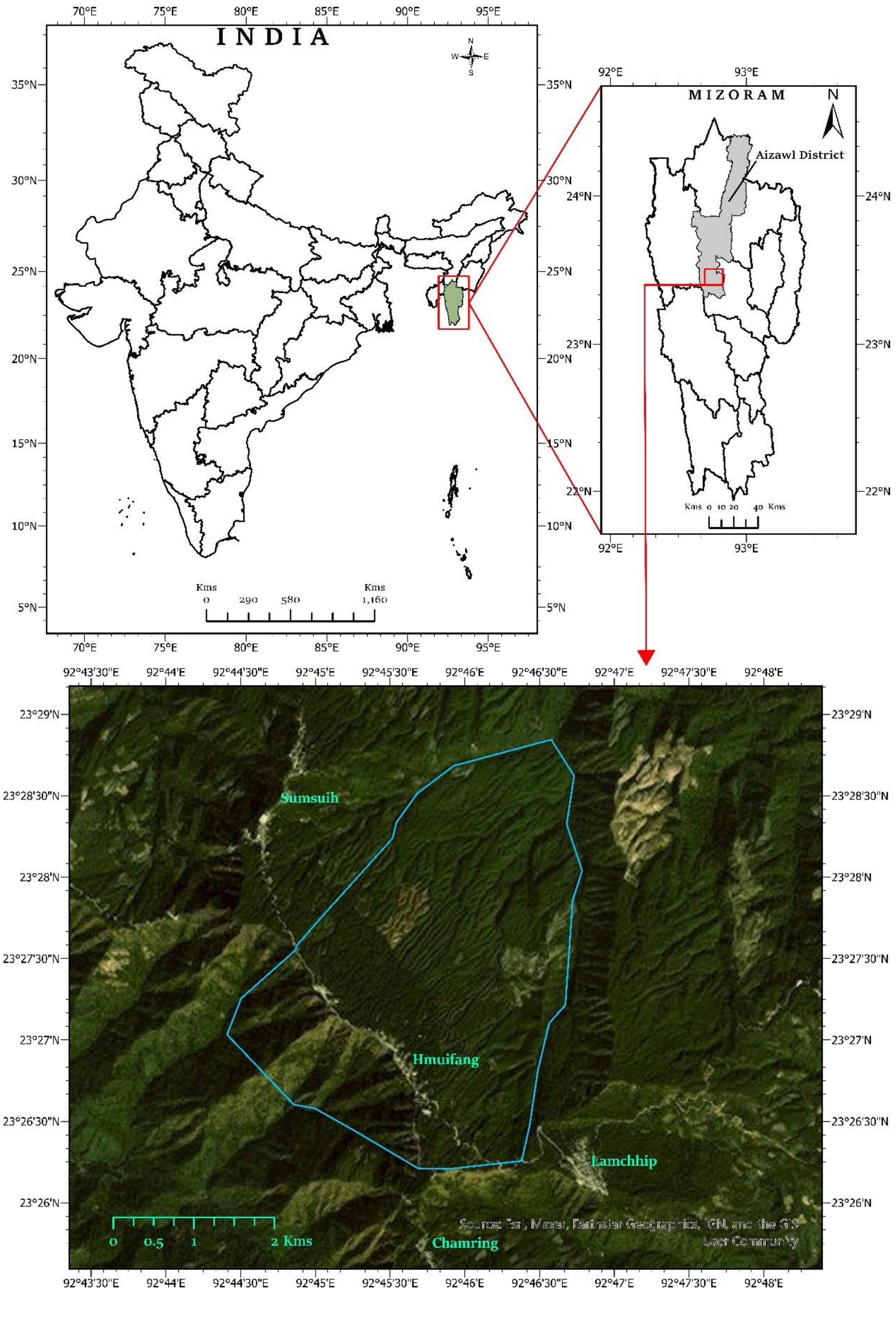

Figure 3.1: Map of the study area.

3.2 Methods

3.2.1 Site selection and sampling

The study site was selected based on several criteria, viz., the area must represent broader ecological and disturbance patterns that are common to Mizoram's forests, it should contain forest stands along a clear level of anthropogenic disturbance from untouched to severely degraded stands, and the practical possibility and accessibility for frequent field visits.

The present study was carried out for two successive years, i.e., from the post-monsoon season of 2022 to the monsoon season of 2024, covering all the three seasons i.e., pre-monsoon, monsoon and post-monsoon. A total of three forest stands, viz., undisturbed (UD), moderately disturbed (MD) and highly disturbed (HD) stands, were selected in and around Hmuifang, Aizawl district, Mizoram (Photo plate 3-14).

3.2.2 Disturbance Index (DI)

To quantify the degree of disturbance caused by anthropogenic activities, disturbance index (DI), canopy cover and light interception were analysed (Pandey and Shukla, 1999). Depending on the disturbance level, the area of research was categorised into 3 stands viz., the UD, MD, and HD stands (Table 3.1), A total of 3 ha (1 ha for each stand) was surveyed during the study.

Table 3.1: Disturbance Index, canopy cover and light interception in the undisturbed, moderately disturbed and highly disturbed forest stands.

Parameter	Forest stand		
	Undisturbed	Moderately disturbed	Highly disturbed
Disturbance Index, DI (%)	<10	10-50	>50
Canopy cover (%)	>50	20-50	<20
Average light interception (%)	>80	50-80	<50

3.2.3 Micro-environment

The micro-environmental conditions namely, relative humidity, light interception and temperature were assessed on site.

3.2.4 Vegetation analysis

For the present study, the method as outlined by Misra (1968) was followed for vegetation analysis. The quadrat size of 10m x 10m for trees, 5m x 5m for shrubs, and 1m x 1m for herbs were laid randomly. In case of trees, all individuals having more than 30 cm girth at breast height (1.37 m) above ground were measured. Identification of species were done using the books, “The book of Mizoram Plants” (Sawmliana, 2003) and “Flora of Mizoram Vol. 1” (Singh et al., 2002). The species identified were then cross-checked with the herbarium records of the Department of Environmental Science, Mizoram University.

The quantitative analysis viz., abundance, density and frequency, were calculated using the methods proposed by Curtis and McIntosh (1950).

3.2.4.1 Abundance

Abundance is the total number of individuals of a species per quadrats of occurrence. It is calculated as-

$$\text{Abundance} = \frac{\text{Total number of individual of a species in all quadrats}}{\text{Total number of quadrats in which the species occured}}$$

3.2.4.2 Density

Density is basically the numerical strength of a particular species in an area. It can be defined as the total number of individuals of a particular species in all the quadrats studied. It can be calculated as-

$$\text{Density} = \frac{\text{Total number of individual of a species in all quadrats}}{\text{Total number of quadrats studied}}$$

3.2.4.3 Frequency

Frequency is used to find out how frequent a particular species occurred in an area. It is the number of quadrats in which species occur. Frequency can be calculated as-

$$\text{Frequency} = \frac{\text{Number of quadrats in which species occured}}{\text{Total number of quadrats studied}} \text{ x } 100$$

3.2.4.4 Basal area

The method of Phillips (1959) was used for the calculation of basal area.

$$\text{Basal area} = \frac{\text{gbh}^2}{4\pi}$$

Where,

gbh= girth at breast height (1.37m from the ground)

3.2.4.5 Importance Value Index (IVI)

The IVI is calculated to know the ecological success and dominance of a species within the community. It is the sum of relative density, relative dominance and relative frequency of a species (Phillips, 1959).

Relative frequency is the degree of individual species in an area to the number of all the occurred species. It is calculated as-

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

Relative density is the numerical strength of a species to the number of individuals of all species, and is calculated as-

$$\text{Relative Density (\%)} = \frac{\text{Density of a species}}{\text{Density of all species}} \text{ x } 100$$

Relative dominance is basically the coverage species value with respect to the sum of coverage of the rest of the species in an area. It is calculated as-

$$\text{Relative Dominance (\%)} = \frac{\text{Basal area of a species}}{\text{Basal area of all species}} \text{ x } 100$$

Important Value Index (IVI)= Relative frequency + Relative density + Relative dominance

3.2.5 Biodiversity indices

3.2.5.1 Distribution pattern

Whitford index is used to find out the distribution pattern of a species (Whitford, 1949). The distribution pattern may be contagious (A:F ratio > 0.05), random (A:F ratio ranging between 0.025-0.05) or regular (A:F ratio < 0,025). It is calculated as-

$$\text{Distribution Pattern} = \text{A: F Ratio}$$

Where,

A= Abundance

F= Frequency

3.2.5.2 Shannon-Wiener index (H´)

It is the most common measure of species diversity. It gives idea of both diversity and evenness of a species in an area. It is calculated using Shannon and Weiner (1963) formula which is as given below-

$$H' = - \Sigma \text{ (ni/N) ln (ni/N)}$$

Where,

ni= Total number of individuals of a species i

N= Total number of individuals of all species in an area

3.2.5.3 Pielou index (J)

It gives idea about how evenly species are distributed in an area. It is calculated using the formula provided by Pie Lou (1969) as follows-

$$E = \frac{H'}{\ln S}$$

Where,

H´= Shannon-Wiener diversity index value

S= Total number of species

3.2.5.4 Simpson index (D)

The Simpson index is a dominance index as it gives more weightage to common or dominant species. It is calculated following the method of Simpson (1949) as follows-

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

Where,

ni= Number of individuals in the i^th^ species

N= Total number of individuals

3.2.5.5 Margalef's diversity index (D_{mg})

It is a species richness index and is calculated using Margalef (1958) method as follows-

$$Dmg = \frac{(S-1)}{lnN}$$

Where,

S= Number of species

N= Number of individuals

3.2.5.6 Sorensen similarity index (S_E)

This index measures the similarity of two communities depending on the species composition and is calculated using the method of Sorensen (1948), as follows-

$$S_E = \frac{2C}{A+B}$$

Where,

A= Total species in first community

B= Total species in second community

C= Total species common in both communities

3.2.6 Soil analysis

Soil samples were taken from the three forest stands, viz., undisturbed, moderately disturbed and highly disturbed stands, across all the seasons i.e., pre-monsoon (February to May), monsoon (June to September), and post-monsoon (October to January), from two depths, i.e., topsoil (0 – 10 cm) and subsoil (10 – 20 cm). The soil samples were collected from the site by inserting a 10 cm scaled soil corer with 5.2 cm inner diameter.

3.2.6.1 Soil pH

pH is used to determine the alkalinity and acidity of the soil. Using an electronic pH meter, the pH was measured in a 1:5 soil:water solution (Allen et al., 1974; Anderson and Ingram, 1993).

3.2.6.2 Soil moisture content (SMC)

The SMC was assessed following the gravimetric method of Allen et al. (1974).

$$\text{Moisture content (\%)} = \frac{W_1 - W_2}{W_1} \text{ x } 100$$

Where,

W_1= Initial weight before drying the soil (g)

W_2= Final weight after drying the soil (g)

3.2.6.3 Bulk density (BD)

The BD is used to measure the soil's compaction. It is calculated following Anderson and Ingram (1993) as-

$$\text{Bulk Density } (g/cm^3) = \frac{\text{Weight of oven dried soil}}{\text{Volume of soil core}}$$

3.2.6.4 Soil organic carbon (SOC)

The SOC was calculated following the Walkey and Black's titration method (1934). The formula is as follows-

$$\text{SOC (\%)} = \frac{0.003 \text{ x } 10 \text{ (B} - \text{T) x } 100}{\text{B x S}}$$

Where,

B= Volume of ferrous ammonium sulphate solution for blank titration (ml)

T= Volume of ferrous ammonium sulphate solution needed for soil (ml)

S= Weight of the soil (g)

3.2.6.5 Total nitrogen (TN)

The total nitrogen was analysed using the Kjeldahl Digestion method developed by Walkey and Black (1934) using the formula-

$$\text{Total Nitrogen (\%)} = \frac{14 \text{ x N x V}}{\text{v x } 1000}$$

Where,

N= Normality of acid

V= Volume of extract

V= Volume of sample

3.2.6.6 Available phosphorus ($P_{avail.}$)

The $P_{avail.}$ was determined using spectrophotometer method of Bray and Kurtz (1945) using the formula-

$$\text{Available phosphorus (Kg ha}^{-1}\text{)} = \frac{R \text{ x V x 1 x } (2.224 \text{ x } 10^6)}{v \text{ x } S \text{ x } 10^6}$$

Where,

R= Weight of the aliquot in mg

V= Total volume of the extractant

v= Volume of aliquot taken for the analysis

S= Weight of the soil

3.2.6.7 Available potassium ($K_{avail.}$)

The $K_{avail.}$ was determined using the flame photometer method of Jackson (1973) and was calculated using the formula-

$$\text{Available potassium (Kg ha}^{-1}) = \frac{\text{R x V x 224 x }10^6}{\text{W x }10^6}$$

Where,

V= Total volume of extractant

R= Weight of aliquot in mg

W= Weight of the soil

3.2.6.8 Statistical analysis

To check the significance and validity of data, particularly for soil, standard error, correlation coefficient and one-way ANOVA were computed.

3.2.7 Carbon stock estimation

3.2.7.1 Estimation of tree biomass

A non-destructive approach was taken for estimation of biomass and carbon stock in trees. All trees having girth size of 30 cm and above were counted. The trees were then identified, followed by measurement of the tree height.

3.2.7.1.1 Estimation of aboveground biomass of trees (AGB_{trees})

The AGB_{trees} was estimated using allometric equation developed for trees in northeast part of India (Nath et al., 2019)

$$AGB_{trees} = 0.32(D^2 \text{ x } H\delta)^{0.75}\text{x } 1.34$$

Where,

D= Diameter at breast height of tree (cm)

H= Height of tree (m)

$\boldsymbol{\delta}$= Specific gravity of tree species (g cm^{-3})

The specific wood gravity of trees was derived from the global wood density database developed by Zanne et al. (2009).

3.2.7.1.2 Estimation of belowground biomass of trees (BGB_{trees})

The BGB_{trees} was calculated following Cairns et al. (1997).

$$BGB_{trees} = \exp\left[-1.085 + 0.9256 \times \ln\left(AGB_{trees}\right)\right]$$

The combined value of AGB_{trees} and BGB_{trees} makes up the total biomass of trees.

3.2.7.2 Calculation of biomass in understorey vegetation and litter

A destructive approach was taken for understorey vegetation (herbs and shrubs) for estimation of biomass and carbon stock.

3.2.7.2.1 Estimation of aboveground biomass (AGB)

According to Pearson et al. (2005), the amount of biomass in understorey vegetation and litter can be calculated as-

$$AGB = \frac{W_{field}}{A} \times \frac{W_{subsample,dry}}{W_{subsample,fresh}} \times \frac{1}{10{,}000}$$

Where,

AGB= Aboveground biomass (t ha^{-1})

A= Size of the area in which samples were collected (ha)

$W_{sub\text{-}sample,\ dry}$= Weight of oven-dried subsample (g)

$W_{sub\text{-}sample,\ wet}$= Weight of fresh subsample (g)

W_{field}= Weight of wet field sample (g)

3.2.7.2.2 Estimation of belowground biomass (BGB)

For understorey vegetation (herbs and shrubs), 26% of the total AGB is considered as BGB, following Ramakutty et al (2007).

$$BGB\ (t) = 0.26 \times AGB$$

3.2.7.3 Estimation of total forest carbon stock

The estimation of carbon stock from the biomass was done by multiplying the total biomass by a conservation factor that represents the average carbon content in biomass. The carbon stock was considered as 50% of the total biomass following Brown et al. (1989). The total forest carbon stock is the sum of total carbon stored in soil, litter and vegetation (aboveground and belowground) carbon stored in trees, shrubs, and herbs.

Chapter 4

RESULTS AND DISCUSSION

The present research aimed to study the effects of anthropogenic disturbances in the forests of the Aizawl district of Mizoram. The findings of the study are as given below:

4.1 Disturbance index, Canopy cover and Light intensity in the Forest stands

The study area was divided into three forest stands, viz., undisturbed (UD), moderately disturbed (MD) and highly disturbed (HD) stands, based on certain ecological factors (Disturbance Index or DI, canopy cover and average light interception) that demonstrated the extent that anthropogenic activities had affected the area under study (Table 4.1).

Table 4.1: Average disturbance Index, canopy cover and light interception along the disturbance gradient.

Parameter	Forest stand		
	Undisturbed	Moderately disturbed	Highly disturbed
Disturbance Index, DI (%)	0	26.80	71.89
Canopy cover (%)	74	49	9
Light interception (%)	85	64	32

4.1.1 Disturbance Index (DI)

The Disturbance Index (DI) showed a distinct trend across the 3 forest stands (Table 4.1). The UD stand had a DI of 0%, which suggests that there were little or no anthropogenic activities going on. The MD stand, on the other hand, had a DI of 26.80%, which suggests that some anthropogenic activities took place, making the area moderately disturbed, The HD stand, with a DI of 71.89%, showed that the area experienced a high level of disturbance. These fall within the range provided by Mishra (2012), Gogoi et al. (2017), Borah et al. (2014) and Pandey and Shukla (1999).

4.1.2 Canopy cover

Canopy cover was seen to drop with increase in disturbance (Table 4.1). The study done by Mishra et al. (2004), Mishra (2012), and Sagar and Devy (2022), showed a similar pattern, where the UD stand had a denser canopy when compared to the MD and the HD stands. The UD stand had the most canopy cover (74%), indicating a thick and layered vegetation, so direct sunlight could not reach the forest floor. In the MD stand, the canopy cover reduced to 49%, indicating partial canopy opening due to the removal of trees caused by anthropogenic activities. The HD stand with a canopy cover of just 9% indicate that the forest was open with minimum vegetation.

4.1.3 Light interception

The light interception was highest in the UD stand, followed by the MD stand and the HD stand, respectively. Similar trend was witnessed by Mishra (2012), Mishra et al. (2004) and Sagar and Devy (2022). The average amount of light that was blocked was 85% in the UD stand, 64% in MD stand, and 32% in HD stand (Table 4.1). The lower interception values in the disturbed stands indicate that more light could pass through, which resulted in change in the microclimatic environment.

4.2 Micro-environment

4.2.1 Relative humidity

The relative humidity was seen to be ranging between 69.1±0.35% (pre-monsoon season in HD stand) and 98.6±0.46% (monsoon season in UD stand) (Table 4.2).

Table 4.2: Seasonal variation in relative humidity of selected forest stands.

Forest stand	Season		
	Pre-monsoon (%)	Monsoon (%)	Post-monsoon (%)
Undisturbed	75.7±0.57	98.6±0.46	87.3±0.53
Moderately disturbed	72.2±0.55	98.3±0.49	84.8±0.66
Highly disturbed	69.1±0.35	96.7±0.65	82.4±0.95

During the pre-monsoon season, the relative humidity in the UD stand was 75.7±0.57%, followed by the MD stand at 72.2±0.55% and the HD stand at 69.1±0.35%. All the forest stands experienced the highest relative humidity during the monsoon season, with the UD stand having maximum humidity at 98.6±0.46%, followed by the MD stand at 98.3±0.49% and the HD stand at 96.7±0.65%, respectively. During the post-monsoon season, the relative humidity was recorded to be 87.30±0.53%, 84.80±0.66%, and 82.4±0.95% in the UD, MD and HD forest stands respectively (Table 4.2). This drop in relative humidity with increase in the level of disturbance i.e., from UD to MD and then finally to HD stand was also documented by Mishra (2012), Gottardini et al. (2023) and De Frenne et al (2021), showing how canopy helps in maintaining moisture as reduction in canopy reduces moisture. The UD stand had the highest humidity irrespective of the seasons. The dense canopy prevented penetration of sunlight thereby reducing evaporation and maintaining the humidity. The MD stand had lower relative humidity compared to the UD stand as partial vegetation and canopy loss resulted in a mixed forest structure with both intact and disturbed patches. The relative humidity was found to be lowest in the HD stand because of wider canopy gap allowing more wind and sunlight penetration, resulting in loss of moisture. The humidity was lowest during the pre-monsoon season across all forest stands, as the air was drier and temperature was rising, while the monsoon season experienced the highest relative humidity due to continuous rainfall and cloud cover. The post-monsoon season had higher humidity compared to pre-monsoon because though the air was starting to dry up, the soil retained some moisture from the monsoon season. This pattern where the relative humidity was maximum during the monsoon season, followed by the post-monsoon and the pre-monsoon season, was similar with the report by Mishra (2012), Mehta et al. (2017) and Barbhuyan et al. (2024).

4.2.2 Ambient air temperature

Air temperature significantly varied throughout the three seasons across all stands (Table 4.3). The temperature was seen to be ranging between 17.5±0.53°C (post-monsoon season in UD stand) and 28.2±0.84°C (pre-monsoon season in HD stand).

Table 4.3: Seasonal variation in ambient air temperature of selected forest stands.

Forest stand	Season		
	Pre-monsoon (°C)	Monsoon (°C)	Post-monsoon (°C)
Undisturbed	23.3±0.59	19.2±0.53	17.5±0.53
Moderately disturbed	25.6±0.49	20.8±0.55	18.6±0.55
Highly disturbed	28.2±0.84	23.4±0.49	20.4±0.50

During the pre-monsoon season, the UD stand had the lowest temperature at 23.3±0.59°C, when compared to the MD stand at 25.6±0.49°C and temperature was highest in the HD stand at 28.2±0.84°C. Compared to the pre-monsoon season, the monsoon season experienced cooler temperature, where the UD stand recorded the temperature to be 19.2±0.53°C, followed by the MD stand at 20.8±0.55°C and the HD stand recorded 23.4±0.49°C. The post-monsoon season had the lowest temperature across all seasons at 17.5±0.53°C, 18.6±0.55°C, and 20.4±0.50°C in the UD, MD and HD stands respectively. The readings were consistent to the findings past literature (Mishra, 2012; Barbhuyan et al., 2024; Mehta et al., 2017). The decrease in temperature in the UD stand emphasize the role of canopy cover for keeping the forest cool. The dense canopy kept the understorey cool and moist, while the open canopy allowed more light to penetrate making the area warmer and drier (Mishra, 2012; Gottardini et al., 2023; De Frenne et al., 2021).

4.3 Vegetation analysis

The analysis of diversity of flora across the disturbance gradient showed distinct difference in structure and composition among the forest stands. Each vegetation layer i.e., trees, shrubs and herbs responded differently to the varying level of disturbance, indicating change in structure and function of forest (Table 4.4).

Table 4.4: Plant diversity of selected forest stands along the disturbance gradient.

Parameters	Trees			Shrubs			Herbs			Total		
	UD	MD	HD	UD	MD	HD	UD	MD	HD	UD	MD	HD
Number of Family	45	37	22	10	21	17	17	28	37	72	86	76
Number of genera	75	58	26	12	30	28	24	53	71	111	141	125
Number of species	99	78	35	13	35	30	25	57	77	137	170	142

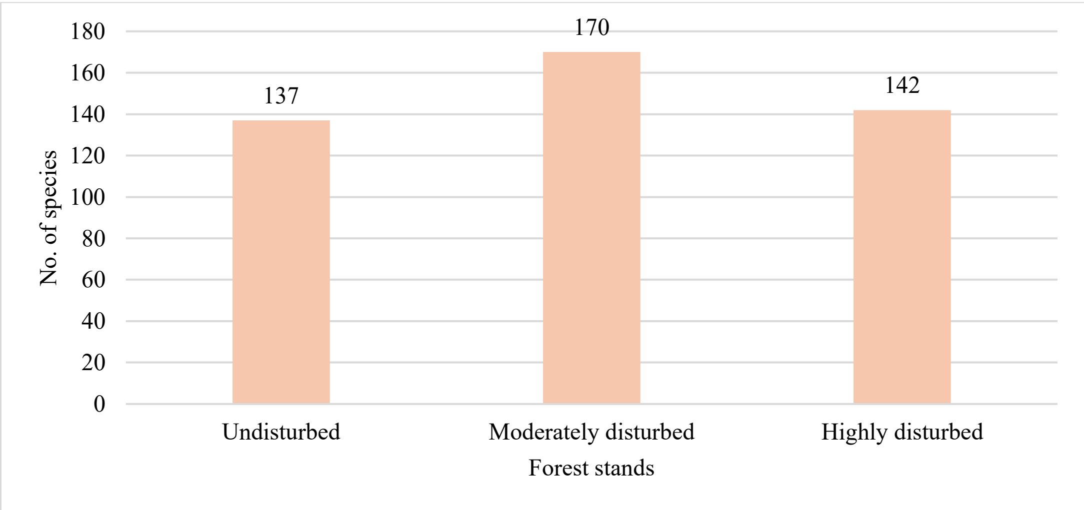

Figure 4.1: Overall plant diversity of selected forest stands along the disturbance gradient.

Total plant diversity showed distinct variation over the disturbance gradient (Figure 4.1). The UD stand documented 137 species, 111 genera, and 72 families of plants, but maximum plant species was observed in MD stand with 170 species, 141 genera, and 86 families. The HD stand comprised of 142 species, 125 genera, and 76 families, where most of the species were herbaceous. The MD stand had the most diversity, followed by the HD and the UD stands respectively. This arrangement supports the intermediate disturbance hypothesis (IDH) which states that mild disturbance allows more diversity (Mishra et al., 2004; Singh, 2021; Pandey and Singh, 1985; Sheil and Burslem, 2003). The increase in diversity in the MD stand indicate that mild or controlled disturbance can provide favourable condition i.e. a combination of light and shade environments, facilitating the co-existence of both shade-tolerant and light-demanding colonies. However, under extreme disturbance, this equilibrium is disrupted resulting in the replacement of sensitive species with rapid growing, disturbance tolerant species. The findings are in line with the past literature (Lalchhuananawma and Lalramnghinglova, 2008; Mishra et al., 2004; Lalfakawma et al., 2009; Bhuyan et al., 2003).

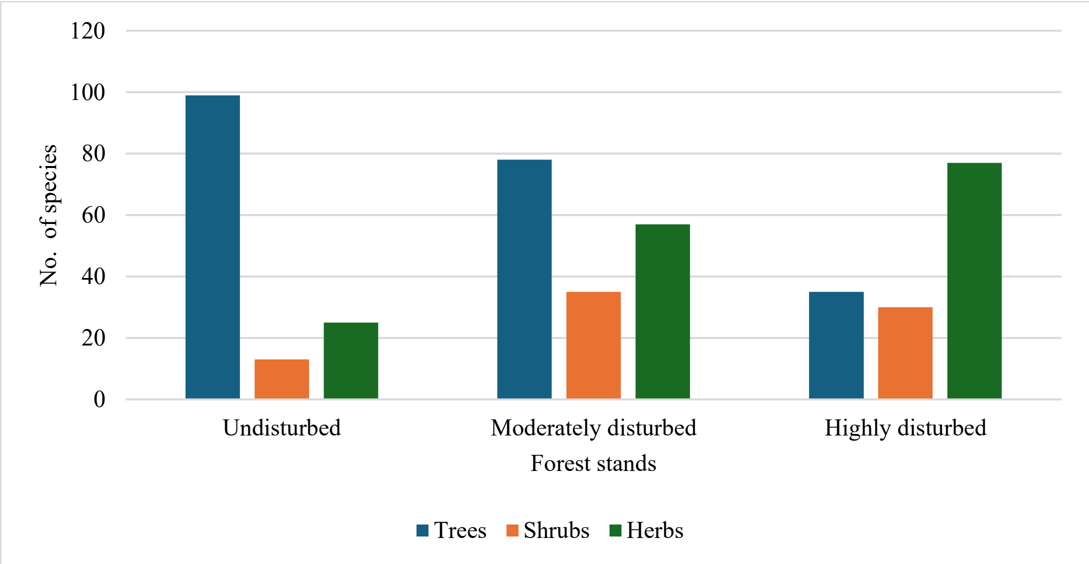

Figure 4.2: Number of species of trees, shrubs and herbs along the disturbance.

The tree diversity tends to decrease with increase in disturbance (Figure 4.2). A total of 128 tree species were documented in all the forest stands, which was the similar value obtained by Datta and Rawat (2008), Devi et al. (2018), and Gopalakrishna et al. (2015). The UD stand had the highest diversity, with 99 species, 75 genera and 45 families, pointing towards a healthy ecosystem with tree species that are firm and typical of mature forests (Whitmore, 1998). Similar number of tree species were documented in Mizoram's forests by researchers like Lalzarzovi and Lalnuntluanga (2022) and Malsawmsanga (2011). The high tree diversity in the UD forest stand was due to the conservation of the forest for a long time by the locals (Devi et al., 2018). As the forest experienced moderate level of disturbance in the MD stand, the tree diversity also decreased (78 species, 58 genera and 37 families), which was in line with the values documented by past researchers (Lalrinkimi and Lallianthanga, 2019; Sarkar and Devi, 2014; Lalfakawma et al., 2009; Rasingam and Parthasarathy, 2009). The HD stand experienced maximum disturbance, thereby only included 35 species, 26 genera and 22 families. Ovung et al. (2021) recorded a comparable number of tree species as the forest was young with signs of overexploitation and an ongoing recovery process. The drop in the tree diversity implies that anthropogenic activities like selective logging of trees for timber and harvesting of non-timber forest products affect the vegetation layers by eliminating the mature trees and restricting the growth of shade-tolerant species (Grant et al., 2010; Lamare et al., 2024; Singh et al., 2015). The sudden decrease in tree diversity showed a shift from a well-structured, diverse, and mature community to a simpler vegetation type which is dominated by fast growing, shade-intolerant and disturbance tolerant species. The similar downward trend in tree species diversity with increase in disturbance was recorded by Mishra et al. (2004), Mishra et al. (2005), Malik et al. (2014), Bitew and Tesfaye (2017), Sahoo et al. (2020), and Borah et al. (2021).

The highest diversity of shrubs was found in the forest stand that was experiencing moderate level of disturbance, followed by highly disturbed and finally by the undisturbed forest stand (Figure 4.2). Similar trend was recorded in past literature (Lalchhuananawma and Lalramnghinglova, 2008; Uniyal et al., 2010; Malsawmsanga, 2011; Sangma and Mishra, 2017; Lalrinkimi and Lallianthanga, 2019; Lalzarzovi and Lalnuntluanga, 2022; Sahoo et al., 2020). The shrub diversity in the UD stand was the lowest (13 species, 12 genera, and 10 families) while the MD stand had maximum shrub diversity (35 species, 30 genera, and 21 families). The HD stand had a slight decline (30 species, 28 genera, and 17 families) when compared to the MD stand but was still higher than the UD stand (Appendix-3). The intermediate disturbance effect on the shrub diversity can be attributed to the increased light availability due to partial canopy opening due to mild disturbance, making the conditions favourable for shade-intolerant shrubs to grow and flourish while enough shade is available for the shade-tolerant species to thrive (Jha and Singh, 1990; Sangma and Mishra, 2017). The thick canopy in UD stands makes it hard for the shrubs to grow as there is limited sunlight and extreme disturbance might make the condition too harsh for shrub to grow, so in HD stand the shrub diversity had slightly declined (Uniyal et al., 2010).

Herbs react positively to disturbance (Table 4.4), with diversity increasing from the UD stand (25 species, 24 genera, and 17 families) to the MD stand (57 species, 53 genera, and 28 families) and highest in the HD stand (77 species, 71 genera, and 37 families) (Appendix-4). Similar trend was documented by researchers like Uniyal et al. (2010), Sangma and Mishra (2017), Lalchhuananawma and Lalramnghinglova (2008), Lalzarzovi and Lalnuntluanga (2022), Malsawmsanga (2011) and Lalrinkimi and Lallianthanga (2019) and Sahoo et al. (2020). The disturbed forest stands have more canopy opening which means there is more open space and allows more light to penetrate. These provide a favourable condition for herbaceous species to thrive and flourish (Kumar and Ram, 2005). The increase in herb species in disturbed forest stands suggest that they exhibit greater resilience and can rapidly grow in disturbed conditions where competition is less and space is more (Turner et al., 1998).

4.3.1 Tree community characteristics

A comparative study on the characteristics of tree community across three different levels of anthropogenic disturbance has been given in Table 4.5. Since the primary focus of the study was on trees, quantitative analysis was restricted to tree species only. However, the list of shrub and herb species along with their presence or absence in the UD, MD and the HD stands were recorded and mentioned in Appendix 2 and 3 respectively.

Table 4.5: Community characteristics of trees along different forest stands.

Parameters	Forest stands		
	Undisturbed	Moderately disturbed	Highly disturbed
Number of Family	45	37	22
Number of Genera	75	58	26
Number of Species	99	78	35
Tree density (individual/ha)	1275	955	314
Total basal area (m^2/ha)	40.20	26.00	5.79
Shannon-Weiner diversity index (H')	4.15	4.00	3.23
Pielou's evenness index (J)	0.91	0.90	0.88
Simpson's dominance index (D)	0.02	0.03	0.05
Margalef's species richness index (Dmg)	13.71	11.22	5.91

The tree density dropped along the disturbance gradient (Table 4.5, Figure 4.3). The UD stand documented tree density at 1275 individuals ha^{-1}, the MD stand had 955 individuals ha^{-1}, and the HD stand had only 314 individuals ha^{-1}. The tree density values were within the range of 240 to 1620 individuals ha^{-1} reported for the tropical and sub-tropical forests of the northeastern part of India (Mishra and Jeeva, 2012; Joshi, 2020; Devi et al., 2018; Suchiang et al., 2020; Ao et al., 2021; Lamare et al., 2024). The UD stand had the highest density, indicating a dense multi-layered structure of mature forest stand. The value in UD stand was consistent with the finding of Sharma et al. (2018). The tree density in MD stand was lower than the UD stand but higher than HD stand (Singh, 2021). The drop in the number of trees is mainly due to activities like intense logging and shifting cultivation. Similar trend was found by Mishra et al. (2004), Borah et al. (2014), Sahoo et al. (2020), Uniyal et al. (2010), and Bhuyan et al. (2003).

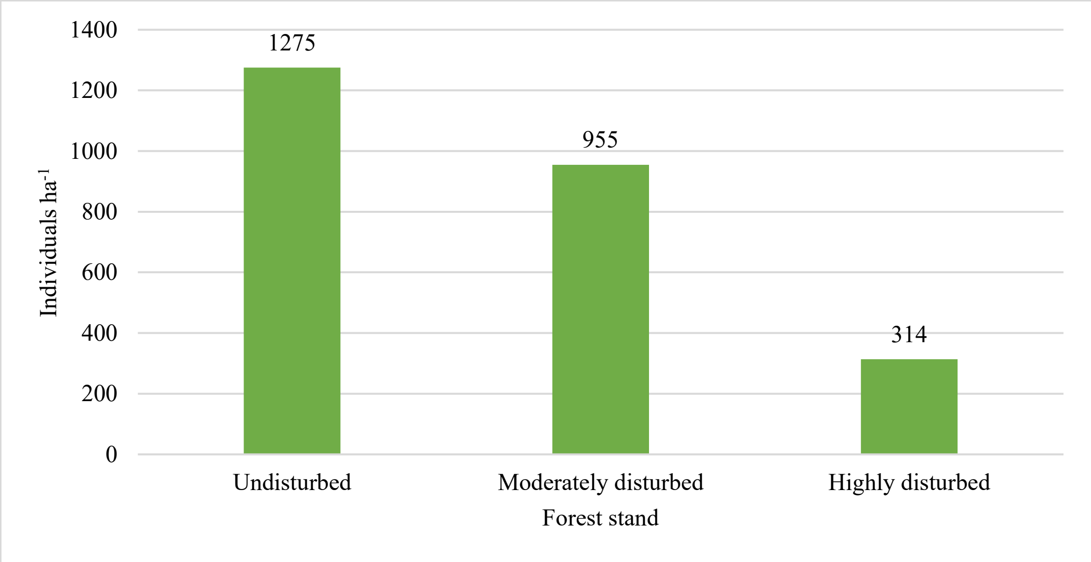

Figure 4.3: Tree density in selected forest stands along the disturbance gradient.

The basal area was highest in UD stand at 40.196 m^2 ha^{-1}. The MD and HD stands recorded a basal area of 25.997 m^2 ha^{-1} and 5.787 m^2 ha^{-1} respectively (Table 4.5). The basal area was reported to decline with increase in disturbance (Mishra et al., 2004, 2005; Sangma and Mishra, 2017; Tenzin and Hasenauer, 2016; Borah and Garkoti, 2011). This extreme drop from the UD to the HD stand was a result of young and open forest with few or no mature trees because of continuous anthropogenic disturbance like deforestation, logging and change of land use (Laurence et al., 1997). Apart from anthropogenic disturbance, changes in age structure, topography, species composition, and successional stage of the forest, are all linked to the variation in the total basal area of the forest community (Lamare et al., 2024; Ovung et al., 2021; Gogoi et al., 2020, Ao et al., 2024).

The Shannon-Wiener index (H′) shows the diversity and evenness of species. The higher value of diversity index indicates greater species richness and stable environment (Devi et al, 2018; Lamare et al., 2024). The UD stand had the highest H′ value (4.15) which is followed by MD stand (4.00) and HD stand (3.23) (Table 4.5, Figure 4.4). Similar results were reported by Bhuyan et al. (2003), Bitew and Tesfaye (2017), and Malik et al. (2014). The H′ was between 0.67 and 4.8, which is typical for Indian forests (Panda et al., 2013; Vishalakshi, 1995; Singh et al., 1984; Devi and Yadava, 2006; Shaheen et al., 2015; Suchiang et al., 2020; Singh et al., 1984; Ao et al., 2021). The decline in value from the UD to the HD stand shows that unique and sensitive species are disappearing while trees that are smaller and able to tolerate disturbance are slowly taking over (Sangma and Mishra,2017; Uniyal et al., 2010; Sahoo et al., 2020). According to Noble and Dirzo (1997), anthropogenic activities like logging and conversion of forests to agricultural lands, leads to an immediate reduction in diversity of species.

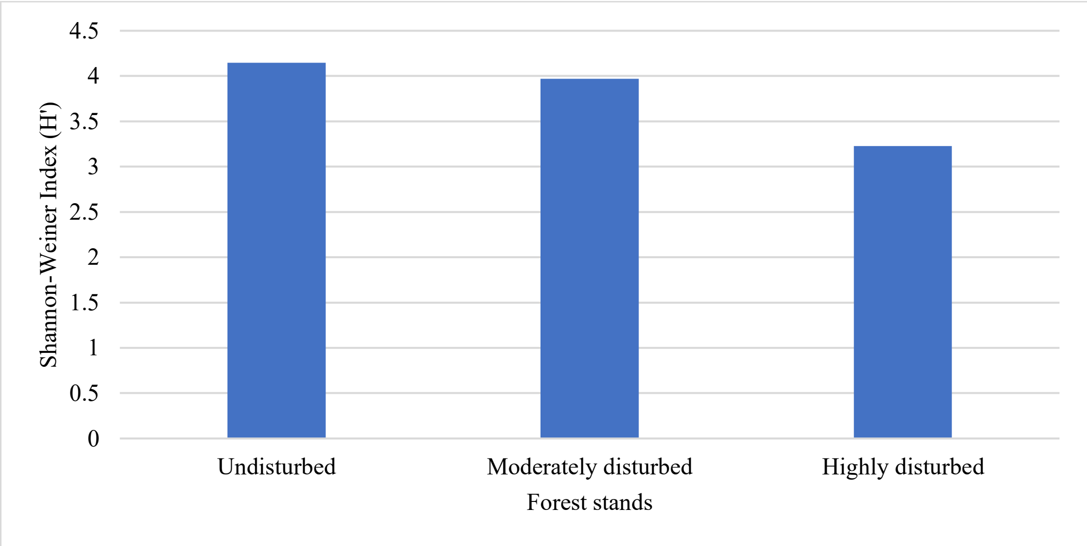

Figure 4.4: Shannon-Wiener diversity index in selected forest stands along the disturbance gradient.

Pielou's evenness index (J) was recorded at 0.91, 0.90, and 0.88 in the UD, MD and HD stands respectively (Table4.5, Figure 4.5). The values were consistent with the results of Bitew and Tesfaye (2017), Ovung et al. (2021), and Borah and Garkoti (2011). The findings were between 0.64 and 1.34, which is typical for tropical forests in India (Lalfakawma et al., 2009; Sahu et al., 2012). The HD stand with the lowest value showed some sign of dominance by one or few species. The UD and MD stands recorded almost the same value, which is close to 1.0, meaning that not one single species dominated the forest intensely. This could mean that higher species evenness exhibited greater consistency in distribution of species (Ovung et al., 2021).

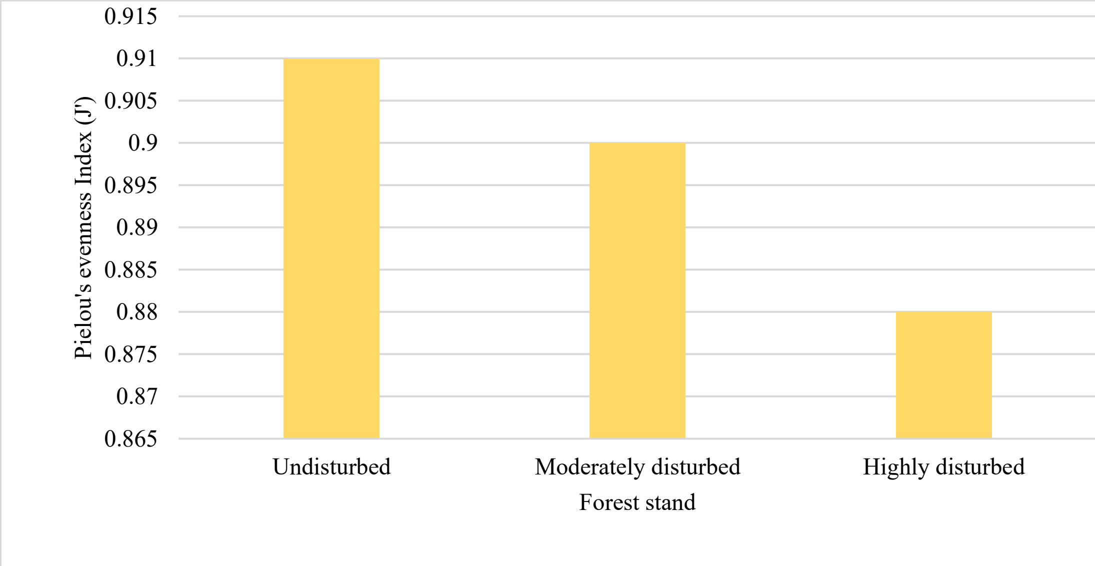

Figure 4.5: Pielou’s evenness index in selected forest stands along the disturbance gradient.

The Simpson’s dominance index (D) was found to be inversely proportional to Shannon-Wiener diversity index (Table 4.5). So, the value slowly increased from 0.02 in UD stand to 0.03 in MD stand and highest in HD stand at 0.05 (Figure 4.6), indicating a shift in community structure from a more even to a more dominant composition. On the other hand, species diversity decreased with increase in disturbance, since lower value indicates higher species. The values are consistent with the findings of researchers like Tynsong et al. (2022) and Saikia et al. (2017). The UD stand recorded a relatively low dominance, and the species are evenly spread. This is typical of a mature and stable forest which is not dominated by just one species. The MD stand reported a gradual increase in the value indicating that the structure of the community is starting to change. Here, few species are starting to dominate, probable due to moderate opening of canopy and selective removal of trees. The HD stand had the highest value, indicating higher dominance by pioneer species or species which are more tolerant to disturbance. Similar trends have been noted in the studies done in the forests of India, where increase in disturbance level increases the dominance value (Mishra et al., 2004; Sangma and Mishra, 2017; Borah and Garkoti, 2011; Ovung and Tripathi, 2021).

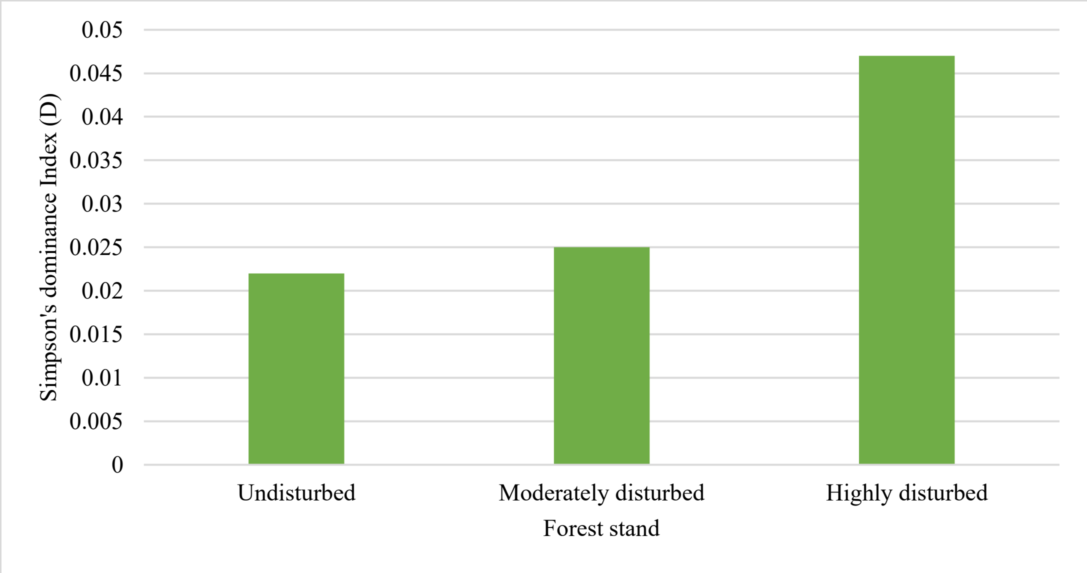

Figure 4.6: Simpson's dominance index (D) in selected forest stands along the disturbance gradient.

Margalef's species richness index (Dmg) decreased along the disturbance gradient (Figure 4.7), going from 13.71 in UD stand to 11.22 in MD stand and 5.91 in HD stand (Table 4.5). The values fall towards the lower side of the range of 4.54 and 23.41 which was reported for India's forests (Satish et al., 2013; Mishra et al., 2005; Lalchhuanawma and Lalramnghinglova, 2011; Kumar et al., 2010). The UD stand demonstrated a relatively higher number of species than MD and HD stands. The drop from UD stand to HD stand by more than half shows the degree of damage anthropogenic activities can cause to biodiversity. According to Ovung et al. (2021), the species richness and evenness are directly proportional to the diversity and are among the most important components affecting the diversity of forest ecosystem.

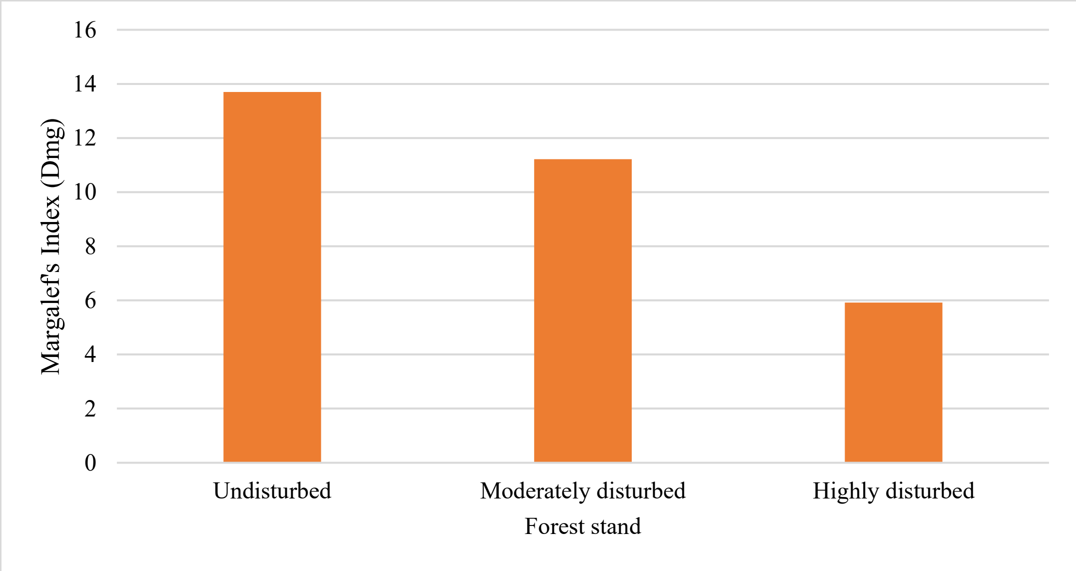

Figure 4.7: Margalef's species richness index (Dmg) in selected forest stand along the disturbance gradient.

4.3.2 Sorensen similarity index (S_E)

The S_E was calculated to find out similar species between different forest stands along the disturbance gradient (Figure 4.8).

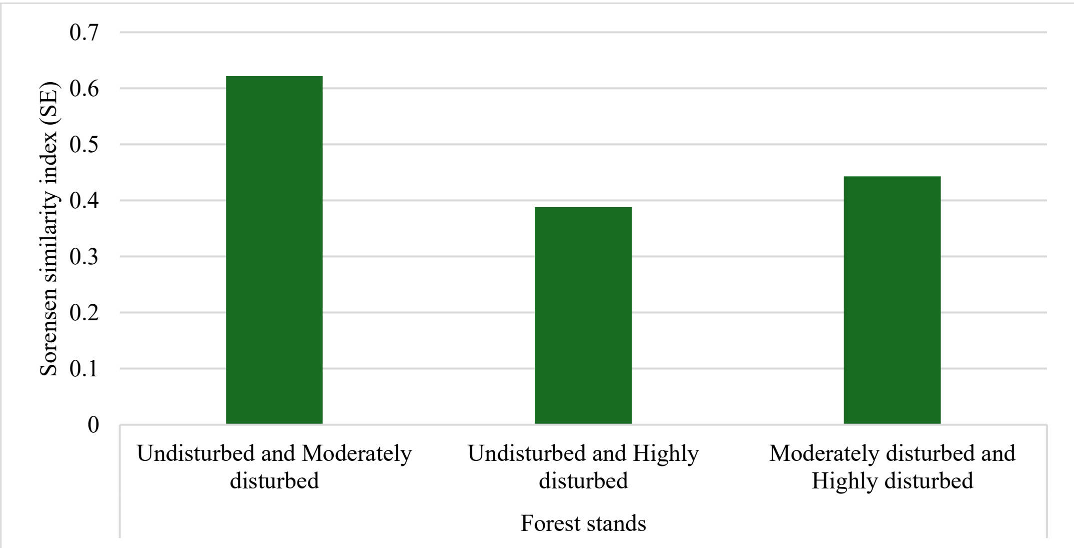

Figure 4.8: Sorensen similarity index along disturbance gradient.

The UD and MD stands was the most similar (0.62), with 55 common species, indicating that the level of disturbance was not too high to change the forest structure completely. The MD and HD stands had lower similarity (0.44) with 25 common species. The findings complimented the findings of Gogoi and Sahoo (2018) and Nemhoihkim et al (2024). This shows a transitional stage where increased disturbance started influencing the variety of species present, where opportunistic species take the place of the sensitive ones. The UD and HD stands had the least similarity (0.39), with only 26 common species, indicating that species which are common in UD stands are taken over by early successional species. The findings were consistent with those of Gogoi and Sahoo, 2018; Behera et al., 2023; Kassahun et al., 2024; Nemhoihkim et al., 2024).

The species that were common in UD and MD stands are *Acer oblongum, Alseodaphnopsis petiolaris, Antidesma bunius, Beilschmiedia gammieana, B. roxburghiana, Calophyllum polyanthum, Castanopsis echinocarpa, C. indica, Celtis timorensis, Croton hookeri, Dipterocarpus retusus, Drimycarpus racemosus, Drypetes indica, Elaeocarpus tectorius, Engelhardia spicata, Eriobotrya bengalensis, Eurya cerasifolia, E. loquaiana, Ficus drupacea, Helicia excelsa, Laurocerasus jenkinsii, Lindera pulcherrima, Lithocarpus elegans, L. pachyphyllus, Litsea monopetala, L. semicarpifolia, Macaranga denticulata, M. indica, Machillus gamblei, Machilus sp., Magnolia doltsopa, Mangifera sylvatica, Meliosma pinnata, Nyssa javanica, Olea dioica, Palaquium polyanthum, Phoebe attenuate, Premna raacemosa, Quercus floribunda, Q. xylocarpa, Rapanea capitellata, Schima wallichii, Symplocos racemosa, S. theifolia, Syzygium claviflorum, S. cuminii, S. praecox, Terminalia bellirica, Toona cilliata, Trema cannabina, Vitex canescens, Wendlandia grandis, Wightia speciosissima*, and *Zizyphus incurve.* The UD and MD stands had 55 species in common, indicating that the disturbance is not extreme enough to drastically alter the species composition in MD stand yet. Common species like *Engelhardia spicata, Quercus floribunda,* and *Beilschmiedia roxburghiana* thrive in mature forests, indicating that the MD stand retains some of its original community structure. This means that the MD stand is at a transitional period where regeneration is active and the forest is still linked to its original state.

The species that were common in UD and HD stands are *Beilschmiedia roxburghiana, Castanopsis echinocarpa, Celtis timorensis, Diospyros lanceifolia, Dipterocarpus retusus, Eurya cerasifolia, E. laquaiana, Ficus drupacea, Helicia excelsa, Lithocarpus elegans, L. pachyphyllus, Litsea cubeba, Macaranga denticulata,* *M. indica, Nyssa javanica, Quercus floribunda, Q. xylocarpa, Rapanea capitellata, Schima wallichii, Stevia rabaudiana, Symplocos theifolia, Syzygium claviflorum, S. cuminii, S. praecox, Wendlandia grandis,* and *Zizyphus incurve.* About 26 species were found to be common in UD and HD stands, indicating that disturbance can change the forest structure. Many of the shade-loving and late successional tree species are missing in HD stand and these species are replaced by disturbance tolerant and pioneer species like *Schima wallichii, Macaranga denticulata, Lithocarpus elegans* and *Dipterocarpus retusus.* Some of these species are flexible and can live in both open and shaded areas.

The species that were common in MD and HD stands are *Beilschmiedia roxburghiana, Castanopsis echinocarpa, Celtis timorensis, Dipterocarpus retusus, Elaeocarpus lanceifolius, Eurya cerasifolia, E. loquaiana, Ficus drupacea, Garcinia succifolia, Helicia excelsa, Lithocarpus elegans, L. pachyphyllus, Macaranga denticulata, M. indica, Nyssa javanica, Quercus floribunda, Q. xylocarpa, Rapanea capitellata, Schima wallichii, Symplocos theifolia, Syzygium claviflorum, S. cuminii, S. praecox, Wendlandia grandis*, and *Zizyphus incurva.* The MD and HD stands have 25 species in common, suggesting that these two stands contain many disturbance-tolerant species. *Macaranga denticulata, Schima wallichii, Papanea capitellata, Symplocos theifolia,* and *Syzygium cuminii* are some common species that thrive well in open, disturbed areas with simpler community structure.

4.3.3 Girth class distribution of trees

Table 4.6: Number of individuals in different girth classes along the disturbance gradient.

Forest Stand	Girth class (cm)					Total
	30-60	60-90	90-120	120-150	>150	
Undisturbed	701	377	113	51	33	1275
Moderately disturbed	692	177	68	13	5	955
Highly disturbed	276	29	8	1	0	314

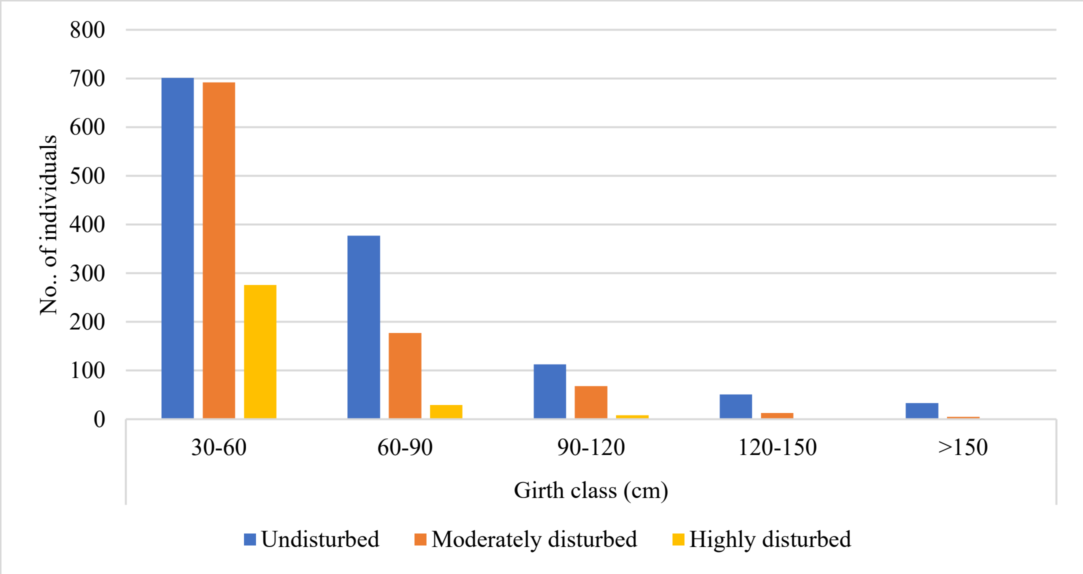

Figure 4.9: Girth class distribution of trees in different forest stands.

The number of tree individuals in different girth classes along the selected forest stands is given in Table 4.6. In the UD stand, trees were well represented throughout all the girth classes with maximum trees in the lower and middle girth classes and some trees with very large girths (Figure 4.9). A total of 701 individual trees fell within the 30-60 cm girth class. This was followed with 377 tree individuals (60-90 cm), 113 individuals (90-120cm), 51 individuals (120-150cm), and 33 individuals (>150cm) girth class (Table 4.6). This pattern, where trees of all girth sizes are present, is typical of a healthy and self-sustaining forest (Buragohain et al., 2023; Hrahsel et al., 2019; Ao et al., 2023; Ao et al., 2024). Most of the trees had smaller or medium girth sizes in comparison to the large girth sized trees, indicating that the forest had both active regenerating and mature trees, which keeps the forest structure stable. The MD forest stand showed more decline in tree number in each girth class than the UD stand (Bhuyan et al., 2003; Borah et al., 2014). There were 692 individual trees that were between 30-60 cm, 177 individuals had 60-90 cm girth size, 68 individuals had girth size of 90-120 cm, 13 individuals had girth falling between 120-150 cm, and only 5 individuals had girth size of more than 150 cm (Table 4.6). Though regeneration was still taking place, the reduction of mature trees shows they were selectively removed. The presence of many younger stems suggest that regeneration is taking place but at a slower rate due to change in canopy cover and microclimate.

As disturbance increased, there was reduction of trees with higher girths, similar with the findings of Mishra et al. (2004) and Mishra et al. (2005). In the HD stand, 276 individual trees had 30-60 cm girth size, 29 on 60-90 cm girth class, 8 in the 90-120 cm class, 1 in 120-150 cm class and zero in the 150 cm class (Table 4.6). The presence of very few or absence of bigger trees indicated that the forest was unstable (Bhuyan et al., 2003; Borah et al., 2014; Anbarashan and Parthasarathy, 2012). The absence of trees with larger girths in the disturbed forest stands indicates high extraction rates from these classes due to various anthropogenic activities like shifting cultivation, logging, and grazing.

There is clear change in the species, family, tree density, frequency, abundance, and patterns of distribution, as the level of disturbance increased (Table 4.7, 4.8, and 4.9). In the UD forest stand, most of the species belonged to families like Lauraceae, Fagaceae, Moraceae etc. Similarly, in the MD stand, the dominant families include Lauraceae, Fagaceae and Euphorbiaceae and in the HD stand, Fagaceae, Moraceae, and Myrtaceae were the dominant families.

The number of trees in each stand varied. In UD forest, *Engelhardia spicata* (76 individuals ha^{-1}), *Quercus floribunda* (60 individuals ha^{-1}), and *Lindera pullcherrima* (51 individuals ha^{-1}) had maximum density. In MD forest, *Rapanea capitellata* (59 individuals ha^{-1}) was maximum, followed by *Drimycarpus racemosus* (48 individuals ha^{-1}), *Helicia excelsa* (47 individuals ha^{-1}), and *Croton hookeri* (43 individuals ha^{-1}) respectively. The large number of *Croton hookeri*, a pioneer species, showed that the composition is starting to change. In HD stand, *Schima wallichii* (37 individuals ha^{-1}) was the most dominant species, followed by *Wendlandia grandis* (25 individuals ha^{-1}) and *Quercus xylocarpa* (22 individuals ha^{-1}). This slow change in the dominant species from shade-tolerant species in UD stand to light-demanding pioneer in the HD stand shows how disturbance change the status and structure of the community.

In UD stand, *Engelhardia spicata* had the highest frequency at 46, followed by *Helicia excelsa* (38), and *Quercus floribunda* (37), indicating that these species are widely distributed. Abundance values ranged from 1.00 to 2.25, indicating a stable community. In MD stand, the highest frequencies were recorded for *Rapanea capitellata* (37), *Helicia excelsa* (32) and *Drimycarpus racemosus* (32), respectively, and abundance ranged from 1.00 to 2.50. In HD stand, *Schima wallichii* (27) had the highest frequency, followed by *Wendlandia grandis* (18) and *Quercus xylocarpa* (15). Abundance values ranged between 1.00 and 2.00.

The Whitford index (A:F) is used to find out the distribution pattern of species in an area which may be regular (<0.025), random (0.025-0.05), and contagious (≥0.5). Almost all the species in the UD stand were contagious (Whitford, 1949). Forest ecosystems mostly have contagious distribution pattern (Thakur et al., 2020; Saha et al, 2016; Dar and Sundarapandian, 2016). The species namely, *Engelhardia spicata, Helicia excelsa, Lindera pulcherrima,* and *Quercus floribunda,* were the only species that showed random distribution, indicating that these species may have the ability to flourish in a wide variety of microclimatic habitats within the stand. Similar trend was seen in the MD stand where most of the species followed contagious pattern and few species viz., *Celtis timorensis, Croton hookeri, Drimycarpus racemosus, Drypetes indica, Helicia excelsa,* and *Rapanea capitellata*, showed random distribution. In the HD stand, all the species had contagious distribution i.e., no species was randomly or consistently distributed. This may be because high disturbance level can lead to uneven conditions i.e., some areas may be too dry and open while others may still be having some moisture and shade, so the trees grow in the conditions suitable for them, resulting in clustering (Borah and Garkoti, 2011; Sharma et al., 2023).

Table 4.7: Tree community characteristics in the undisturbed forest stand.

S.N	Scientific name	Family	Density (individual/ha)	Frequency (F)	Abundance (A)	A/F ratio	Distribution
1	*Acer oblongum* Wall. Ex DC.	Sapindaceae	8	5	1.6	0.32	contagious
2	*Acrocarpus fraxinifolious* Wight & Arn	Fabaceae	4	3	1.33	0.44	contagious
3	*Ailanthus integrifolia* subsp. Calycina (Pierre) Noot.	Simaroubaceae	6	4	1.5	0.38	contagious
4	*Albezia ncurvee* (DC.) Boivin.	Fabaceae	6	4	1.5	0.38	contagious
5	*Alnus nepalensis* D. Don	Betulaceae	9	6	1.5	0.25	contagious
6	*Alseodaphnopsis petiolaris* (Meisn.) H.W.Li & J.Li	Lauraceae	19	14	1.36	0.1	contagious
7	*Antidesma bunius* (L.) Spreng	Phyllanthaceae	7	5	1.4	0.28	contagious
8	*Balakata baccata* (Roxb.) Esser	Euphorbiaceae	6	5	1.2	0.24	contagious
9	*Beilschmiedia gammieana* King ex Hook.f.	Lauraceae	17	9	1.89	0.21	contagious
10	*Beilschmiedia roxburghiana* Nees.	Lauraceae	8	5	1.6	0.32	contagious
11	*Betula alnoides* Buch. -Ham. Ex D. Don.	Betulaceae	6	5	1.2	0.24	contagious
12	*Calophyllum polyanthum* Wall. Ex Planch. & Triana	Calophyllaceae	18	8	2.25	0.28	contagious
13	*Camellia kissi* Wall.	Theaceae	5	4	1.25	0.31	contagious
14	*Castanopsis echinocarpa* Miq.	Fagaceae	6	4	1.5	0.38	contagious

15	*Castanopsis indica* A.DC.	Fagaceae	6	5	1.2	0.24	contagious
16	*Celtis timorensis* Span.	Cannabaceae	21	13	1.62	0.12	contagious
17	*Chukrasia tabularis* A.Juss.	Meliaceae	4	4	1	0.25	contagious
18	*Cinnamomum bejolghota* (Buch.-Ham.) Sweet	Lauraceae	13	7	1.86	0.27	contagious
19	*Cinnamomum cassia* (L.) J.Presl	Lauraceae	4	4	1	0.25	contagious
20	*Cinnamomum glanduliferum* (Wall.) Meisn.	Lauraceae	3	2	1.5	0.75	contagious
21	*Coffea khasiana* Hook. F.	Rubiaceae	5	3	1.67	0.56	contagious
22	*Croton Hookeri* Croizat	Euphorbiaceae	18	9	2	0.22	contagious
23	*Debregeasia longifolia* (Burm.f.) Wedd.	Urticaceae	4	2	2	1	contagious
24	*Diospyros lanceifolia* Roxb.	Ebenaceae	21	13	1.62	0.12	contagious
25	*Dipterocarpus retusus* Blume	Dipterocarpaceae	38	28	1.36	0.05	contagious
26	*Drimycarpus racemosus* (Roxb.) Hook.f. ex Marchand	Anacardiceae	49	22	2.23	0.1	contagious
27	*Drypetes indica* (Mull.-Arg.) Pax & K. Hoffm.	Putranjivaceae	31	21	1.48	0.07	contagious
28	*Elaecoarpus tectorius* Poir.	Elaeocarpaceae	29	16	1.81	0.11	contagious
29	*Embelia tsjeriam-cottam* (Roem. & Schult.) A.DC.	Primulaceae	9	7	1.29	0.18	contagious
30	*Engelhardia spicata* Lechen ex Blume	Juglandaceae	76	46	1.65	0.04	random
31	*Eriobotrya bengalensis* Kurz	Rosaceae	17	9	1.89	0.21	contagious

32	*Euphorbia cotinifolia* L.	Euphorbiaceae	5	3	1.67	0.56	contagious
33	*Eurya cerasifolia* (D.Don) Kobuski	Pentaphylacaceae	25	16	1.56	0.1	contagious
34	*Eurya loquaiana* Dunn	Pentaphylacaceae	5	4	1.25	0.31	contagious
35	*Ficus benjamina* L.	Moraceae	3	2	1.5	0.75	contagious
36	*Ficus drupacea* Thunb.	Moraceae	3	3	1	0.33	contagious
37	*Ficus simplicissima* Lour.	Moraceae	2	2	1	0.5	contagious
38	*Firmiana colorata (*Roxb.) R.Br.	Malvaceae	3	2	1.5	0.75	contagious
39	*Glochidion lanceolarium* (Roxb.) Voigt	Phyllanthaceae	5	4	1.25	0.31	contagious
40	*Helicia excelsa* Blume	Proteaceae	67	38	1.76	0.05	random
41	*Helicia robusta* (Roxb.) R. Br. Ex Blume	Proteaceae	3	2	1.5	0.75	contagious
42	*Heteropanax fragrans* (Roxb.) Seem.	Araliaceae	9	6	1.5	0.25	contagious
43	*Ixora nigricans* R.Br. ex Wight & Arn.	Rubiaceae	3	2	1.5	0.75	contagious
44	*Laurocerasus jenkinsii* (Hook.f. & Thomson) Browicz	Rosaceae	5	4	1.25	0.31	contagious
45	*Ligustrum robustum* (Roxb.) Blume	Oleaceae	4	3	1.33	0.44	contagious
46	*Lindera nacusua* var. nacusua	Lauraceae	5	3	1.67	0.56	contagious
47	*Lindera pulcherrima* (Nees) Benth. Ex Hook.f.	Lauraceae	51	33	1.55	0.05	random
48	*Lithocarpus dealbatus* Rehder	Fagaceae	3	2	1.5	0.75	contagious

49	*Lithocarpus elegans* (Blume) Hatus. Ex Soepadmo	Fagaceae	25	17	1.47	0.09	contagious
50	*Lithocarpus pachyphyllus* Rehder	Fagaceae	11	5	2.2	0.44	contagious
51	*Litsea cubeba* (Lour.) Pers.	Lauraceae	6	3	2	0.67	contagious
52	*Litsea monopetala* (Roxb.) Pers.	Lauraceae	18	12	1.5	0.13	contagious
53	*Litsea salicifolia* Hook.f.	Lauraceae	10	7	1.43	0.2	contagious
54	*Litsea semicarpifolia* (Wall. Ex Nees) Hook. F.	Lauraceae	12	11	1.09	0.1	contagious
55	*Macaranga denticulata* Müll.Arg.	Euphorbiaceae	24	12	2	0.17	contagious
56	*Macaranga indica* Wight	Euphorbiaceae	27	16	1.69	0.11	contagious
57	*Machilus gamblei* King ex Hook.f.	Lauraceae	6	5	1.2	0.24	contagious
58	*Machilus sp.*	Lauraceae	3	2	1.5	0.75	contagious
59	*Magnolia doltsopa* (Buch.-Ham. Ex DC.) Figlar	Magnoliaceae	3	2	1.5	0.75	contagious
60	*Magnolia hodgsonii* (Hook. F. & Thoms) Keng	Magnoliaceae	8	6	1.33	0.22	contagious
61	*Mangifera sylvatica* Roxb.	Anacardiaceae	2	1	2	2	contagious
62	*Meliosma pinnata* (Roxb.) Maxim.	Sabiaceae	31	24	1.29	0.05	contagious
63	*Myrica esculenta* Buch.-Ham. Ex D.Don	Myricaceae	5	3	1.67	0.56	contagious
64	*Nyssa javanica* (Blume) Wangerin	Nyssaceae	12	7	1.71	0.24	contagious
65	*Olea dioica* Roxb.	Oleaceae	18	12	1.5	0.13	contagious

66	*Ostodes paniculata* Blume	Euphorbiaceae	27	15	1.8	0.12	contagious
67	*Palaquium polyanthum* Merr.	Sapotaceae	3	3	1	0.33	contagious
68	*Persea odoratissima* (Nees) Kosterm.	Lauraceae	2	2	1	0.5	contagious
69	*Phoebe ncurvee* (Nees) Nees	Lauraceae	6	4	1.5	0.38	contagious
70	*Pinus kesiya* Royle ex Gordon	Pinaceae	12	10	1.2	0.12	contagious
71	*Podocarpus neriifolius* D. Don	Podocarpaceae	6	4	1.5	0.38	contagious
72	*Premna racemosa* Wall. Ex Schauer	Lamiaceae	7	5	1.4	0.28	contagious
73	*Prunus undulata* Buch.-Ham. Ex D.Don	Rosaceae	4	2	2	1	contagious
74	*Pyrularia edulis* (Wall.) A.DC.	Santalaceae	5	3	1.67	0.56	contagious
75	*Quercus floribunda* Lindl. Ex A.Camus	Fagaceae	60	37	1.62	0.04	random
76	*Quercus xylocarpa* Kurz	Fagaceae	25	15	1.67	0.11	contagious
77	*Randia wallichii* Hook. F.	Rubiaceae	3	3	1	0.33	contagious
78	*Rapanea capitellata* (Wall.) Mez	Primulaceae	19	10	1.9	0.19	contagious
79	*Saurauia napaulensis* DC.	Actinidiaceae	4	3	1.33	0.44	contagious
80	*Saurauia punduana* Wall.	Actinidiaceae	9	6	1.5	0.25	contagious
81	*Schima khasiana* Dyer	Theaceae	4	3	1.33	0.44	contagious
82	*Schima wallichii* (DC.) Choisy	Theaceae	8	6	1.33	0.22	contagious
83	*Semecarpus anacardium* L. f.	Anacardiaceae	2	2	1	0.5	contagious

84	*Sterculia villosa* Roxb.	Malvaceae	2	1	2	2	contagious
85	*Stevia rabaudiana* (Bertoni) Hemsl.	Asteraceae	5	4	1.25	0.31	contagious
86	*Symplocos racemosa* Roxb.	Symplocaceae	7	4	1.75	0.44	contagious
87	*Symplocos theifolia* D. Don	Symplocaceae	26	16	1.63	0.1	contagious
88	*Syzygium claviflorum* (Roxb.) Wall. Ex Steud.	Myrtaceae	4	3	1.33	0.44	contagious
89	*Syzygium cuminii* (L.) Skeels	Myrtaceae	6	6	1	0.17	contagious
90	*Syzygium praecox* (Roxb.) Rathakr. And N.C.Nair	Myrtaceae	6	4	1.5	0.38	contagious
91	*Terminalia bellirica* (Gaertn.) Roxb.	Combretaceae	7	5	1.4	0.28	contagious
92	*Toddalia asiaica* (L.) Lam.	Rutaceae	5	4	1.25	0.31	contagious
93	*Toona cilliata* M. Roem	Meliaceae	9	4	2.25	0.56	contagious
94	*Trema cannabina* Lour.	Cannabaceae	2	1	2	2	contagious
95	*Vitex canescens* Kurz	Lamiaceae	2	2	1	0.5	contagious
96	*Vitex quinata* F.N.Williams	Lamiaceae	17	8	2.13	0.27	contagious
97	*Wendlandia grandis (*Hook.f.) Cowan	Rubiaceae	36	19	1.89	0.1	contagious
98	*Wightia speciosissima* (D.Don) Merr.	Paulowniaceae	7	7	1	0.14	contagious
99	*Zizyphus ncurve* Roxb.	Rhamnaceae	33	25	1.32	0.05	contagious

Table 4.8: Tree community characteristics in the moderately disturbed forest stand.

S.N	Scientific name	Family	Density (individual/ha)	Frequency (F)	Abundance (A)	A/F ratio	Distribution
1	*Acer oblongum* Wall. Ex DC.	Sapindaceae	12	7	1.71	0.245	contagious
2	*Alseodaphnopsis petiolaris* (Meisn.) H.W.Li & J.Li	Lauraceae	25	18	1.39	0.077	contagious
3	*Antidesma bunius* (L.) Spreng	Phyllanthaceae	3	3	1	0.333	contagious
4	*Bauhinia variegata* L.	Fabaceae	5	4	1.25	0.313	contagious
5	*Beilschmiedia gammieana* King ex Hook.f.	Lauraceae	8	6	1.33	0.222	contagious
6	*Beilschmiedia roxburghiana* Nees.	Lauraceae	8	4	2	0.5	contagious
7	*Benkara fasciculata* (Roxb.) Ridsdale	Rubiaceae	10	5	2	0.4	contagious
8	*Bischofia javanica* Blume	Phyllanthaceae	10	4	2.5	0.625	contagious
9	*Bruinsmia polysperma* (C.B.Clarke) Steenis	Styracaceae	8	7	1.14	0.163	contagious
10	*Calophyllum polyanthum* Wall. Ex Planch. & Triana	Calophyllaceae	8	5	1.6	0.32	contagious
11	*Castanopsis echinocarpa* Miq.	Fagaceae	12	7	1.71	0.245	contagious
12	*Castanopsis indica* A.DC.	Fagaceae	8	4	2	0.5	contagious
13	*Celtis timorensis* Span.	Cannabaceae	30	25	1.2	0.048	random
14	*Cinnamomum tamala* (Buch.-Ham.) T.Nees & Eberm.	Lauraceae	6	6	1	0.167	contagious

15	*Croton Hookeri* Croizat	Euphorbiaceae	43	31	1.39	0.045	random
16	*Dimocarpus longan* Lour.	Sapindaceae	5	4	1.25	0.313	contagious
17	*Diospyros stricta Roxb.*	Ebenaceae	7	5	1.4	0.28	contagious
18	*Dipterocarpus retusus* Blume	Dipterocarpaceae	23	14	1.64	0.117	contagious
19	*Drimycarpus racemosus* (Roxb.) Hook.f. ex Marchand	Anacardiceae	48	32	1.5	0.047	random
20	*Drypetes indica* (Mull.-Arg.) Pax & K. Hoffm.	Putranjivaceae	41	29	1.41	0.049	random
21	*Dysoxylum gotadhora* (Buch.-Ham.) Mabb.	Meliaceae	4	3	1.33	0.444	contagious
22	*Dysoxylum mollissimum* Blume	Meliaceae	19	14	1.36	0.097	contagious
23	*Elaecoarpus tectorius* Poir.	Elaeocarpaceae	6	5	1.2	0.24	contagious
24	*Elaeocarpus lanceifolius* Roxb.	Elaeocarpaceae	4	2	2	1	contagious
25	*Elaeocarpus rugosus Roxb.* Ex G.Don	Elaeocarpaceae	5	4	1.25	0.313	contagious
26	*Engelhardia spicata* Lechen ex Blume	Juglandaceae	32	21	1.52	0.073	contagious
27	*Eriobotrya bengalensis* Kurz	Rosaceae	7	4	1.75	0.438	contagious
28	*Eurya cerasifolia* (D.Don) Kobuski	Pentaphylacaceae	8	6	1.33	0.222	contagious
29	*Eurya loquaiana* Dunn	Pentaphylacaceae	7	6	1.17	0.194	contagious
30	*Ficus curtipes* Corner	Moraceae	17	13	1.31	0.101	contagious
31	*Ficus drupacea* Thunb.	Moraceae	5	4	1.25	0.313	contagious

32	*Ficus gibbosa* Blume	Moraceae	2	2	1	0.5	contagious
33	*Firmiana colorata (*Roxb.) R.Br.	Malvaceae	2	2	1	0.5	contagious
34	*Fraxinus floribunda* Wall.	Oleaceae	4	2	2	1	contagious
35	*Garcinia cowa* Roxb. Ex Choisy	Clusiaceae	3	3	1	0.333	contagious
36	*Garcinia succifolia* Kurz	Clusiaceae	5	3	1.67	0.556	contagious
37	*Helicia excelsa* Blume	Proteaceae	47	32	1.47	0.046	random
38	*Juglans regia* Linn.	Juglandaceae	3	3	1	0.333	contagious
39	*Laurocerasus jenkinsii* (Hook.f. & Thomson) Browicz	Rosaceae	7	5	1.4	0.28	contagious
40	*Lindera pulcherrima* (Nees) Benth. Ex Hook.f.	Lauraceae	2	1	2	2	contagious
41	*Lithocarpus elegans* (Blume) Hatus. Ex Soepadmo	Fagaceae	13	10	1.3	0.13	contagious
42	*Lithocarpus pachyphyllus* Rehder	Fagaceae	8	4	2	0.5	contagious
43	*Litsea monopetala* (Roxb.) Pers.	Lauraceae	9	7	1.29	0.184	contagious
44	*Litsea semicarpifolia* (Wall. Ex Nees) Hook. F.	Lauraceae	4	3	1.33	0.444	contagious
45	*Macaranga denticulata* Müll.Arg.	Euphorbiaceae	27	16	1.69	0.105	contagious
46	*Macaranga indica* Wight	Euphorbiaceae	35	19	1.84	0.097	contagious
47	*Machilus gamblei* King ex Hook.f.	Lauraceae	5	5	1	0.2	contagious
48	*Machilus glaucescens* (Nees) Wight	Lauraceae	12	10	1.2	0.12	contagious

49	*Machilus sp.*	Lauraceae	5	3	1.67	0.556	contagious
50	*Magnolia doltsopa* (Buch.-Ham. Ex DC.) Figlar	Magnoliaceae	8	5	1.6	0.32	contagious
51	*Mangifera sylvatica* Roxb.	Anacardiaceae	2	2	1	0.5	contagious
52	*Meliosma pinnata* (Roxb.) Maxim.	Sabiaceae	8	5	1.6	0.32	contagious
53	*Memecylon grande* Retz.	Melastomataceae	6	4	1.5	0.375	contagious
54	*Morus macroura* Miq.	Moraceae	10	7	1.43	0.204	contagious
55	*Nyssa javanica* (Blume) Wangerin	Nyssaceae	6	5	1.2	0.24	contagious
56	*Olea dioica* Roxb.	Oleaceae	23	15	1.53	0.102	contagious
57	*Olea salicifolia* Wall. Ex G.Don	Oleaceae	4	3	1.33	0.444	contagious
58	*Palaquium polyanthum* Merr.	Sapotaceae	8	4	2	0.5	contagious
59	*Phoebe ncurvee* (Nees) Nees	Lauraceae	4	3	1.33	0.444	contagious
60	*Premna racemosa* Wall. Ex Schauer	Lamiaceae	7	5	1.4	0.28	contagious
61	*Quercus floribunda* Lindl. Ex A.Camus	Fagaceae	8	5	1.6	0.32	contagious
62	*Quercus xylocarpa* Kurz	Fagaceae	21	11	1.91	0.174	contagious
63	*Rapanea capitellata* (Wall.) Mez	Primulaceae	59	37	1.59	0.043	random
64	*Schima khasiana* Dyer	Theaceae	4	4	1	0.25	contagious
65	*Schima wallichii* (DC.) Choisy	Theaceae	28	16	1.75	0.109	contagious
66	*Symplocos racemosa* Roxb.	Symplocaceae	7	4	1.75	0.438	contagious

67	*Symplocos theifolia* D. Don	Symplocaceae	9	5	1.8	0.36	contagious
68	*Syzygium claviflorum* (Roxb.) Wall. Ex Steud.	Myrtaceae	11	8	1.38	0.172	contagious
69	*Syzygium cuminii* (L.) Skeels	Myrtaceae	8	6	1.33	0.222	contagious
70	*Syzygium praecox* (Roxb.) Rathakr. And N.C.Nair	Myrtaceae	3	2	1.5	0.75	contagious
71	*Terminalia bellirica* (Gaertn.) Roxb.	Combretaceae	9	6	1.5	0.25	contagious
72	*Toona cilliata* M. Roem	Meliaceae	4	3	1.33	0.444	contagious
73	*Trema cannabina* Lour.	Cannabaceae	2	2	1	0.5	contagious
74	*Vitex canescens* Kurz	Lamiaceae	7	4	1.75	0.438	contagious
75	*Wendlandia grandis (*Hook.f.) Cowan	Rubiaceae	38	20	1.9	0.095	contagious
76	*Wightia speciosissima* (D.Don) Merr.	Paulowniaceae	2	2	1	0.5	contagious
77	*Xantolis hookeri* (C.B.Clarke) P.Royen	Sapotaceae	10	9	1.11	0.123	contagious
78	*Zizyphus ncurve* Roxb.	Rhamnaceae	12	7	1.71	0.245	contagious

Table 4.9: Tree community characteristics in the highly disturbed forest stand.

S.N	Scientific name	Family	Density (individual/ha)	Frequency (F)	Abundance (A)	A/F ratio	Distribution
1	*Beilschmiedia roxburghiana* Nees.	Lauraceae	3	3	1	0.333	contagious
2	*Carallia brachiata* (Lour.) Merr.	Rhizophoraceae	11	9	1.22	0.136	contagious
3	*Castanopsis echinocarpa* Miq.	Fagaceae	13	10	1.3	0.13	contagious
4	*Castanopsis tribuloides* A.DC.	Fagaceae	10	8	1.25	0.156	contagious
5	*Celtis timorensis* Span.	Cannabaceae	15	12	1.25	0.104	contagious
6	*Diospyros lanceifolia* Roxb.	Ebenaceae	2	2	1	0.5	contagious
7	*Dipterocarpus retusus* Blume	Dipterocarpaceae	9	5	1.8	0.36	contagious
8	*Dysoxylum excelsum* Blume	Meliaceae	10	6	1.67	0.278	contagious
9	*Elaeocarpus lanceifolius* Roxb.	Elaeocarpaceae	3	2	1.5	0.75	contagious
10	*Eurya cerasifolia* (D.Don) Kobuski	Pentaphylacaceae	13	12	1.08	0.09	contagious
11	*Eurya loquaiana* Dunn	Pentaphylacaceae	7	6	1.17	0.194	contagious
12	*Ficus drupacea* Thunb.	Moraceae	8	4	2	0.5	contagious
13	*Ficus religiosa* L.	Moraceae	2	2	1	0.5	contagious
14	*Ficus semicordata* Buch. Ham ex Sm.	Moraceae	3	2	1.5	0.75	contagious
15	*Garcinia succifolia* Kurz	Clusiaceae	2	2	1	0.5	contagious

16	*Helicia excelsa* Blume	Proteaceae	15	8	1.88	0.234	contagious
17	*Lithocarpus elegans* (Blume) Hatus. ex Soepadmo	Fagaceae	1	1	1	1	contagious
18	*Lithocarpus pachyphyllus* Rehder	Fagaceae	4	3	1.33	0.444	contagious
19	*Litsea cubeba* (Lour.) Pers.	Lauraceae	7	6	1.17	0.194	contagious
20	*Macaranga denticulata* Müll.Arg.	Euphorbiaceae	17	9	1.89	0.21	contagious
21	*Macaranga indica* Wight	Euphorbiaceae	11	6	1.83	0.306	contagious
22	*Mangifera indica* L.	Anacardiaceae	5	4	1.25	0.313	contagious
23	*Nyssa javanica* (Blume) Wangerin	Nyssaceae	1	1	1	1	contagious
24	*Quercus floribunda* Lindl. ex A.Camus	Fagaceae	5	3	1.67	0.556	contagious
25	*Quercus xylocarpa* Kurz	Fagaceae	22	15	1.47	0.098	contagious
26	*Rapanea capitellata* (Wall.) Mez	Primulaceae	17	13	1.31	0.101	contagious
27	*Rhus chinensis* Mill.	Anacardiaceae	8	7	1.14	0.163	contagious
28	*Schima wallichii* (DC.) Choisy	Theaceae	37	27	1.37	0.051	contagious
29	*Stevia rabaudiana* (Bertoni) Hemsl.	Asteraceae	1	1	1	1	contagious
30	*Symplocos theifolia* D. Don	Symplocaceae	3	2	1.5	0.75	contagious
31	*Syzygium claviflorum* (Roxb.) Wall. ex Steud.	Myrtaceae	12	10	1.2	0.12	contagious
32	*Syzygium cuminii* (L.) Skeels	Myrtaceae	4	3	1.33	0.444	contagious

33	*Syzygium praecox* (Roxb.) Rathakr. And N.C.Nair	Myrtaceae	2	2	1	0.5	contagious
34	*Wendlandia grandis (*Hook.f.) Cowan	Rubiaceae	25	18	1.39	0.077	contagious
35	*Zizyphus incurva* Roxb.	Rhamnaceae	6	4	1.5	0.375	contagious

4.3.4 IUCN conservation status of tree species

The International Union for Conservation of Nature (IUCN) Red List categorises species into categories depending on how likely they are to become extinct: Extinct (EX), Extinct in the Wild (EW), Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concerned (LC), Data Deficient (DD), and Not Evaluated (NE).

Among the 128 species recorded in the area, species like *Acer oblongum, Ailanthus integrifolia, Alnus nepalensis, Antidesma bunius, Balakata baccata,* etc. fall into the LC category, indicating that these species still have a stable population as they are widespread and can handle disturbances and continue to thrive (Table 4.10). However, the presence of VU species, viz., *Alseodaphnopsis petiolaris, Elaeocarpus rugosus,* and *Memecylon grande*, as well as EN species, viz., *Dipterocarpus retusus* and *Palaquium polyanthum*, indicate that conservation of these species is very important. These species are usually found in older, less disturbed forests, and are sensitive to disturbed areas where activities like selective logging or shifting cultivation happens. *Saurauia punduana* is designated as CR, indicating that it is at a very high risk of extinction and needs immediate conservation intervention. It was recorded to be found only in the UD stand, showing the importance of having an intact, well protected habitat for CR species to thrive, and its presence in the study site indicates that the region still provides refuge for species that are on the edge of extinction around the world. Many species were marked as Data Deficient (DD) or Not Evaluated (NE), indicating gap in formal assessment instead of lack of care for conservation.

Table 4.10: IUCN Red List status and distribution of recorded tree species.

Sl. No.	Species	Family	UD	MD	HD	IUCN
1	*Acer oblongum* Wall. ex DC.	Sapindaceae	✓	✓	-	LC
2	*Acrocarpus fraxinifolious* Wight & Arn	Fabaceae	✓	-	-	NA
3	*Ailanthus integrifolia* subsp. calycina (Pierre) Noot.	Simaroubaceae	✓	-	-	LC

4	*Albezia stipulata* (DC.) Boivin.	Fabaceae	✓	-	-	NA
5	*Alnus nepalensis* D. Don	Betulaceae	✓	-	-	LC
6	*Alseodaphnopsis petiolaris* (Meisn.) H.W.Li & J.Li	Lauraceae	✓	✓	-	VU
7	*Antidesma bunius* (L.) Spreng	Phyllanthaceae	✓	✓	-	LC
8	*Balakata baccata* (Roxb.) Esser	Euphorbiaceae	✓	-	-	LC
9	*Bauhinia variegata* L.	Fabaceae	-	✓	-	LC
10	*Beilschmiedia gammieana* King ex Hook.f.	Lauraceae	✓	✓	-	NA
11	*Beilschmiedia roxburghiana* Nees.	Lauraceae	✓	✓	-	LC
12	*Benkara fasciculata* (Roxb.) Ridsdale	Rubiaceae	-	✓	-	LC
13	*Betula alnoides* Buch.-Ham. Ex D. Don.	Betulaceae	✓	-	-	LC
14	*Bischofia javanica* Blume	Phyllanthaceae	-	✓	-	LC
15	*Bruinsmia polysperma* (C.B.Clarke) Steenis	Styracaceae	-	✓	-	NA
16	*Calophyllum polyanthum* Wall. ex Planch. & Triana	Calophyllaceae	✓	✓	-	NT
17	*Camellia kissi* Wall.	Theaceae	✓	-	-	LC
18	*Carallia brachiata* (Lour.) Merr.	Rhizophoraceae	-	-	✓	LC
19	*Castanopsis echinocarpa* Miq.	Fagaceae	✓	✓	✓	LC
20	*Castanopsis indica* A.DC.	Fagaceae	✓	✓	-	LC
21	*Castanopsis tribuloides* A.DC.	Fagaceae	-	-	✓	LC
22	*Celtis timorensis* Span.	Cannabaceae	✓	✓	✓	LC
23	*Chukrasia tabularis* A.Juss.	Meliaceae	✓	-	-	LC
24	*Cinnamomum bejolghota* (Buch.-Ham.) Sweet	Lauraceae	✓	-	-	LC
25	*Cinnamomum cassia* (L.) J.Presl	Lauraceae	✓	-	-	LC
26	*Cinnamomum glanduliferum* (Wall.) Meisn.	Lauraceae	✓	-	-	LC
27	*Cinnamomum tamala* (Buch.-Ham.) T.Nees & Eberm.	Lauraceae	-	✓	-	LC
28	*Coffea khasiana* Hook. F.	Rubiaceae	✓	-	-	NA
29	*Croton Hookeri* Croizat	Euphorbiaceae	✓	✓	-	NA

30	*Debregeasia longifolia* (Burm.f.) Wedd.	Urticaceae	✓	-	-	LC
31	*Dimocarpus longan* Lour.	Sapindaceae	-	✓	-	DD
32	*Diospyros lanceifolia* Roxb.	Ebenaceae	✓	-	✓	LC
33	*Diospyros stricta Roxb.*	Ebenaceae	-	✓	-	NA
34	*Dipterocarpus retusus* Blume	Dipterocarpaceae	✓	✓	✓	EN
35	*Drimycarpus racemosus* (Roxb.) Hook.f. ex Marchand	Anacardiceae	✓	✓	-	NA
36	*Drypetes indica* (Mull.-Arg.) Pax & K. Hoffm.	Putranjivaceae	✓	✓	-	LC
37	*Dysoxylum excelsum* Blume	Meliaceae	-	-	✓	LC
38	*Dysoxylum gotadhora* (Buch.-Ham.) Mabb.	Meliaceae	-	✓	-	NA
39	*Dysoxylum mollissimum* Blume	Meliaceae	-	✓	-	LC
40	*Elaecoarpus tectorius* Poir.	Elaeocarpaceae	✓	✓	-	NA
41	*Elaeocarpus lanceifolius* Roxb.	Elaeocarpaceae	-	✓	✓	NA
42	*Elaeocarpus rugosus Roxb.* ex G.Don	Elaeocarpaceae	-	✓	-	VU
43	*Embelia tsjeriam-cottam* (Roem. & Schult.) A.DC.	Primulaceae	✓	-	-	NA
44	*Engelhardia spicata* Lechen ex Blume	Juglandaceae	✓	✓	-	LC
45	*Eriobotrya bengalensis* Kurz	Rosaceae	✓	✓	-	LC
46	*Euphorbia cotinifolia* L.	Euphorbiaceae	✓	-	-	LC
47	*Eurya cerasifolia* (D.Don) Kobuski	Pentaphylacaceae	✓	✓	✓	LC
48	*Eurya loquaiana* Dunn	Pentaphylacaceae	✓	✓	✓	LC
49	*Ficus benjamina* L.	Moraceae	✓	-	-	LC
50	*Ficus curtipes* Corner	Moraceae	-	✓	-	NA
51	*Ficus drupacea* Thunb.	Moraceae	✓	✓	✓	NE
52	*Ficus gibbosa* Blume	Moraceae	-	✓	-	NA
53	*Ficus religiosa* L.	Moraceae	-	-	✓	LC
54	*Ficus semicordata* Buch. Ham ex Sm.	Moraceae	-	-	✓	LC
55	*Ficus simplicissima* Lour.	Moraceae	✓	-	-	LC
56	*Firmiana colorata (*Roxb.) R.Br.	Malvaceae	✓	✓	-	LC

57	*Fraxinus floribunda* Wall.	Oleaceae	-	✓	-	LC
58	*Garcinia cowa* Roxb. Ex Choisy	Clusiaceae	-	✓	-	LC
59	*Garcinia succifolia* Kurz	Clusiaceae	-	✓	✓	LC
60	*Glochidion lanceolarium* (Roxb.) Voigt	Phyllanthaceae	✓	-	-	NA
61	*Helicia excelsa* Blume	Proteaceae	✓	✓	✓	LC
62	*Helicia robusta* (Roxb.) R. Br. Ex Blume	Proteaceae	✓	-	-	LC
63	*Heteropanax fragrans* (Roxb.) Seem.	Araliaceae	✓	-	-	NE
64	Ixora nigricans R.Br. ex Wight & Arn.	Rubiaceae	✓	-	-	LC
65	*Juglans regia* Linn.	Juglandaceae	-	✓	-	LC
66	*Laurocerasus jenkinsii* (Hook.f. & Thomson) Browicz	Rosaceae	✓	✓	-	NA
67	*Ligustrum robustum* (Roxb.) Blume	Oleaceae	✓	-	-	LC
68	Lindera nacusua var. nacusua	Lauraceae	✓	-	-	LC
69	*Lindera pulcherrima* (Nees) Benth. ex Hook.f.	Lauraceae	✓	✓	-	LC
70	*Lithocarpus dealbatus* Rehder	Fagaceae	✓	-	-	LC
71	*Lithocarpus elegans* (Blume) Hatus. ex Soepadmo	Fagaceae	✓	✓	✓	LC
72	*Lithocarpus Pachyphyllus* Rehder	Fagaceae	✓	✓	✓	LC
73	*Litsea cubeba* (Lour.) Pers.	Lauraceae	✓	-	✓	LC
74	*Litsea monopetala* (Roxb.) Pers.	Lauraceae	✓	✓	-	LC
75	*Litsea salicifolia* Hook.f.	Lauraceae	✓	-	-	LC
76	Litsea semicarpifolia (Wall. ex Nees) Hook. F.	Lauraceae	✓	✓	-	NA
77	*Macaranga denticulata* Müll.Arg.	Euphorbiaceae	✓	✓	✓	LC
78	*Macaranga indica* Wight	Euphorbiaceae	✓	✓	✓	LC
79	*Machilus gamblei* King ex Hook.f.	Lauraceae	✓	✓	-	LC
80	*Machilus glaucescens* (Nees) Wight	Lauraceae	-	✓	-	LC
81	*Machilus* sp.	Lauraceae	✓	✓	-	NA
82	*Magnolia doltsopa* (Buch.-Ham. ex DC.) Figlar	Magnoliaceae	✓	✓	-	DD
83	Magnolia hodgsonii (Hook. f. & Thoms) Keng	Magnoliaceae	✓	-	-	LC

84	*Mangifera indica* L.	Anacardiaceae	-	-	✓	DD
85	Mangifera sylvatica Roxb.	Anacardiaceae	✓	✓	-	LC
86	*Meliosma pinnata* (Roxb.) Maxim.	Sabiaceae	✓	✓	-	NE
87	*Memecylon grande* Retz.	Melastomataceae	-	✓	-	VU
88	*Morus macroura* Miq.	Moraceae	-	✓	-	LC
89	*Myrica esculenta* Buch.-Ham. ex D.Don	Myricaceae	✓	-	-	NA
90	*Nyssa javanica* (Blume) Wangerin	Nyssaceae	✓	✓	✓	NA
91	*Olea dioica* Roxb.	Oleaceae	✓	✓	-	NE
92	*Olea salicifolia* Wall. Ex G.Don	Oleaceae	-	✓	-	LC
93	*Ostodes paniculata* Blume	Euphorbiaceae	✓	-	-	LC
94	*Palaquium polyanthum* Merr.	Sapotaceae	✓	✓	-	EN
95	*Persea odoratissima* (Nees) Kosterm.	Lauraceae	✓	-	-	NA
96	*Phoebe attenuata* (Nees) Nees	Lauraceae	✓	✓	-	LC
97	*Pinus kesiya* Royle ex Gordon	Pinaceae	✓	-	-	LC
98	*Podocarpus neriifolius* D. Don	Podocarpaceae	✓	-	-	LC
99	*Premna racemosa* Wall. ex Schauer	Lamiaceae	✓	✓	-	NA
100	*Prunus undulata* Buch.-Ham. ex D.Don	Rosaceae	✓	-	-	LC
101	*Pyrularia edulis* (Wall.) A.DC.	Santalaceae	✓	-	-	LC
102	*Quercus floribunda* Lindl. ex A.Camus	Fagaceae	✓	✓	✓	LC
103	*Quercus xylocarpa* Kurz	Fagaceae	✓	✓	✓	LC
104	*Randia wallichii* Hook. F.	Rubiaceae	✓	-	-	NA
105	*Rapanea capitellata* (Wall.) Mez	Primulaceae	✓	✓	✓	NA
106	*Rhus chinensis* Mill.	Anacardiaceae	-	-	✓	LC
107	*Saurauia napaulensis* DC.	Actinidiaceae	✓	-	-	LC
108	*Saurauia punduana* Wall.	Actinidiaceae	✓	-	-	CR
109	*Schima khasiana* Dyer	Theaceae	✓	✓	-	LC
110	*Schima wallichii* (DC.) Choisy	Theaceae	✓	✓	✓	LC
111	*Semecarpus anacardium* L. f.	Anacardiaceae	✓	-	-	LC

112	*Sterculia villosa* Roxb.	Malvaceae	✓	-	-	LC
113	*Stevia rabaudiana* (Bertoni) Hemsl.	Asteraceae	✓	-	✓	NA
114	*Symplocos racemosa* Roxb.	Symplocaceae	✓	✓	-	LC
115	*Symplocos theifolia* D. Don	Symplocaceae	✓	✓	✓	NA
116	*Syzygium claviflorum* (Roxb.) Wall. ex Steud.	Myrtaceae	✓	✓	✓	LC
117	*Syzygium cuminii* (L.) Skeels	Myrtaceae	✓	✓	✓	LC
118	*Syzygium praecox* (Roxb.) Rathakr. And N.C.Nair	Myrtaceae	✓	✓	✓	NA
119	*Terminalia bellirica* (Gaertn.) Roxb.	Combretaceae	✓	✓	-	LC
120	*Toddalia asiaica* (L.) Lam.	Rutaceae	✓	-	-	NA
121	*Toona cilliata* M. Roem	Meliaceae	✓	✓	-	LC
122	*Trema cannabina* Lour.	Cannabaceae	✓	✓	-	NA
123	*Vitex canescens* Kurz	Lamiaceae	✓	✓	-	LC
124	*Vitex quinata* F.N.Williams	Lamiaceae	✓	-	-	LC
125	*Wendlandia grandis (*Hook.f.) Cowan	Rubiaceae	✓	✓	✓	NA
126	*Wightia speciosissima* (D.Don) Merr.	Paulowniaceae	✓	✓	-	NA
127	*Xantolis hookeri* (C.B.Clarke) P.Royen	Sapotaceae	-	✓	-	NA
128	*Zizyphus incurva* Roxb.	Rhamnaceae	✓	✓	✓	NA

Abbreviation: ✓ : Present, **-**: Absent.

Species which were present in all the three stands, i.e., UD, MD and HD stands, viz., *Beilschmiedia roxburghiana, Castanopsis echinocarpa, Celtis timorensis, Dipterocarpus retusus, Eurya cerasifolia, E. loquaiana, Ficus drupacea, Helicia excelsa, Lithocarpus elegans, L. pachuphyllus, Macaranga denticulata, M. indica, Nyssa javanica, Quercus floribunda, Q. xylocarpa, Rapanea capitellata, Schima wallichii, Symplocos theifolia, Syzygium claviflorum, S. cuminii, S. praecox, Wendlandia grandis,* and *Zizyphus incurve*, indicate that these species are generally able to adapt to different environmental changes (Table 4.10). They can live and thrive in both mature forest with dense canopy and open, disturbed forest (Connell and Slatyer, 1977; Tang et al., 2020).

Species which were present in UD stand are *Acrocarpus fraxinifolious, Ailanthus integrifolia, Albezia stipulate, Alnus nepalensis, Balakata baccata, Betula alnoides, Camellia kissi, Chukrasia tabularis, Cinnamomum bejolghota, C. cassia, C. glanduliferum, Coffea khasiana, Debregeasia longfolia, Embelia tsjeriam-cottam, Euphorbia cotinifolia, Ficus benjamina, F. simplicissima, Glochidion lanceolarium, Helicia robusta, Heteropanax fradrans, Ixora nigricans, Lingustrum robustum, Lindera nacusua, Lithocarpus dealbatus, Litsea salicifolia, Magnolia hodgsonii, Myrica esculenta, Ostodes paniculata, Persea odoratissima, Pinus kesiya, Podocarpus neriifolius, Prunus undulata, Pyrularia edulis, Pandia wallichii, Saurauria napaulensis, S. punduana, Semecarpus anacardium, Sterculia villosa, Toddalia asiaica,* and *Vitex quinata (*Table 4.10). These species are typical of mature, relatively undisturbed forests. They are linked to late-successional, or climax forest communities characterised by dense canopy cover, high moisture content and minimal anthropogenic influences that facilitate their regeneration (Thom and Seidl, 2016; Lalfakawma et al., 2009).

Species present only in MD stand, viz., *Bauhinia variegata, Benkara fasciculata, Bischofia javanica, Bruinsmia polysperma, Cinnamomum tamala, Dimocarpus longan, Diospyros stricta, Dysoxylum gotadhoro, D. mollissimum, Elaeocarpus rugosus, Ficus curtipes, Ficus gibbosa, Fraxinus floribunda, Garcinia cowa, Juglans regia, Machilus glaucescens, Memecylon grande, Morus macroura, Olea salicifolia,* and *Xantolis hookeri,* indicate that they are mid-successional species that benefit from intermediate disturbance (Table 4.10). Such environments have a mix of partial shade and partial opening in the canopy which form a perfect condition for many species to thrive (Mishra et al., 2004; Swart et al., 2019).

Species found only in HD stand are *Carallia brachiata, Castanopsis tribuloides, Dysoxylum excelsum, Ficus religiosa, F. semicordata, Mangifera indica,* and *Rhus chinensis* (Table 4.10). These species are typical of early-successional communities that can thrive in disturbed areas with more sunlight. These species are usually fast growing and have strong photosynthetic capacity and can colonize exposed ground (Lalfakawma et al. 2009; Mishra et al., 2004).

4.3.5 Importance value index and dominance - distribution of tree species

The Importance Value Index (IVI) is a measure of species dominance and indicates its significance to the forest community. IVI is the sum of relative density, relative dominance and relative frequency (Singh et al., 2015; Parthasarathy and Karthikeyan, 1997; Mishra et al, 2004; Borah et al, 2014). The species rank based on decreasing order of IVI in the UD, MD and HD forest stands is given in Table 4.11.

The IVI values in the UD forest stand were more evenly distributed with no extreme dominance by single species. *Engelhardia spicata* was the most dominant species with IVI score of 18.89, followed by *Quercus floribunda* with an IVI score of 17.11 and *Lindera pulcherrima* with an IVI score of 11.94. These moderate values indicate that though some species are more dominant than the others, no single species totally control the forest structure. Also, the species share resources and space instead of one overtaking them. The top-ranked tree species belonged mostly to Fagaceae (*Quercus floribunda, Quercus xylocarpa, Lithocarpus elegans*), Juglandaceae (*Engelhardia spicata*), and Lauraceae (*Lindera pulcherrima*) families. *Vitex canescens, Mangifera sylvatica, Sterculia villosa, Trema cannabina,* etc. are some of the species with IVI value lower than 2.00, indicating a lesser dominance in the forest. The IVI reflects the wide variety of flora that provides food and shelter to a huge number of fauna, which keeps the community stable and maintains balance in the forest (Devi et al., 2018).

Drimycarpus racemosus with an IVI value of 15.67, was the most dominant and ecologically important species in the MD stand. This was followed by *Croton hookeri* and *Rapanea capitellata* with IVI values of 13.20 and 11.97 respectively. Species like *Croton hookeri*, which is a pioneer species, dominate the MD forest, indicating that the community is starting to reorganise because of disturbance. Some of the tree species like *Engelhardia spicata* (IVI of 11.43) and *Helicia excelsa* (IVI 10.25) are still dominating but their values have reduced when compared to the UD stand, indicating that their ecological importance dropped in comparison to the UD stand. Other significant species present in this stand are *Alseodaphnopsis petiolaris*, *Macaranga denticulata, Dipterocarpus retusus, Lindera pulcherrima, etc.,* indicating their moderate roles in the forest community. Also, species like *Schima wallichii*, which are usually predominantly present in disturbed areas, was seen to have IVI value of 5.93 and was on the 15th position in MD stand, indicating that pioneer species were already starting to grow. Overall, the MD stand had a mix of dominant, moderately valuable, and less ecologically important species. The MD stand still maintained species diversity, though shift in the community structure due to disturbance has been observed.

In HD forest stand, *Schima wallichii* had the highest IVI value of 44.71, indicating that this species made up a major part of the community structure. This was followed by *Wendlandia grandis* (IVI of 25.03) and *Quercus xylocarpa* (IVI of 20.98). These species had adapted well in the changing environment caused due to anthropogenic disturbance and are surviving under conditions that were not preferred by other species. The presence of species like *Macaranga denticulata* and *Macaranga indica* (rank 4 and 12 respectively) infers the transition to pioneer dominated communities.

The IVI shows shift in dominance of species. In the UD stand, *Engelhardia spicata* was the most dominant species, but it was replaced by *Drimycarpus racemosus* in the MD stand which was further replaced by *Schima wallichii* in the HD stand. Similarly, there was shift in position of co-dominant species along disturbance gradient. There was a clear pattern of succession, going from the climax or late successional species becoming the most dominant or common in the UD stand, to early successional species or pioneer species being the most dominant in the HD stand. This alteration of species composition and forest structure does not only show the level of disturbance but also show how the ecosystem function. Also, in UD stand, IVI values varied from high to medium to low across diverse species, indicating a balanced distribution, while in HD stand one or few species were more dominant. This trend was observed by Borah et al. (2014), Mishra et al. (2004), Devi et al. (2018), and Sharma et al. (2018).

The dominance-distribution curve (Figure 4.10) depicts that the UD and the MD stands showed the log normal distribution assuming stable and complex communities. However, the HD stand showed short-hooked curve depicting an unstable community.

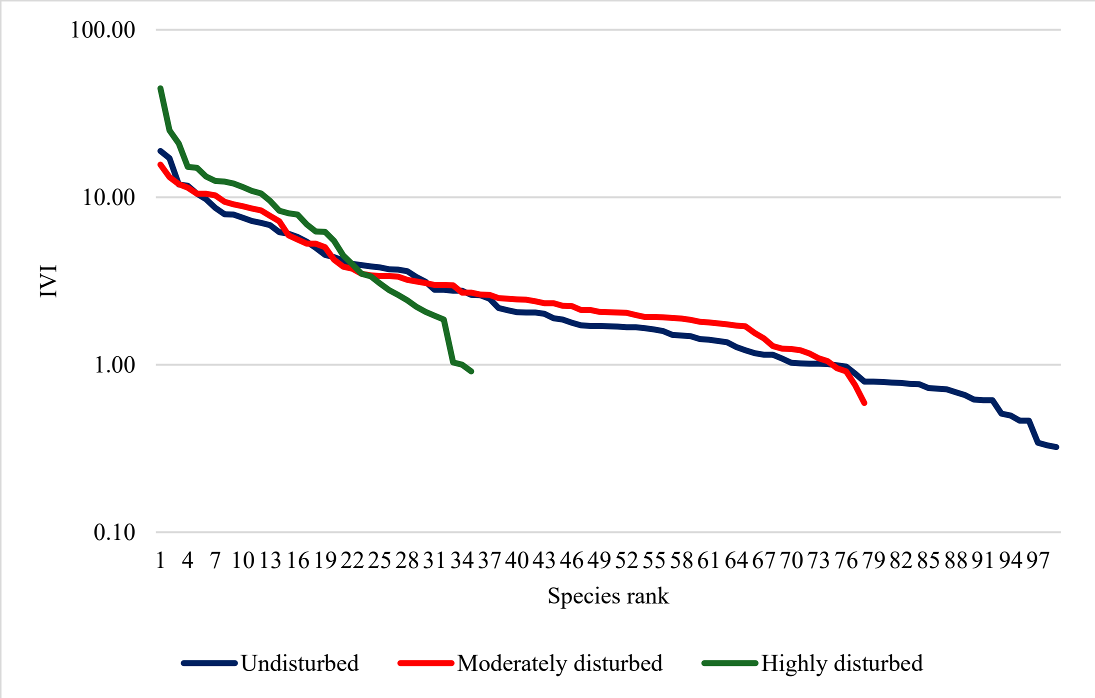

Figure 4.10: Dominance-distribution curve in selected forest stands based on IVI.

Table 4.11: Tree species dominance along the disturbance gradient (based on IVI).

Species Rank	Undisturbed		Moderately disturbed		Highly disturbed	
	Scientific name	IVI	Scientific name	IVI	Scientific name	IVI
1	*Engelhardia spicata* Lechen ex Blume	18.89	*Drimycarpus racemosus* (Roxb.) Hook.f. ex Marchand	15.67	*Schima wallichii* (DC.) Choisy	44.71
2	*Quercus floribunda* Lindl. ex A.Camus	17.11	*Croton Hookeri* Croizat	13.2	*Wendlandia grandis (*Hook.f.) Cowan	25.03
3	*Lindera pulcherrima* (Nees) Benth. ex Hook.f.	11.94	*Rapanea capitellata* (Wall.) Mez	11.97	*Quercus xylocarpa* Kurz	20.98
4	*Helicia excelsa* Blume	11.72	*Engelhardia spicata* Lechen ex Blume	11.43	*Macaranga denticulata* Müll.Arg.	15.2
5	*Ostodes paniculata* Blume	10.49	*Wendlandia grandis (*Hook.f.) Cowan	10.48	*Rapanea capitellata* (Wall.) Mez	14.99
6	*Dipterocarpus retusus* Blume	9.76	*Drypetes indica* (Mull.-Arg.) Pax & K. Hoffm.	10.47	*Celtis timorensis* Span.	13.29
7	*Drimycarpus racemosus* (Roxb.) Hook.f. ex Marchand	8.66	*Helicia excelsa* Blume	10.25	*Castanopsis echinocarpa* Miq.	12.54
8	*Quercus xylocarpa* Kurz	7.91	*Quercus xylocarpa* Kurz	9.42	*Carallia brachiata* (Lour.) Merr.	12.41
9	*Wendlandia grandis (*Hook.f.) Cowan	7.87	*Quercus floribunda* Lindl. ex A.Camus	9.08	*Syzygium claviflorum* (Roxb.) Wall. ex Steud.	12.06
10	*Lithocarpus elegans* (Blume) Hatus. ex Soepadmo	7.53	*Celtis timorensis* Span.	8.82	*Eurya cerasifolia* (D.Don) Kobuski	11.49
11	*Zizyphus incurva* Roxb.	7.23	*Alseodaphnopsis petiolaris* (Meisn.) H.W.Li & J.Li	8.57	*Helicia excelsa* Blume	10.93
12	*Elaecoarpus tectorius* Poir.	7.03	*Macaranga denticulata* Müll.Arg.	8.36	*Macaranga indica* Wight	10.54

13	*Meliosma pinnata* (Roxb.) Maxim.	6.83	*Macaranga indica* Wight	7.76	*Castanopsis tribuloides* A.DC.	9.51
14	*Pinus kesiya* Royle ex Gordon	6.18	*Dipterocarpus retusus* Blume	7.19	*Dipterocarpus retusus* Blume	8.31
15	*Macaranga indica* Wight	6.05	*Schima wallichii* (DC.) Choisy	5.93	*Ficus drupacea* Thunb.	8.03
16	*Drypetes indica* (Mull.-Arg.) Pax & K. Hoffm.	5.8	*Schima khasiana* Dyer	5.59	*Dysoxylum excelsum* Blume	7.89
17	*Macaranga denticulata* Müll.Arg.	5.44	*Lindera pulcherrima* (Nees) Benth. ex Hook.f.	5.28	*Rhus chinensis* Mill.	6.88
18	*Symplocos theifolia* D. Don	4.98	*Olea dioica* Roxb.	5.28	*Eurya loquaiana* Dunn	6.24
19	*Eurya cerasifolia* (D.Don) Kobuski	4.52	*Premna racemosa* Wall. ex Schauer	5.04	*Litsea cubeba* (Lour.) Pers.	6.21
20	*Litsea monopetala* (Roxb.) Pers.	4.39	*Castanopsis echinocarpa* Miq.	4.23	*Zizyphus incurva* Roxb.	5.5
21	*Alseodaphnopsis petiolaris* (Meisn.) H.W.Li & J.Li	4.19	*Lithocarpus elegans* (Blume) Hatus. ex Soepadmo	3.84	*Mangifera indica* L.	4.49
22	*Calophyllum polyanthum* Wall. ex Planch. & Triana	4.01	*Litsea semicarpifolia* (Wall. ex Nees) Hook. F.	3.75	*Quercus floribunda* Lindl. ex A.Camus	3.98
23	*Celtis timorensis* Span.	3.92	*Meliosma pinnata* (Roxb.) Maxim.	3.5	*Lithocarpus pachyphyllus* Rehder	3.49
24	*Diospyros lanceifolia* Roxb.	3.87	*Elaecoarpus tectorius* Poir.	3.42	*Syzygium cuminii* (L.) Skeels	3.37
25	*Eriobotrya bengalensis* Kurz	3.81	*Elaeocarpus rugosus Roxb.* ex G.Don	3.39	*Ficus semicordata* Buch. Ham ex Sm.	3.06
26	*Olea dioica* Roxb.	3.71	*Syzygium claviflorum* (Roxb.) Wall. ex Steud.	3.39	*Beilschmiedia roxburghiana* Nees.	2.79
27	*Rapanea capitellata* (Wall.) Mez	3.69	*Acer oblongum* Wall. ex DC.	3.36	*Symplocos theifolia* D. Don	2.61

28	*Croton Hookeri* Croizat	3.62	*Zizyphus incurva* Roxb.	3.21	*Elaeocarpus lanceifolius* Roxb.	2.42
29	*Litsea semicarpifolia* (Wall. ex Nees) Hook. F.	3.35	*Symplocos theifolia* D. Don	3.15	*Garcinia succifolia* Kurz	2.22
30	*Beilschmiedia gammieana* King ex Hook.f.	3.13	*Nyssa javanica* (Blume) Wangerin	3.07	*Diospyros lanceifolia* Roxb.	2.07
31	*Cinnamomum bejolghota* (Buch.-Ham.) Sweet	2.8	*Garcinia succifolia* Kurz	3	*Ficus religiosa* L.	1.96
32	*Vitex quinata* F.N.Williams	2.8	*Bruinsmia polysperma* (C.B.Clarke) Steenis	3	*Syzygium praecox* (Roxb.) Rathakr. And N.C.Nair	1.86
33	*Lithocarpus pachyphyllus* Rehder	2.77	*Ficus curtipes* Corner	2.98	*Lithocarpus elegans* (Blume) Hatus. ex Soepadmo	1.03
34	*Nyssa javanica* (Blume) Wangerin	2.76	*Morus macroura* Miq.	2.7	*Nyssa javanica* (Blume) Wangerin	1
35	*Syzygium cuminii* (L.) Skeels	2.61	*Dysoxylum mollissimum* Blume	2.69	*Stevia rabaudiana* (Bertoni) Hemsl.	0.91
36	*Syzygium praecox* (Roxb.) Rathakr. And N.C.Nair	2.61	*Syzygium cuminii* (L.) Skeels	2.62		
37	*Alnus nepalensis* D. Don	2.48	*Calophyllum polyanthum* Wall. ex Planch. & Triana	2.61		
38	*Machilus gamblei* King ex Hook.f.	2.18	*Terminalia bellirica* (Gaertn.) Roxb.	2.5		
39	*Betula alnoides* Buch.-Ham. Ex D. Don.	2.12	*Beilschmiedia gammieana* King ex Hook.f.	2.48		
40	*Chukrasia tabularis* A.Juss.	2.06	*Syzygium praecox* (Roxb.) Rathakr. And N.C.Nair	2.46		
41	*Castanopsis indica* A.DC.	2.05	*Benkara fasciculata* (Roxb.) Ridsdale	2.45		

42	*Litsea salicifolia* Hook.f.	2.05	*Lithocarpus pachyphyllus* Rehder	2.39		
43	*Embelia tsjeriam-cottam* (Roem. & Schult.) A.DC.	2.01	*Xantolis hookeri* (C.B.Clarke) P.Royen	2.33		
44	*Castanopsis echinocarpa* Miq.	1.9	*Litsea monopetala* (Roxb.) Pers.	2.33		
45	*Acer oblongum* Wall. ex DC.	1.86	*Machilus gamblei* King ex Hook.f.	2.25		
46	*Phoebe attenuata* (Nees) Nees	1.78	*Bischofia javanica* Blume	2.24		
47	*Beilschmiedia roxburghiana* Nees.	1.72	*Eurya loquaiana* Dunn	2.13		
48	*Heteropanax fragrans* (Roxb.) Seem.	1.7	*Cinnamomum tamala* (Buch.-Ham.) T.Nees & Eberm.	2.12		
49	*Magnolia hodgsonii* (Hook. f. & Thoms) Keng	1.7	*Eurya cerasifolia* (D.Don) Kobuski	2.07		
50	*Wightia speciosissima* (D.Don) Merr.	1.7	*Machilus glaucescens* (Nees) Wight	2.06		
51	*Toona cilliata* M. Roem	1.69	*Diospyros stricta Roxb.*	2.05		
52	*Acrocarpus fraxinifolious* Wight & Arn	1.68	*Symplocos racemosa* Roxb.	2.04		
53	*Saurauia punduana* Wall.	1.67	*Castanopsis indica* A.DC.	1.98		
54	*Schima wallichii* (DC.) Choisy	1.65	*Machilus* sp.	1.93		
55	*Cinnamomum cassia* (L.) J.Presl	1.63	*Bauhinia variegata* L.	1.92		
56	*Terminalia bellirica* (Gaertn.) Roxb.	1.59	*Memecylon grande* Retz.	1.92		
57	*Balakata baccata* (Roxb.) Esser	1.51	*Beilschmiedia roxburghiana* Nees.	1.9		

58	*Symplocos racemosa* Roxb.	1.49	*Palaquium polyanthum* Merr.	1.89		
59	*Myrica esculenta* Buch.-Ham. ex D.Don	1.48	*Mangifera sylvatica* Roxb.	1.85		
60	*Ailanthus integrifolia* subsp. calycina (Pierre) Noot.	1.42	*Eriobotrya bengalensis* Kurz	1.8		
61	*Premna racemosa* Wall. ex Schauer	1.41	*Dimocarpus longan* Lour.	1.79		
62	*Antidesma bunius* (L.) Spreng	1.38	*Antidesma bunius* (L.) Spreng	1.77		
63	*Podocarpus neriifolius* D. Don	1.36	*Magnolia doltsopa* (Buch.-Ham. ex DC.) Figlar	1.74		
64	*Syzygium claviflorum* (Roxb.) Wall. ex Steud.	1.28	*Vitex canescens* Kurz	1.71		
65	*Albezia stipulata* (DC.) Boivin.	1.22	*Laurocerasus jenkinsii* (Hook.f. & Thomson) Browicz	1.7		
66	*Laurocerasus jenkinsii* (Hook.f. & Thomson) Browicz	1.17	*Olea salicifolia* Wall. Ex G.Don	1.55		
67	*Euphorbia cotinifolia* L.	1.15	*Toona cilliata* M. Roem	1.44		
68	*Lindera nacusua* var. nacusua	1.15	*Ficus drupacea* Thunb.	1.29		
69	*Lithocarpus dealbatus* Rehder	1.09	*Fraxinus floribunda* Wall.	1.25		
70	*Stevia rabaudiana* (Bertoni) Hemsl.	1.03	*Garcinia cowa* Roxb. Ex Choisy	1.24		
71	*Toddalia asiaica* (L.) Lam.	1.02	*Phoebe attenuata* (Nees) Nees	1.22		
72	*Eurya loquaiana* Dunn	1.01	*Juglans regia* Linn.	1.17		
73	*Glochidion lanceolarium* (Roxb.) Voigt	1.01	*Firmiana colorata (*Roxb.) R.Br.	1.09		

74	*Camellia kissi* Wall.	1.01	*Dysoxylum gotadhora* (Buch.-Ham.) Mabb.	1.05		
75	*Pyrularia edulis* (Wall.) A.DC.	0.99	*Ficus gibbosa* Blume	0.95		
76	*Litsea cubeba* (Lour.) Pers.	0.98	*Elaeocarpus lanceifolius* Roxb.	0.91		
77	*Coffea khasiana* Hook. F.	0.89	*Wightia speciosissima* (D.Don) Merr.	0.76		
78	*Ligustrum robustum* (Roxb.) Blume	0.79	*Trema cannabina* Lour.	0.59		
79	*Saurauia napaulensis* DC.	0.79				
80	*Schima khasiana* Dyer	0.79				
81	*Palaquium polyanthum* Merr.	0.78				
82	*Ficus drupacea* Thunb.	0.78				
83	*Debregeasia longifolia* (Burm.f.) Wedd.	0.77				
84	*Prunus undulata* Buch.-Ham. ex D.Don	0.77				
85	*Machilus* sp.	0.73				
86	*Magnolia doltsopa* (Buch.-Ham. ex DC.) Figlar	0.72				
87	*Cinnamomum glanduliferum* (Wall.) Meisn.	0.71				
88	*Randia wallichii* Hook. F.	0.68				
89	*Ficus benjamina* L.	0.66				

90	*Helicia robusta* (Roxb.) R. Br. Ex Blume	0.62				
91	*Firmiana colorata (*Roxb.) R.Br.	0.61				
92	*Ixora nigricans* R.Br. ex Wight & Arn.	0.61				
93	*Persea odoratissima* (Nees) Kosterm.	0.51				
94	*Semecarpus anacardium* L. f.	0.5				
95	*Ficus simplicissima* Lour.	0.46				
96	*Vitex canescens* Kurz	0.46				
97	*Mangifera sylvatica* Roxb.	0.34				
98	*Sterculia villosa* Roxb.	0.33				
99	*Trema cannabina* Lour.	0.32				

4.3.6 Dominance-distribution of families

The UD stand, with 45 families, had the highest number of family when compared to other forest stands. Lauraceae was the most common family, with 16 species. This was followed by Fagaceae with 7 species and Euphorbiaceae with 6 species. Similar findings were documented by some researchers like Singh et al. (2015), Lamare et al. (2024) and Sharma et al. (2018). The dominant families like Lauraceae and Fagaceae, indicates the preservation of biodiversity in the UD stand, as both the families are typical of forests which are at mature successional stage (Sharma et al. 2020). Families like Pinaceae, Podocarpaceae, Magnoliaceae, and Dipterocarpaceae, which are typical of primary forests were present in the stand, indicating minimal human interference (Table 4.12, Figure 4.11).

The MD stand had 37 families out of which species belonging to Lauraceae was maximum at 11 species, which was slightly lower than the UD stand. Around 5 species belonged to the family Fagaceae. Moraceae family moved up to third place in MD stand with 4 species, which indicated that pioneer species or species which had greater disturbance tolerance started becoming common there, as they are generally capable of flourishing in disturbed areas. (Kumar and Singh, 2021; Singh et al., 2015). Some of the families to be primarily affected by disturbance viz., Pinaceae, Podocarpaceae, Magnoliaceae, Myricaceae, Rutaceae, Santalaceae, Simaroubaceae and Urticaceae, were missing in MD stand.

The HD stand consisted of tree species belonging to only 22 families. Fagaceae was found to be the most important family with 6 species, followed by Moraceae and Myrtaceae family, both having 3 species each. The presence of Fagaceae in HD stand, though the number of species declined, shows that they can easily adapt to change in environmental conditions. This means that species belonging to these families are more tolerant to disturbance (Verma and Joshi, 2018; Singh et al., 2015). Lauraceae had only 2 species in the HD stand, which is a drastic drop from the UD stand. This indicates decline in the number of disturbance-sensitive families.

The family dominance-distribution curve showed shift in position of family dominance along the disturbance gradient (Figure 4.11). Lauraceae was the most dominant family in both the UD and the MD stands, indicating its strong ecological amplitude. However, Lauraceae was replaced by Fagaceae as the most dominant family in the HD stand, indicating a shift towards species groups which can withstand disturbance as well as changed habitat conditions. Moreover, Fagaceae stands co-dominant family in the UD and MD stands and replaced by Moraceae in the HD stand.

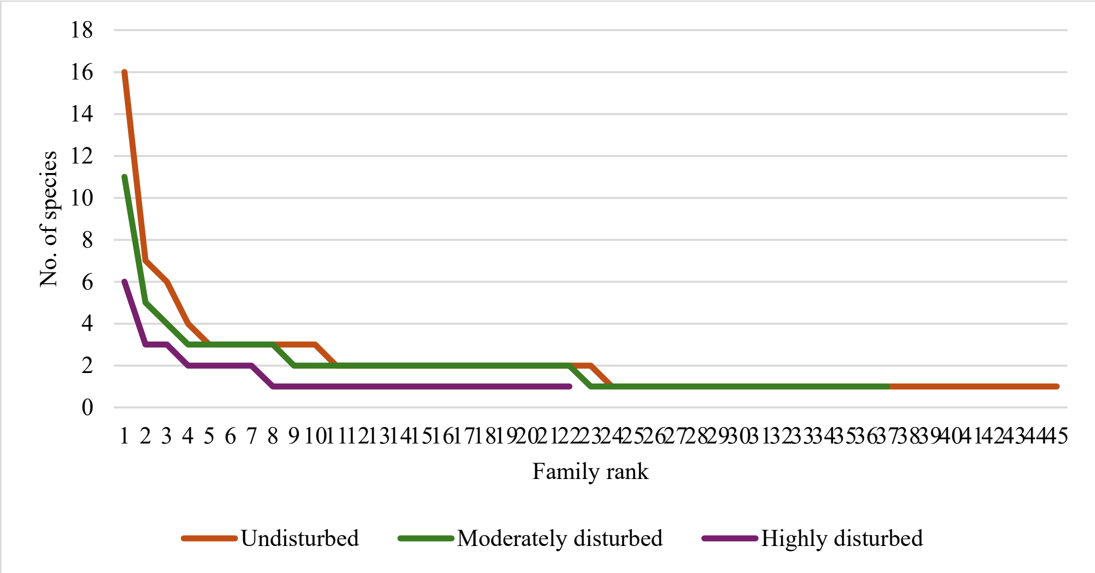

Figure 4.11: Family dominance-distribution curve along the disturbance gradient.

Table 4.12: Family dominance in selected forest stands along the disturbance gradient.

Family Rank	Family	No. of species (UD)	Family	No. of species (MD)	Family	No. of species (HD)
1	Lauraceae	16	Lauraceae	11	Fagaceae	6
2	Fagaceae	7	Fagaceae	5	Moraceae	3
3	Euphorbiaceae	6	Moraceae	4	Myrtaceae	3
4	Rubiaceae	4	Elaeocarpaceae	3	Anacardiaceae	2
5	Anacardiaceae	3	Euphorbiaceae	3	Euphorbiaceae	2
6	Lamiaceae	3	Meliaceae	3	Lauraceae	2
7	Moraceae	3	Myrtaceae	3	Pentaphylacaceae	2
8	Myrtaceae	3	Oleaceae	3	Asteraceae	1
9	Rosaceae	3	Anacardiaceae	2	Cannabaceae	1
10	Theaceae	3	Cannabaceae	2	Clusiaceae	1

11	Actinidiaceae	2	Clusiaceae	2	Dipterocarpaceae	1
12	Betulaceae	2	Fabaceae	2	Ebenaceae	1
13	Cannabaceae	2	Juglandaceae	2	Elaeocarpaceae	1
14	Fabaceae	2	Lamiaceae	2	Meliaceae	1
15	Magnoliaceae	2	Pentaphylacaceae	2	Nyssaceae	1
16	Malvaceae	2	Phyllanthaceae	2	Primulaceae	1
17	Meliaceae	2	Rosaceae	2	Proteaceae	1
18	Oleaceae	2	Rubiaceae	2	Rhamnaceae	1
19	Pentaphylacaceae	2	Sapindaceae	2	Rhizophoraceae	1
20	Phyllanthaceae	2	Sapotaceae	2	Rubiaceae	1
21	Primulaceae	2	Symplocaceae	2	Symplocaceae	1
22	Proteaceae	2	Theaceae	2	Theaceae	1
23	Symplocaceae	2	Calophyllaceae	1		
24	Araliaceae	1	Combretaceae	1		
25	Asteraceae	1	Dipterocarpaceae	1		
26	Calophyllaceae	1	Ebenaceae	1		
27	Combretaceae	1	Magnoliaceae	1		
28	Dipterocarpaceae	1	Malvaceae	1		
29	Ebenaceae	1	Melastomataceae	1		
30	Elaeocarpaceae	1	Nyssaceae	1		
31	Juglandaceae	1	Paulowniaceae	1		
32	Myricaceae	1	Primulaceae	1		
33	Nyssaceae	1	Proteaceae	1		
34	Paulowniaceae	1	Putranjivaceae	1		
35	Pinaceae	1	Rhamnaceae	1		
36	Podocarpaceae	1	Sabiaceae	1		
37	Putranjivaceae	1	Styracaceae	1		
38	Rhamnaceae	1				
39	Rutaceae	1				

40	Sabiaceae	1				
41	Santalaceae	1				
42	Sapindaceae	1				
43	Sapotaceae	1				
44	Simaroubaceae	1				
45	Urticaceae	1				

4.4 Soil analysis

Anthropogenic disturbances may cause changes in the physico-chemical properties of soil, decreasing the productivity of the soil in the forest (Sunar et al., 2017).

4.4.1 Soil temperature

The temperature of the soil was seen to vary along the three forest stands across all the seasons and soil depths (Table 4.13) (Figure 4.12). The soil temperature was seen to range from 15.22±0.44°C (post-monsoon season at 10-20 cm depth in UD stand) to 22.53±0.55°C (pre-monsoon season at 0-10 cm depth in HD stand).

Table 4.13: Seasonal variation in soil temperature along the disturbance gradient.

Forest stands	Soil depth (cm)	Seasons		
		Pre-monsoon (°C)	Monsoon (°C)	Post-monsoon (°C)
Undisturbed	0-10	21.24±0.56	16.25±0.72	16.52±0.47
	10-20	20.40±0.60	15.23±0.69	15.22±0.44
Moderately disturbed	0-10	22.21±0.20	18.27±1.06	18.90±0.93
	10-20	20.91±0.45	16.80±1.31	17.65±1.10
Highly disturbed	0-10	22.53±0.55	19.72±0.75	20.64±0.87
	10-20	21.62±0.53	18.64±0.61	18.76±0.87

The soil temperature increased with increase in disturbance. Similar results were documented by researchers like Mishra (2012), Sunar et al. (2017) and Madhurima and Mishra (2023). The soil temperature was greatly influenced by ambient temperature because the canopy opening permitted increased absorption of solar radiation (Singh et al., 2021). In UD stand, the soil temperature ranged from 15.22±0.44°C to 21.24±0.56°C across depths and seasons. The values were relatively low when compared to other forest stands, probably due to the dense canopy cover and large litter accumulation, which kept the soil cooler and reduced the heating of forest floor. The MD stand experienced temperatures ranging from 16.80±1.31°C to 22.21±0.20°C across depths and seasons. The values were slightly higher than UD stand. This could be the result of partial canopy opening which allowed more light to enter and warm the soil. In HD stand, the soil temperature was recorded to be much higher than the other forest stands, ranging between 18.64±0.61°C and 22.53±0.55°C, depending on the depth and season. This increase may be a result of the soil being more exposed to direct sunlight.

The temperature of the soil was lowest during the monsoon, indicating that constant rain and dense cloud kept the soil cool. The rainwater keeps wetting the forest floor and makes it cooler and due to dense cloud, the ground does not get direct sunlight most of the time. During the post-monsoon season, the dense clouds are absent, and the sunlight reaches the forest floor, making it warmer and the pre-monsoon season experiences hot and dry weather, thereby making the soil temperature rise even more. This pattern, where the soil temperature is higher during the pre-monsoon season when compared to post-monsoon season because of seasonality has been observed by Mishra (2012), Shaik and Bhosle (2013), and Sunar et al. (2017). The topsoil had higher temperature than the subsoil as it was in direct contact with sunlight and air and responded quickly to change in temperature (Madhurima and Mishra, 2023). On the other hand, the subsoil remained cooler as it shielded underneath and since heat takes longer time to travel through the soil, so the deeper layer warms up more slowly (Garcia-Garcia et al., 2023).

Correlation analysis between different soil parameters, disturbance, season and soil depth is shown in Table 4.20. According to Opeyemi et al. (2020), values less than 0.2 have little or no correlation, values ranging between 0.9 and 1.00 indicates very high correlation, values falling between the range of 0.7 and 0.9 indicates high correlation, values ranging between 0.5 and 0.7 indicates moderate correlation, while values ranging between 0.25 and 0.50 indicate low correlation.

The soil temperature was seen to have a strong positive correlation ($r=0.462$, $p<0.01$) with the level of disturbance, but it was negatively correlated ($r=-0.752$, $p<0.01$) with soil moisture content. These findings show that disturbance leads to rise in soil temperature due to canopy loss and increase in moisture content of soil reduced the soil temperature (Appendix-1).

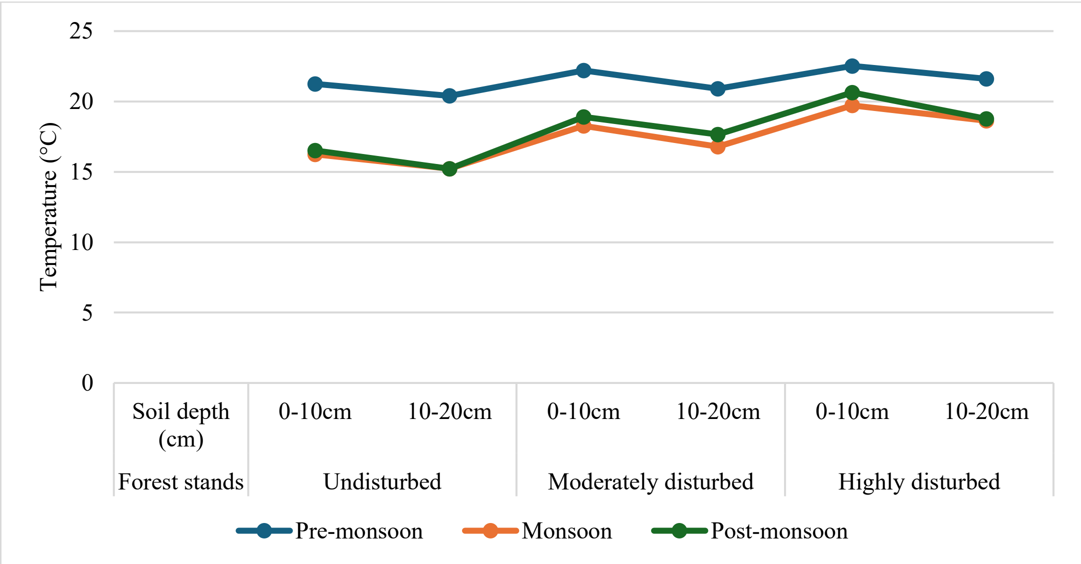

Figure 4.12: Seasonal variation in soil temperature along the disturbance gradient.

4.4.2 Soil moisture content (SMC)

The soil moisture content changed across the disturbance gradient, seasons and depth of soil, and ranged between 17.44±0.52% (pre-monsoon season at 10-20 cm depth in HD stand) and 44.13±0.48% (monsoon season at 0-10 cm depth in UD stand). This shows that the more disturbed the forest was, the less moisture it could hold (Table 4.14, Figure 4.13). The SMC exhibited an increasing trend with decrease in disturbance across all seasons. Similar results have been found by other researchers (Mishra, 2012; Lalthakimi et al., 2023; Sunar et al., 2017; Madhurima and Mishra, 2023).

Table 4.14: Soil moisture content in selected forest stands along the disturbance gradient.

Forest stands	Soil depth (cm)	Seasons		
		Pre-monsoon (%)	Monsoon (%)	Post-monsoon (%)
Undisturbed	0-10	30.78±0.53	44.13±0.48	39.56±0.34
	10-20	29.18±0.84	42.62±0.51	37.67±0.55
Moderately disturbed	0-10	24.51±0.48	38.22±0.41	34.18±0.11
	10-20	23.71±0.96	36.04±0.6	32.66±0.53
Highly disturbed	0-10	18.41±0.56	28.16±0.53	20.30±0.48
	10-20	17.44±0.52	27.23±0.30	21.40±0.54

The SMC was maximum in UD stand, ranging from 29.18±0.84% to 44.13±0.48% across all depths and seasons**.** The UD stand can hold huge amount of moisture because of intact canopy, proper root system that can hold more water, thick litter on forest floor acting as mulch, well-structured soil profile which soaked water well and kept it from evaporating. The MD stand documented SMC ranging between 23.71±0.96% and 38.22±0.41% across depths and seasons. The forest stand can hold good amount of moisture, but due to reduction in canopy density and thinner layer of litter, it was not able to hold as much moisture as UD stand. The least amount of soil moisture was documented in HD stand which ranged from 17.44±0.52% to 28.16±0.53%. The findings depict low retention of moisture under highly disturbed condition could be linked to the removal of vegetation and disruption of topsoil, resulting in highly weathered condition of soil.

The moisture content of the soil was found to be highest in UD stand during the monsoon season, which was in line with the findings of Manpoong et al. (2025) and Singh et al. (2020). During pre-monsoon season, the SMC was found to be the lowest, which may be because of the prevailing dry weather condition (Sunar et al., 2017). Even during monsoon season, the moisture content was not very high in HD stand compared to the other stands. Factors like loss of vegetation cover, soil compaction, and increased runoff contribute to less water retention, making it harder for water to soak in and accelerate soil drying. The monsoon season held the highest soil moisture when compared to the other seasons (Mishra, 2012; Sunar et al., 2017; Manpoong et al., 2025). As the subsoil was not exposed to direct sunlight, so moisture content was more there instead of the topsoil.

There was a negative correlation ($r=-0.762$, $p<0.01$) between SMC and disturbance level, indicating that increase in disturbance resulted in less moisture content. The SMC was positively correlated with SOC ($r=0.604$, $p<0.01$) and macronutrients viz., N ($r=0.584$, $p<0.01$), P ($r=0.555$, $p<0.01$), and K (0.558, $p<0.01$). These links indicate that the soils with good amount of organic matter and nutrients tend to hold more water because the soil is better structured and more porous (Appendix.1).

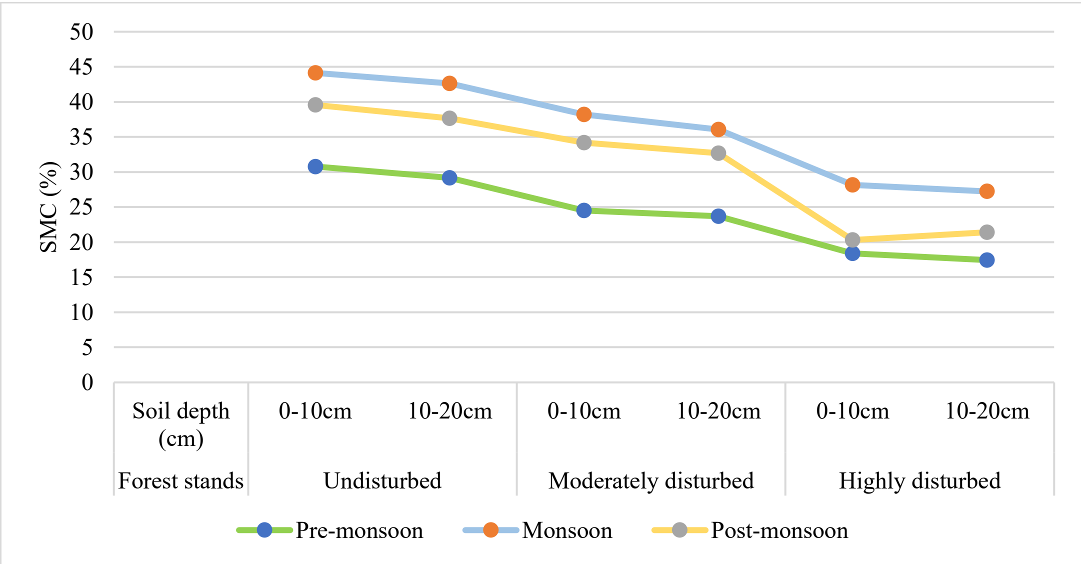

Figure 4.13: Soil moisture content in different forest stands along the disturbance gradient

4.4.3 Bulk density (BD)

The bulk density of soil which measures soil porosity and compaction, was seen to increase with increase in disturbance (Table 4.15, Figure 4.14), with values ranging between 0.81±0.11 g cm^{-3} (pre-monsoon season at 0-10cm depth in UD stand) and 1.38±0.01 g cm^{-3} (monsoon season at 10-20cm depth in HD stand). With increase in the level of disturbance, the soil's BD was reported to gradually increase. Similar trend was found by Sharma et al., 2018; Sunar et al., 2017; Madhurima and Mishra, 2023; Kenyee et al., 2019).

Table 4.15: Soil bulk density in different forest stands along the disturbance gradient.

Forest stands	Soil depth (cm)	Seasons		
		Pre-monsoon (g cm^{-3})	Monsoon (g cm^{-3})	Post-monsoon (g cm^{-3})
Undisturbed	0-10	0.81±0.11	0.96±0.08	0.87±0.05
	10-20	0.88±0.11	1.03±0.06	0.93±0.04
Moderately disturbed	0-10	0.82±0.02	1.07±0.01	1.03±0.02
	10-20	0.86±0.02	1.13±0.02	1.07±0.05
Highly disturbed	0-10	1.02±0.02	1.35±0.01	1.29±0.18
	10-20	1.09±0.02	1.38±0.01	1.34±0.18

The BD was lowest in the UD stand, ranging from 0.81±0.11 g cm^{-3} to 1.03±0.06 g cm^{-3} across depths and seasons. This indicates that the soil is well-aerated and have good porosity which is good for root growth and microbial activity. In MD stand the BD was seen to range between 0.82±0.02 g cm^{-3} and 1.13±0.02 g cm^{-3}. The highest BD was recorded in the HD stand, ranging between 1.02±0.02 g cm^{-3} and 1.38±0.01 g cm^{-3}. This indicates that the soil was highly compact. The higher values in HD stand may be attributed to the soil texture and presence of less pore space between the soil particles (Nang, 2016; Sunar et al., 2017). The BD increased with increase in the depth of soil (Madhurima and Mishra, 2023; Sharma et al., 2023). The BD of the topsoil was lower because it has more organic matter which makes the soil softer, and the presence of fine roots kept the soil loosely packed. The range of BD recorded aligns with those of Manpoong and Tripathi (2019) and Tiwari et al. (2023). During pre-monsoon season, the soil is dry, loose, and full of air spaces resulting in low BD, while the monsoon season was found to have the highest BD due to continuous rainfall and waterlogging which presses the soil and compact it, thereby reducing the pore space.

There was a positive correlation (r=0.644, p<0.01) between BD and disturbance level, indicating that when BD increases with increase in disturbance. The BD was negatively correlated to SOC (r=-0.579, p<0.01), and macronutrients like N (r=-0.681, p<0.01), P (r=-0.598, p<0.01) and K (r=-0.648, p<0.01), indicating that reduction of organic matter and essential nutrients increases the soil's BD (Appendix-1).

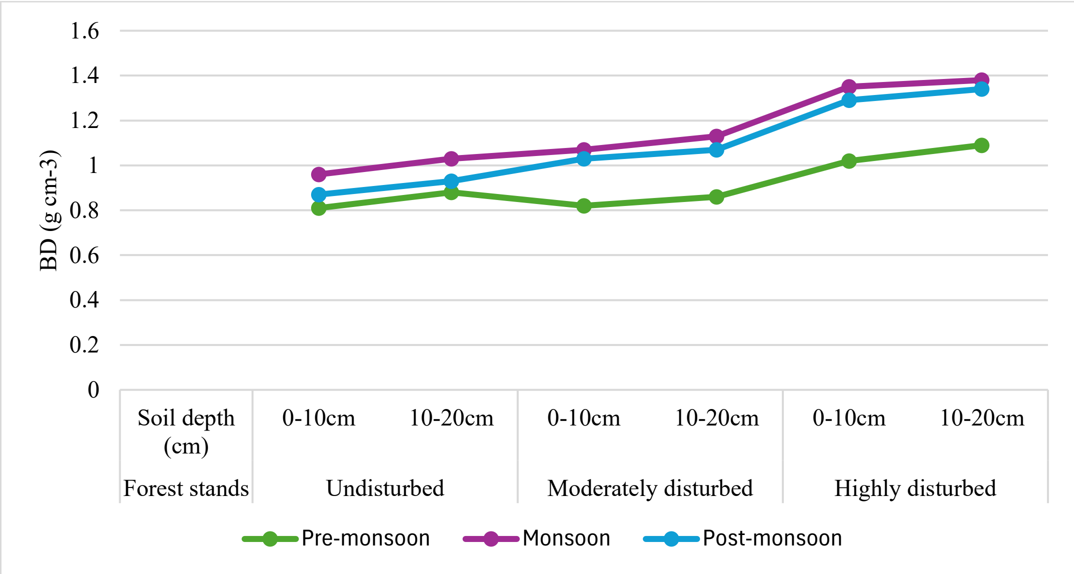

Figure 4.14: Soil bulk density in selected forest stand along the disturbance gradient.

4.4.4 pH

Soil pH was moderately to slightly acidic across all forest stands (Table 4.16, Figure 4.15), with values ranging between 5.27±0.04 (pre-monsoon season at 0-10cm depth in UD stand) and 6.20±0.05 (post-monsoon season at 10-20cm depth in MD stand. The range of values recorded were consistent with the findings of other researchers like Mishra (2012), Ovung et. al. (2021), Singh and Tripathi (2020), Sunar et al. (2017), and Lalthakimi et al. (2013).

Table 4.16: pH of soil in selected forest stand along the disturbance gradient.

Forest stands	Soil depth (cm)	Seasons		
		Pre-monsoon	Monsoon	Post-monsoon
Undisturbed	0-10	5.27±0.04	5.62±0.05	5.97±0.03
	10-20	5.43±0.05	5.84±0.06	6.13±0.03
Moderately disturbed	0-10	5.48±0.19	5.65±0.04	6.06±0.04
	10-20	5.65±0.17	5.85±0.05	6.20±0.05
Highly disturbed	0-10	5.51±0.02	5.41±0.07	5.76±0.06
	10-20	5.71±0.05	5.58±0.09	5.91±0.07

In the UD stand, the pH values ranged between 5.27±0.04 and 6.13±0.03 across depths and seasons. The soil here was slightly more acidic than the MD and HD stands (Mishra, 2012). This is mostly because of the rise of litter and decomposition process which generate organic acids. The pH in MD stand was seen between 5.48±0.19 and 6.20±0.05, and in HD stand, the pH ranged from 5.41±0.07 and 5.91±0.07. The higher pH during the pre-monsoon season in HD stand, is mainly due to the release of cations because of anthropogenic activities like shifting cultivation. Burning stimulates the release of nutrients in the soil and thus increases the soil's pH (Ovung et al., 2021; Nemhoihkim et al., 2025). The pH of the subsoil (10-20cm) was slightly higher than the topsoil (0-10cm) in all the forest stands. This is because organic matter breaks down and roots breathe near the surface, producing acids that makes the topsoil a little more acidic. Also, subsoil tend to have higher pH than topsoil because subsurface conditions are more stable and less susceptible to surface-level disturbance and organic acid leaching (Mishra, 2010; Madhurima and Mishra 2023).

There was a strong correlation between soil pH and season ($r=0.728$, $p<0.01$), indicating that leaching and base buildup varies seasonally. There was a moderate positive correlation of soil pH with SMC ($r=0.300$, $p<0.05$) and SOC ($r=0.314$, $p<0.05$), while the pH was negatively correlated with temperature ($r=-0.498$, $p<0.01$), showing that pH value decrease with increase in soil temperature (Appendix-1).

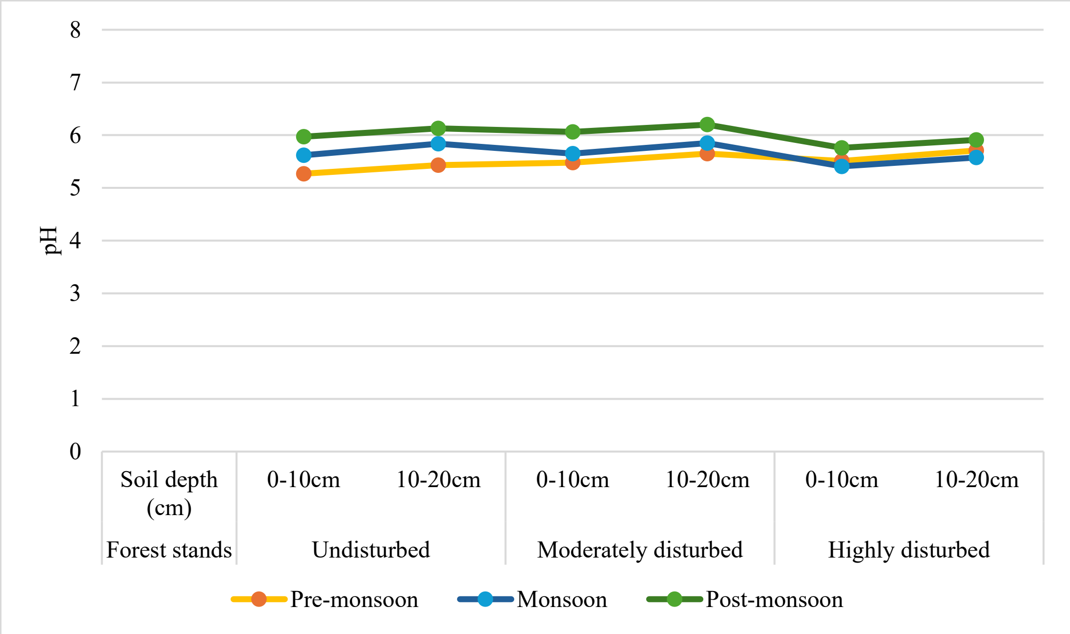

Figure 4.15: pH of soil in selected forest stands along the disturbance gradient.

4.4.5 Total Nitrogen (TN)

Total Nitrogen, which is an important measure of fertility of soil and nutrient cycling, was seen to decrease with increase in disturbance (Table 4.17, Figure 4.16).

Table 4.17: Total Nitrogen in soil of selected forest stands along the disturbance gradient.

Forest stands	Soil depth (cm)	Seasons		
		Pre-monsoon (%)	Monsoon (%)	Post-monsoon (%)
Undisturbed	0-10	0.29±0.02	0.24±0.01	0.34±0.02
	10-20	0.25±0.03	0.21±0.02	0.3±0.04
Moderately disturbed	0-10	0.21±0.03	0.19±0.01	0.24±0.02
	10-20	0.19±0.02	0.18±0.02	0.22±0.01
Highly disturbed	0-10	0.10±0.02	0.08±0.01	0.13±0.01
	10-20	0.09±0.02	0.05±0.01	0.12±0.01

The values ranged from 0.05±0.01% (monsoon season at 10-20cm depth in HD stand) to 0.34±0.02% (post-monsoon season at 0-10cm in UD stand). The values recorded during the study aligns with the results documented by Madhurima and Mishra (2023), Mishra and Laloo (2006), Suddick (2012), Mishra (2012) and Sunar et al. (2017). The level of nitrogen was highest in UD, followed by MD and HD stands respectively. Anthropogenic activities cause disruption to the forest ecosystem which adversely affected the fertility of the soil resulting in decline of total N content from undisturbed to disturbed stands (Mishra, 2012; Zimmer, 2002).

The UD stand had the maximum nitrogen, with values of TN ranging between 0.21±0.02% and 0.34±0.02% across the depths and seasons. High TN content indicates the presence of more nitrogen fixing bacteria or leguminous flora which supports the microbial growth (Sunar et al., 2017; Suddick, 2012). The MD stand had TN ranging between 0.18±0.02% and 0.24±0.02%. The least TN was documented in HD stand with values between 0.05±0.01% and 0.13±0.01% and both the soil depths showed a decline in TN, indicating loss of organic input, increased soil erosion, and lower biological nitrogen retention in the forest stand (Suddick, 2012). The topsoil (0-10cm) had more TN when compared to the subsoil (10-20), indicating continuous litter input, slow decomposition process under dense canopy, and activities of microbes that retain nitrogen (Mishra, 2012). A reduction in the level of TN during the monsoon season compared to other seasons may be because of washing away of topsoil due to heavy rains or due to leaching of nitrogen from the soil, especially in the HD stands (Sunar et al., Sunddick, 2012).

TN was seen to have a strong negative correlation with disturbance level ($r=-0.849$, $p<0.01$), indicating that as disturbance level increased, the nitrogen level decreased. TN was also seen to have negative correlation with temperature ($r=0.356$, $p<0.01$) and BD ($r=-0.681$), while it had a strong positive correlation with SOC ($r=0.833$. $p<0.01$), SMC ($r=0.584$, $p<0.01$), available P ($r=0.875$, $p<0.01$) and K ($r=0.870$, $p<0.01$) (Appendix-1).

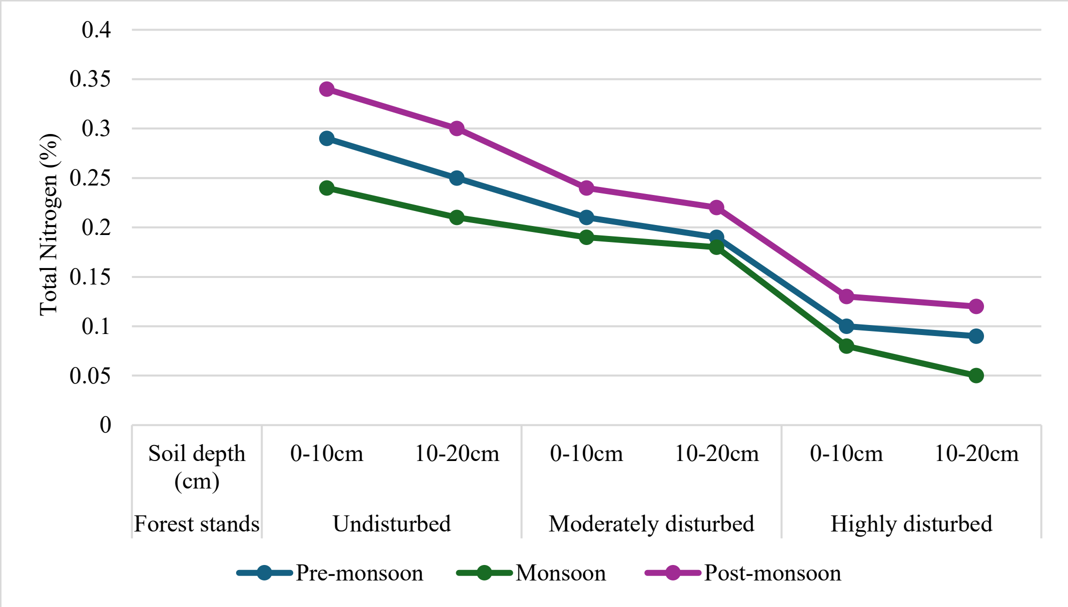

Figure 4.16: Total Nitrogen in selected forest stands along the disturbance gradient.

4.4.6 Available Phosphorus ($P_{avail.}$)

Phosphorus, which is an important nutrient for plant growth, acting as a limiting factor, was decreased with increase in the degree of disturbance (Table 4.18, Figure 4.17).

Table 4.18: Available Phosphorus in soil of selected forest stands along the disturbance gradient.

Forest stands	Soil depth (cm)	Seasons		
		Pre-monsoon (kg ha^{-1})	Monsoon (kg ha^{-1})	Post-monsoon (kg ha^{-1})
Undisturbed	0-10	28.34±0.36	24.02±0.15	31.90±1.21
	10-20	27.34±0.46	22.65±0.51	30.15±0.84
Moderately disturbed	0-10	19.10±0.16	17.94±0.17	20.19±0.28
	10-20	17.91±0.21	16.82±0.38	19.21±0.24
Highly disturbed	0-10	14.32±0.49	9.68±0.45	18.00±0.25
	10-20	10.58±0.22	6.84±0.67	17.24±0.21

The values were seen to be ranging between 6.84±0.67 kg ha^{-1} (monsoon season at 10-20cm depth in HD stand) and 31.90±1.21 kg ha^{-1} (post-monsoon season at 0-10cm depth in UD stand). The values recorded during the study was consistent with the findings of Rawat et al. (2020), Lalthakimi et al. (2023), Tiwari et al. (2020) and Ovung et al. (2021).

The UD stand had P_{avail} values ranging from 22.65±0.51 kg ha^{-1} to 31.90±1.21 kg ha^{-1} across the depths and seasons. The larger concentration of phosphorus may be attributed to the presence of rocks consisting of phosphates and orthophosphates, or due to constant input of organic material via litterfall, steady decomposition, and the presence of active microbes that breakdown organic matter thereby releasing phosphorus (Mishra, 2012; Mishra, 2011; Nang, 2016; Sunar et al.,2017). The $P_{avail.}$ in MD stand was seen to be ranging between 16.82±0.38 kg ha^{-1} and 20.19±0.28 kg ha^{-1}, which was lower when compared to UD stand. The partial loss of canopy and mild soil disturbance started affecting the $P_{avail.}$ in the soil probably due to washing away of topsoil or lesser input of organic matter. The HD stand had the least $P_{avail.}$ with values ranging from 6.84±0.67 kg ha^{-1} and 18.00±0.25 kg ha^{-1}. This reduction may be due to factors like soil erosion, less breakdown of organic matter, and less microbial activity. The open canopy allows heavy rain to hit the ground which washes away the nutrient rich top layer. The decline in the level of phosphorus from undisturbed to disturbed stands was also witnessed by researchers like Mishra (2012), Lalthakimi et al. (2023) and Madhurima and Mishra (2023). Phosphorus level was higher in the topsoil than the subsoil across all seasons and forest stands which is due to the buildup of organic matter and more microbial activity taking place in the surface layer (Sunar et al., 2017; Nang, 2016). $P_{avail.}$ was lowest during the monsoon season in all stands. It was higher in post-monsoon when compared to the pre-monsoon season, which may be because of drier seasons favouring higher retention of $P_{avail.}$ in soil (Arunachalam and Arunachala, 2000; Sunar et al., 2017).

$P_{avail.}$ was seen to be positively correlated to SMC ($r=0.555$, $p<0.01$), SOC ($r=0.884$, $p<0.01$), and total N ($r=0.875$, $p<0.01$, indicating the rise in $P_{avail.}$ as SMC, SOC and total N increases. The $P_{avail.}$ was seen to be negatively correlated with disturbance ($r=-0.880$, $p<0.01$) and BD ($r=-0.598$, $p<0.01$), pointing that soil compaction and increase in disturbance reduces $P_{avail.}$ (Appendix-1).

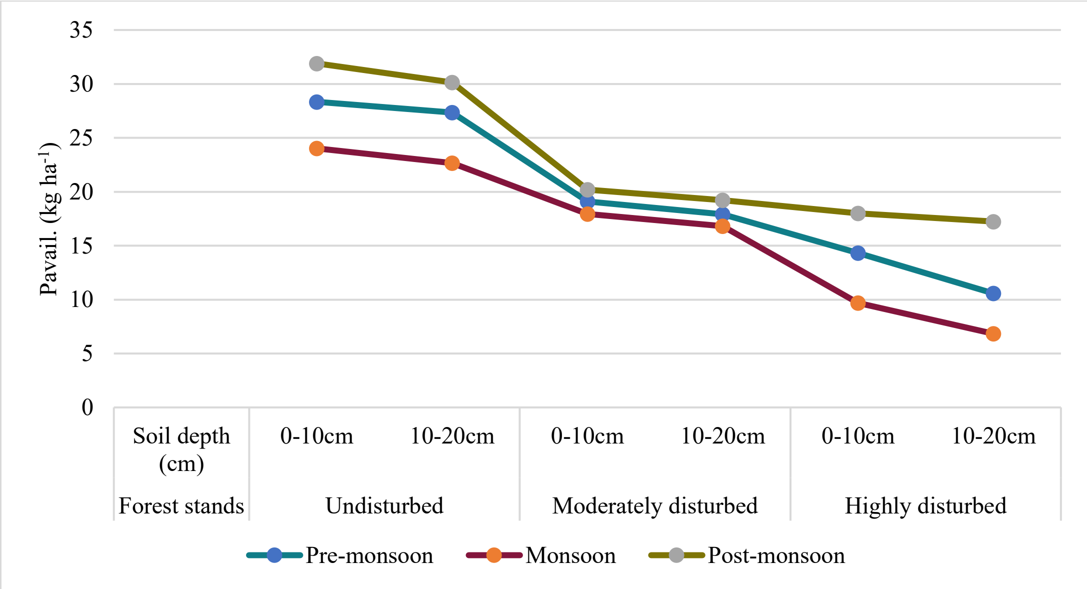

Figure 4.17: Available Phosphorus in selected forest stands along the disturbance gradient.

4.4.7 Available Potassium ($K_{avail.}$)

Potassium which is an important macronutrient was seen to decrease with increase in disturbance (Table 4.19, Figure 4.18).

Table 4.19: Available Potassium in soil of selected forest stands along the disturbance gradient.

Forest stands	Soil depth (cm)	Seasons		
		Pre-monsoon (kg ha^{-1})	Monsoon (kg ha^{-1})	Post-monsoon (kg ha^{-1})
Undisturbed	0-10	191.62±2.07	170.28±1.67	207.41±0.80
	10-20	167.13±1.30	155.72±1.85	183.96±1.85
Moderately disturbed	0-10	147.63±1.62	73.91±2.79	168.33±1.13
	10-20	130.09±1.07	59.05±2.75	151.87±1.69
Highly disturbed	0-10	59.58±1.76	51.26±2.65	81.84±0.85
	10-20	43.43±1.05	39.33±1.75	74.51±1.18

The values ranging between 39.33±1.75 kg ha^{-1} (monsoon season at 10-20cm depth in HD stand) and 207.41±0.80 kg ha^{-1} (post-monsoon season at 0-10cm depth in UD stand). The values recorded during the study was aligning with the results found by Madhurima and Mishra (2023), Vanlalruati et al. (2024) and Ngaihte et al. (2024). The amount of potassium was found to decrease with increase in disturbance, with UD stand holding the highest amount of $K_{avail.}$, followed by MD and HD stands respectively. The result was in line with the records of Sunar et al. (2017), Mehta et al. (2014), and Madhurima and Mishra (2023).

The UD stand had the highest amount of $K_{avail.}$, ranging between 155.72±1.85 kg ha^{-1} and 207.41±0.80 kg ha^{-1}. The high amount may be because of continuous litter fall which resulted in constant decomposition process and nutrients are recycled well under closed canopy. Also, rich layer of humus or organic matter assist in keeping the potassium in the soil by reducing leaching (Bhuyan and Sharma, 2017). The MD stand documented $K_{avail.}$ ranging from 59.05±2.75 kg ha^{-1} to 168.33±1.13 kg ha^{-1}, which is much lesser when compared to UD stand. The least amount of $K_{avail.}$ was recorded in HD stand with values ranging between 39.33±1.75 kg ha^{-1} and 81.84±0.85 kg ha^{-1}. This huge drop from UD to HD stand is due to clearing of vegetation, soil erosion, leaching or reduction in organic matter content resulting in less microbial activity. The level of $K_{avail.}$ was higher during the post-monsoon season when compared to monsoon season which may be due to high mobility during the monsoon where leaching and drainage are frequent (Mehta et al., 2014; Sunar et al., 2017; Basumatary and Bordoloi, 1992). The $K_{avail.}$ was seen to decrease with increase in soil depth, with topsoil having higher level of potassium when compared to subsoil. Leaching effect causes transfer of nutrients to the lower layer of the soil, but nutrient cycling brings back the nutrient to the forest floor through litterfall. When decomposition takes place, potassium is again released so the concentration of $K_{avail.}$ gradually increases in the topsoil (Kumar et al., 1998).

There was a strong negative correlation of $K_{avail.}$ with disturbance ($r=-0.876$, $p<0.01$) and BD ($r=-0.648$, $p<0.01$), indicating that with increase in disturbance and BD of soil, there is decrease in $K_{avail.}$ On the other hand, $K_{avail.}$ was positively correlated to SOC ($r=0.857$, $p<0.01$), total N ($r=0.870$, $p<0.01$), $P_{avail.}$ ($r=0.899$, $p<0.01$) and SMC ($r=0.558$, $p<0.01$) (Annexture 1).

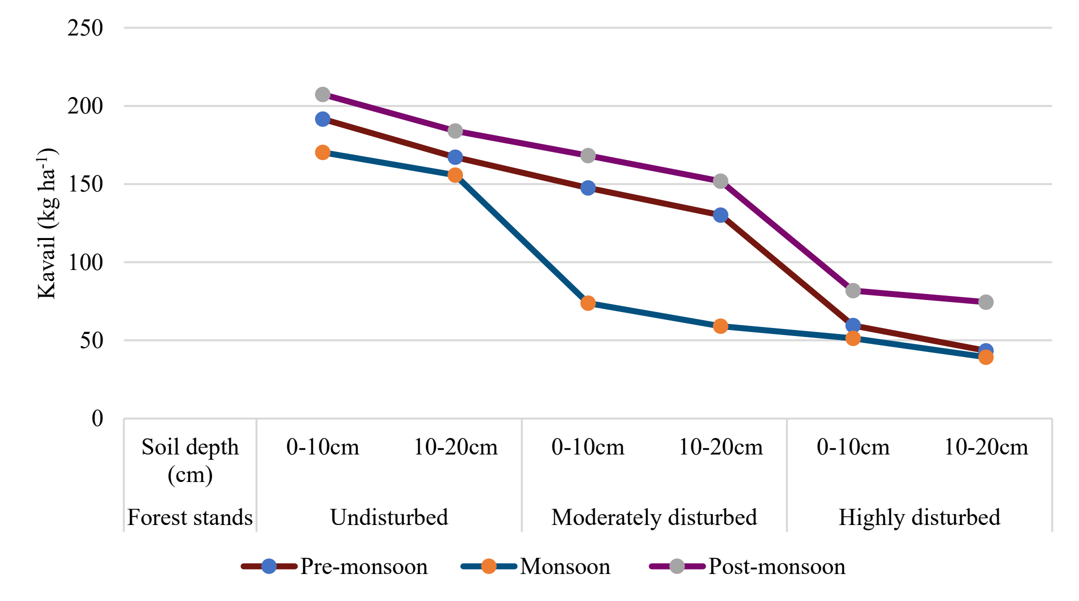

Figure 4.18: Available Potassium in selected forest stands along the disturbance gradient.

4.4.8 Soil organic carbon (SOC)

Soil organic carbon was seen to decrease with increase in disturbance (Table 4.20, Figure 4.19) and has values ranging from 0.92±0.03% (monsoon season at 10-20cm depth in HD stand) to 3.66±0.19% (post-monsoon season at 0-10cm depth in UD stand).

Table 4.20: Soil organic carbon in selected forest stands along the disturbance gradient.

Forest stands	Soil depth (cm)	Seasons		
		Pre-monsoon (%)	Monsoon (%)	Post-monsoon (%)
Undisturbed	0-10	3.19±0.33	2.84±0.17	3.66±0.19
	10-20	3.06±0.34	2.71±0.19	3.53±0.18
Moderately disturbed	0-10	2.64±0.29	2.50±0.37	2.98±0.13
	10-20	2.54±0.29	2.46±0.21	2.90±0.14
Highly disturbed	0-10	1.51±0.08	1.21±0.00	1.91±0.10
	10-20	1.41±0.11	0.92±0.03	1.77±0.10

The values recorded during the study was aligning with the results found by Tiwari et al. (2023) and Lalthakimi et al. (2023). The SOC in different forest stands were in the order: UD>MD>HD, which was the same as the findings of Mishra (2012), Sunar et al. (2017), Mishra and Laloo (2006) and Mishra, (2011).

The SOC was recorded to be highest in the UD stand, with values ranging between 2.71±0.19% and 3.66±0.19% irrespective of all depths and seasons. This may be attributed to the type of soil and the soil condition which encourage the growth of soil microorganisms for more decomposition, which implies high microbial biomass, which may be due to higher moisture content, thereby increasing the carbon content of the soil (Mishra, 2011; Sunar et al, 2017; Mishra and Laloo, 2006). In MD stand, constant input of leaf litter, root turnover, and presence of woody debris results in high carbon content. The MD stand has SOC values ranging from 2.46±0.21% to 2.98±0.13%, indicating allow reduction in the carbon content as disturbance increased. The HD stand recorded the least amount of SOC, ranging between 0.92±0.03% and 1.91±0.10%. This reduction in the amount of organic carbon from undisturbed to disturbed stands may be caused due to limited litter content due to vegetation loss, faster breakdown of organic matter when the soil is exposed to changing moisture or higher temperature and soil erosion (Lal, 2019). The SOC was found to be lowest during the monsoon season, which could be caused by removal of topsoil or loss of nutrients from the surface run-off (Sunar et al., 2017). The increase in SOC from monsoon to post-monsoon season may be because of increase in microbial activity after monsoon, which allows the plant residue, roots and litter to accumulate on the surface floor. When these organic matters are broken down by microbes and incorporated into the soil, the organic carbon content in the soil increases (Yang, 2004). The SOC was higher in the topsoil compared to the subsoil. This was consistent with Mishra (2012), Sharma et al. (2018), Rabha et al. (2014), Monsang et al. (2023), Tiwari et al. (2023), Niirou et al. (2015), Bhuyan and Sharma (2017), and Lalthakimi et al. (2023), Hauchhum and Tripathi (2017), Wapongnungsang et al. (2017) and Shah et al. (2021).

The SOC was negatively correlated with disturbance ($r=-0.839$, $p<0.01$) and soil BD ($r=-0.579$, $p<0.01$), and positively correlated with SMC ($r=0.604$, $p<0.01$) and macronutrients i.e., total N ($r=0.833$, $p<0.01$), $P_{avail.}$ ($r=0.884$, $p<0.01$) and $K_{avail.}$

(r=0.857, p<0.01) (Annexture-1). This indicates the influence of canopy cover, soil structure, and moisture in affecting the carbon storage capacity of the soil.

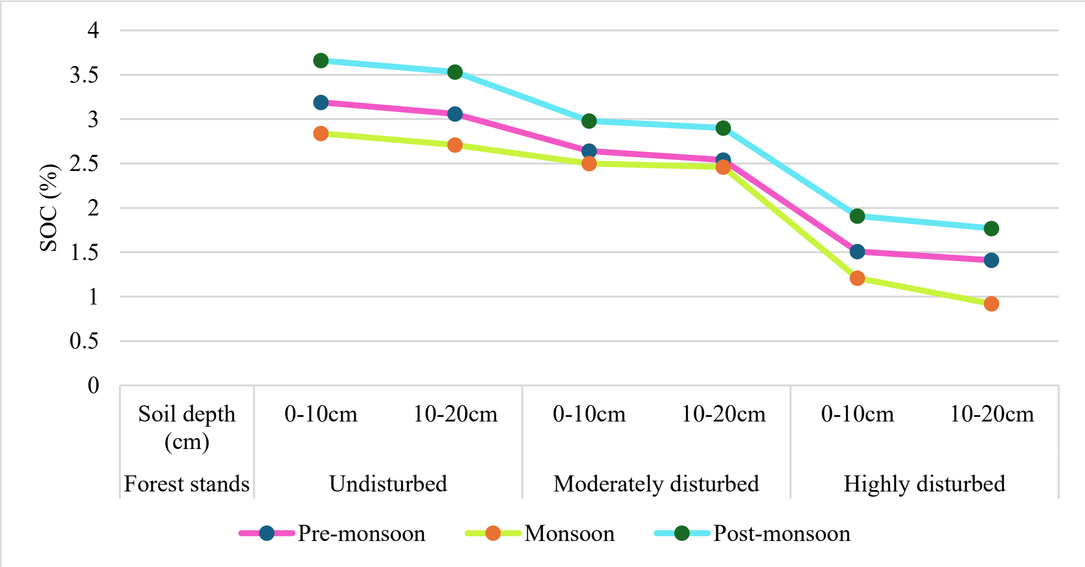

Figure 4.19: Soil organic carbon in selected forest stands along the disturbance gradient.

The one-way ANOVA focuses on how soil properties are influenced across varying degree of disturbance. Soil temperature (F=7.01, p=0.002), SMC (F=36.96, p=0.00), BD (F=20.63, p=0.00), SOC (F=74.80, p=0.00), TN (F=69.40, p=0.00), $P_{avail.}$ (F=93.57, p=0.00), and $K_{avail.}$ (F=84.03, p=0.00) showed high significant differences among the three forest stands, indicating that anthropogenic disturbance greatly affected these soil properties. However, soil depth (F=0.00, p=1.00) and pH (F=1.70, p=0.19) showed no significant difference, indicating that these factors remained relatively stable irrespective of the disturbance level. (Appendix-2).

4.5 Carbon stock analysis

4.5.1 Tree biomass and carbon stock

The tree biomass and carbon stock were seen to decrease along the disturbance gradient (Table 4.21, Figure 4.20). The UD stand was recorded to have the maximum amount of biomass and stored carbon, followed by MD stand and finally the HD stand.

Similar trend was observed by Mir et al. (2021), Gogoi et al. (2017), Deb et al. (2020), Chaudhury et al. (2022) and Borah et al. (2019),

Table 4.21: Biomass and carbon stock of trees in different forest stands.

Forest stand	AGB (t ha^{-1})	BGB (t ha^{-1})	TB (t ha^{-1})	TC (t ha^{-1})
Undisturbed	238.64	126.33	364.98	182.49
Moderately disturbed	145.27	79.94	225.21	112.60
Highly disturbed	29.93	17.55	47.48	23.74

Abbreviation: AGB- Aboveground biomass, BGB- Belowground biomass, TB- Total biomass, TC-Total carbon.

The UD stand had the highest aboveground biomass or AGB (238.64 t ha^{-1}) and belowground biomass or BGB (126.33 t ha^{-1}) when compared to other forest stands. The tree biomass and carbon stock in the UD stand was recorded at 364.98 t ha^{-1} and 182.49 t ha^{-1} respectively. This indicates that the forest has huge potential to store carbon because of its dense canopy and presence of many mature trees. The AGB was in range of 236 to 425 t ha^{-1}, typical of tropical forest of India (Chaturvedi et al., 2011; Gogoi et al., 2017). The MD stand with AGB of 145.27 t ha^{-1} and BGB of 79.94 t ha^{-1} showed a decline when compared to UD stand. The total biomass and carbon stock was recorded at 225.21 t ha^{-1} and 112.60 t ha^{-1}, respectively. This reduction can be a result of some trees being cut down. The AGB recorded in MD stand falls within the range of 116.8 and 278.5 t ha^{-1} reported by Singh and Sahoo (2018). In HD stand the AGB was found to be 29.93 t ha^{-1} and BGB was 17.55 t ha^{-1}. Also, the total biomass was recorded at 47.48 t ha^{-1} and total carbon at 23.74 t ha^{-1}. Similar values were recorded by Thokchom and Yadava (2017), Borah et al. (2013), Gogoi et al. (2017) and Mir et al. (2021). The huge drop may be due to loss of vegetation, where bigger trees were replaced by smaller and faster growing fauna (Gogoi et al., 2020, Lamare et al., 2023). There was a drastic reduction of 87% in the amount of carbon storage from UD to HD stand. This may be because of direct removal of vegetation through selective logging and collection of fuelwoods, which are common practices in the forests of India (Bhuyan et al., 2003; Thakrey et al., 2024).

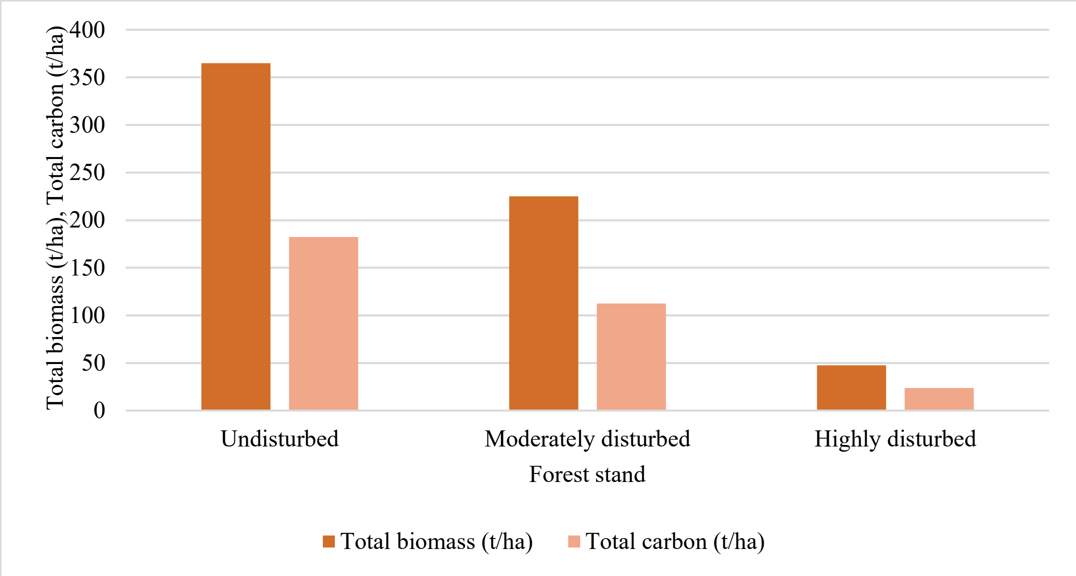

Figure 4.20: Total tree biomass and carbon stock in selected forest stands.

4.5.2 Biomass and carbon stock of trees across girth classes

As forest disturbance increased, the amount of biomass and carbon stock in each girth class slowly decreases, indicating that the number and size of trees are important for storing carbon (Table 4.22 and 4.23, Figure 4.21 and 4.22). The decrease in number of trees in bigger girths from undisturbed to disturbed stands align with the reports of Ao et al. (2023), Borah and Gadkoti (2011) and Mir et al. (2021).

Table 4.22: Biomass of trees in different girth classes of selected forest stands.

Forest Stand	Girth class (cm)					Total (t ha^{-1})
	30-60	60-90	90-120	120-150	>150	
Undisturbed	64.98	111.08	75.62	58.48	54.82	364.98
Moderately disturbed	87.63	65.27	48.45	15.57	8.29	225.21
Highly disturbed	31.08	10.41	4.72	1.28	0	47.48

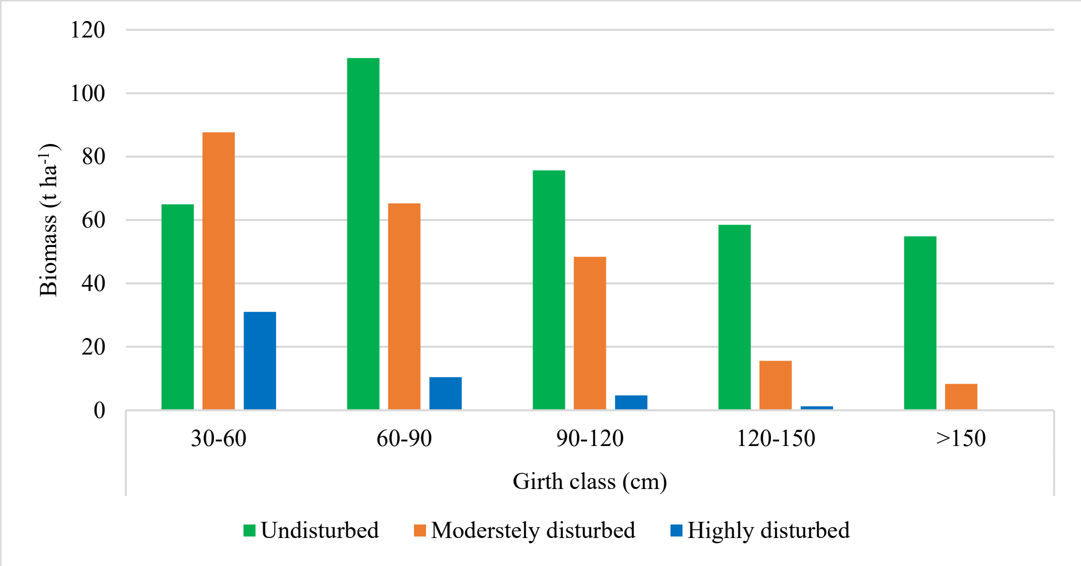

Figure 4.21: Biomass of trees across girth classes in selected forest stands.

In UD stand, the tree biomass and tree carbon stock was seen to be evenly distributed across all girth classes. The 60-90 cm class had maximum biomass (111.08 t ha^{-1}) and carbon (55.38 t ha^{-1}) since there were lots of trees (377) within that size range (Table 7). Most of the trees had medium to large girths which indicates a well-structured and mature forest with high potential of storing carbon (Clark and Clark, 1996; Brown and Lugo, 1992). Trees with more than 150cm girth had 54.82 t ha^{-1} biomass and stored 27.41 t ha^{-1} of carbon despite having only 33 individuals, indicating that these large trees store large amount of carbon when compared to younger trees. This girth size-class distribution shows the natural forest dynamics without any anthropogenic interference. The dominance of the tree biomass and tree carbon stock in girth class was primarily based upon the tree density. The high amount of biomass in bigger girth classes is characteristic of climax forest that have endured long periods of succession, allowing the individual trees to acquire maximum growth and buildup significant carbon stock (Mishra et al., 2004). Different studies have shown that the species wood density is very important in variation of biomass in trees and make up a major part of the total live biomass of the forest (Joshi and Dhyani, 2019; Robiansyah, 2018). In MD stand, 30-60cm girth class had the most biomass (87.63 t ha^{-1}) and carbon (43.82 t ha^{-1}), followed by the trees within 60-90 cm girth class with biomass at 65.27 t ha^{-1} and carbon at 32.64 t ha^{-1}. The number of trees also declined from 692 in 30-60cm girth class to just 5 trees in the biggest class i.e., more than 150 cm girth (Table 7) mainly due to anthropogenic activities like targeted extraction of economically valuable big trees. This indicates a shift towards smaller trees, which lowers the storage of carbon in the stand (Bhat et al., 2012). The removal of big trees widens the canopy gap, allowing the previously suppressed individuals in the lower canopy to flourish and grow faster due to lesser competition for nutrient, light and water. The increased light also promotes seed germination, resulting in increased individuals in lower girth classes (Dupuy and Chazdon, 2006). In HD stand, the 30-60 cm girth class had biomass at 31.075 t ha^{-1} and stored the maximum amount of carbon (15.54 t ha^{-1}), while the other girth classes did not contribute much. Trees with bigger girth classes are very rare, with just one tree in the 120-150 cm class with no tree having more than 150 cm girth, indicating removal of large trees by humans. This pattern is in line with the study done by Gogoi et al. (2022) where biomass distribution across various girth classes showed significant variation with the disturbance level, with trees with bigger girths are intensely affected by anthropogenic activities (Deb et al., 2021; Bradford et al., 2012; Ao et al., 2023). There was a direct link between the number of trees in each girth class and the amount of biomass and carbon stored in the forest. Undisturbed stand with more medium and large trees held more carbon than the disturbed stands with fewer and smaller trees.

Table 4.23: Carbon stock of trees in different girth classes of selected forest stands.

Forest Stand	Girth class (cm)					Total (t ha^{-1})
	30-60	60-90	90-120	120-150	>150	
Undisturbed	32.65	55.38	37.81	29.24	27.41	182.49
Moderately disturbed	43.82	32.64	24.23	7.79	4.14	112.60
Highly disturbed	15.54	5.20	2.36	0.64	0	23.74

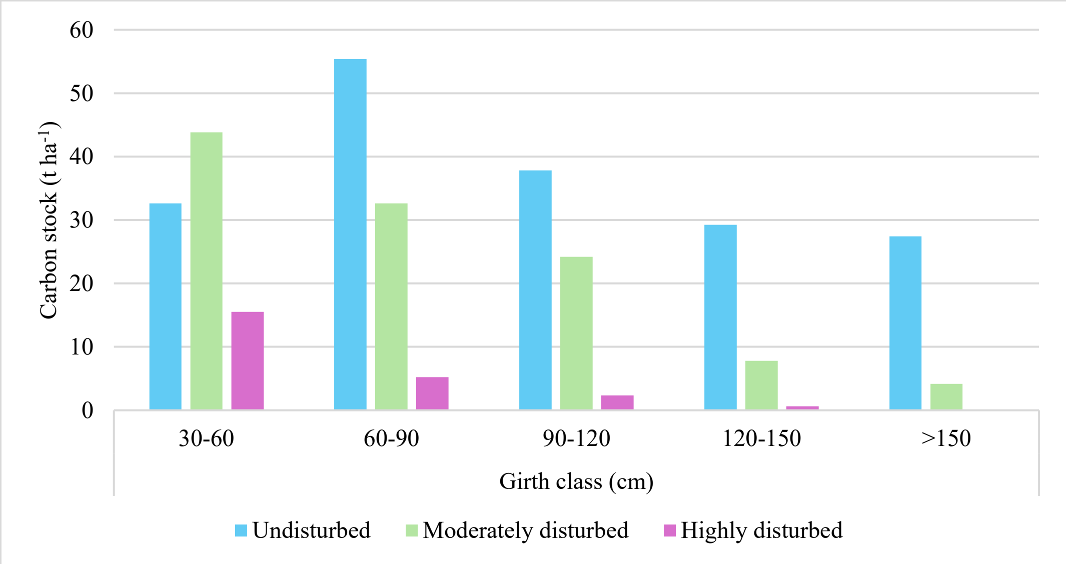

Figure 4.22: Tree carbon stock in different girth classes of selected forest stands.

4.5.3 Major tree species contributing to biomass and carbon stock

The change in the main tree species that store biomass and carbon along the anthropogenic disturbance gradient shows how disturbance can alter and change the forest's composition and structure. Table 4.24 shows the top 5 major tree species contributing to biomass and carbon stock in different forest stands.

In the UD stand, *Ostodes paniculata* was the major contributor of biomass at 30 t ha^{-1} and carbon stock at 15 t ha^{-1} respectively. Other major contributors include *Quercus floribunda, Engelhardia spicata, Quercus xylocarpa, Lindera pulcherrima* etc. The five major species collectively contributed 33.47% of the total carbon and these species are shade-tolerant, slow growing species with high wood density. They are well adapted to low light environments under a closed canopy, facilitate proper nutrient cycling and thrive under stable microclimatic conditions (Rao et al., 1990). Their dominance indicates a mature successional stage characterised by well-established competitive hierarchies resulting from decades to centuries of forest development (Bhuyan et al., 2003).

In the MD stand, *Drimycarpus racemosus* was the main contributor of biomass at 18.37 t ha^{-1} and carbon stock at 9.19 t ha^{-1} carbon, followed by *Quercus xylocarpa, Rapanea capitellata, Schima wallichii* and *Engelhardia spicata,* indicating the occurrence of secondary succession following disturbance. The five major species collectively contributed 28.16% of the total carbon. Species namely, Drimycarpus racemosus and Rapanea capitellata are mid-successional species that quickly respond to the increased light due to opening of canopy (Velho and Krishnadas, 2011). These species grow faster and have lesser wood density compared to the climax species but can tolerate more shade compared to the genuine pioneer species making them ideal for dominating the middle stage of forest recovery (Upadhaya et al., 2008). Quercus xylocarpa was found in all the forest stands, indicating their flexibility in adapting to different environmental changes (Sahoo and Lalfakawma, 2010)

In the HD stand, *Schima wallichii* was the major species contributing to biomass and carbon stock at 11.22 t ha^{-1} and 5.61 t ha^{-1} respectively. This was followed by *Wendlandia grandis* and *Macaranga denticulata*, indicating that the community comprise mainly of early-successional pioneers that survive well in areas that have been highly disturbed. These species have features that help them thrive well in such environments, including fast growth, low wood density, high photosynthetic efficiency in full sunlight, and the ability to swiftly capture accessible nutrients (Sahoo and Lalfakawma, 2010). The five major species collectively contributed 51.24% of the total carbon. *Schima wallichii* is particularly suited to such environment due to its large seed production and dispersal, and ease of establishment on exposed soils (Upadhaya et al., 2008). The prevalence of these pioneers indicates that disturbance in HD stand occurs frequently severely enough to prevent the development of a more mature and climax community (Mishra et al., 2004). Similar findings were reported by Kumar and Ram (2005), where anthropogenic activities disturbed the forest, which made light-demanding species thrive and remove shade-tolerant climax trees. This causes alteration in the composition and structure of the forest.

Table 4.24: Major tree species contributing to biomass and carbon stock in different forest stands.

Forest stand	Species	TB (t/ha)	TC (t/ha)
Undisturbed	*Ostodes paniculata* Blume	30.00	15.00
	Quercus floribunda Lindl. ex A.Camus	28.15	14.07
	Engelhardia spicata Lechen ex Blume	22.30	14.59
	Quercus xylocarpa Kurz	17.88	8.94
	Lindera pulcherrima (Nees) Benth. ex Hook.f.	15.50	8.49
Moderately disturbed	*Drimycarpus racemosus* (Roxb.) Hook.f. ex Marchand	18.37	9.19
	Quercus xylocarpa Kurz	13.33	6.66
	Rapanea capitellata (Wall.) Mez	11.51	5.75
	Schima wallichii (DC.) Choisy	10.65	5.32
	Engelhardia spicata Lechen ex Blume	9.54	4.77
Highly disturbed	*Schima wallichii* (DC.) Choisy	11.22	5.61
	Quercus xylocarpa Kurz	4.13	2.07
	*Wendlandia grandis (*Hook.f.) Cowan	4.10	2.05
	Carallia brachiata (Lour.) Merr.	2.46	1.23
	Macaranga denticulata Müll.Arg.	2.41	1.21

4.5.4 Biomass and carbon stock of understorey vegetation and litter

The biomass and carbon stock of understorey vegetation and litter was seen to vary along different forest stands and seasons (Table 4.25 and 4.26, Figure 4.23 and 4.24). The biomass in shrubs varied along the disturbance gradient, ranging from 0.072 t ha^{-1} (pre-monsoon season in UD stand) to 0.724 t ha^{-1} (pre-monsoon season in MD stand). Similarly, the carbon stored in shrubs ranged from 0.034 t ha^{-1} (pre-monsoon season in UD stand) to 0.344 t ha^{-1} (pre-monsoon season in MD stand).

Table 4.25: Biomass of under-storey vegetation and litter along the disturbance gradient.

Season	Shrubs			Herbs			Litter		
	UD	MD	HD	UD	MD	HD	UD	MD	HD
Pre-monsoon	0.072	0.724	0.355	0.03	0.079	0.178	2.437	0.906	0.217
Monsoon	0.2	0.576	0.461	0.063	0.114	0.229	1.42	0.764	0.162
Post-monsoon	0.086	0.55	0.599	0.059	0.105	0.227	2.1	1.005	0.143

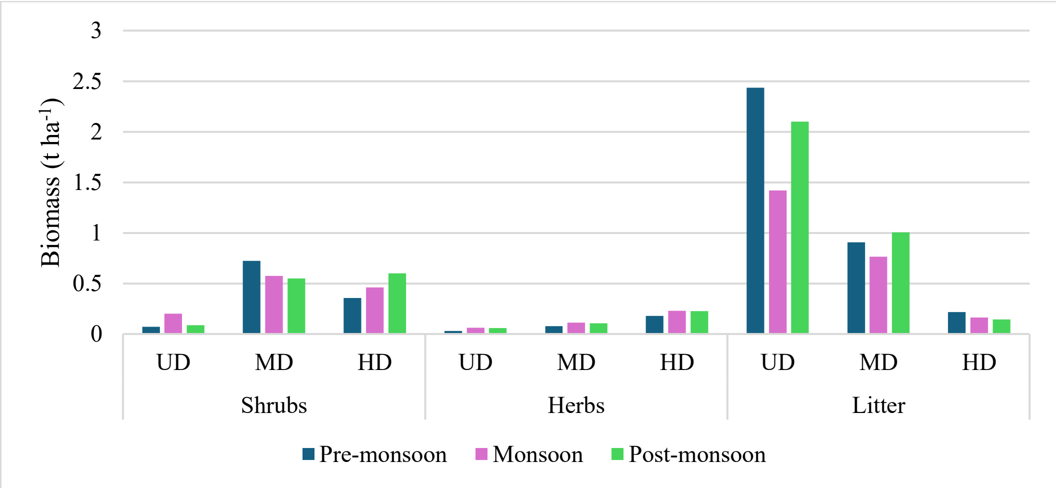

Figure 4.23: Biomass of under-storey vegetation and litter along the disturbance gradient.

The MD stand had the maximum biomass and carbon stock in shrubs as the density of shrubs was the highest there. This was followed by HD stand, and the UD stand witnessed the least amount of biomass and carbon. The UD stand has very dense canopy cover that blocks direct sunlight from reaching the forest floor. This allows only a few shade-tolerant shrubs species to grow there, limiting their density and biomass (Kaushal et al., 2021). Also, the big and mature trees absorb the largest amount of the nutrients and water, making it difficult for the understorey shrubs to thrive (Bhat et al., 2012). In MD stand, more sunlight penetrates through the widened canopy gaps which helps some light-loving shrubs to flourish while still shade-loving shrubs thrive in the shaded areas (Osuri et al., 2019). The was in line with the intermediate disturbance effect where mild disturbance increases the diversity of species, thereby the amount of biomass and carbon stored was maximum in MD stand. The shrub biomass slightly reduced in HD stand despite having more light. This can be due to heavy grazing and periodic surface fires for shifting cultivation. (Bhat et al., 2012).

The biomass and carbon stock values were lower in herbaceous vegetation, when compared to shrubs. The biomass was seen to range between 0.03 t ha^{-1} (pre-monsoon season in UD stand) to 0.229 t ha^{-1} (monsoon season in HD stand), and carbon stock ranged from 0.014 t ha^{-1} (pre-monsoon season in UD stand) to 0.109 t ha^{-1} (monsoon season in HD stand). The herb biomass along with carbon stock was minimum in UD stand, followed by MD stand. The HD stand has the maximum herb biomass and carbon stock because the area is more exposed to sunlight and open space which help fast growing herbs thrive (Bhuyan et al., 2003). In UD stand, the dense canopy and shrub layer keep the layer underneath completely shaded, and thick litter fall covers the floor, making the condition unfavourable for hers to survive. With increase in disturbance, the canopy pens and allows more grasses and herbs to colonise the exposed area (Mishra et al., 2004), thereby increasing the amount of biomass and carbon stock by herbs. Despite the increase of shrubs and herbs along the disturbance gradient, their contribution to biomass and carbon stock is very little and cannot compensate for the loss ofcarbon stored in trees (Gogoi et al., 2020).

Litter made up an important part of the understorey biomass, ranging between 0.143 t ha^{-1} (post-monsoon season in HD stand) and 2.437 t ha^{-1} (pre-monsoon season in UD stand), and carbon stock was seen to be ranging from 0.070 t ha^{-1} (post-monsoon season in HD stand) to 1.157 t ha^{-1} (pre-monsoon season in UD stand). In the UD stand, litter biomass and carbon remained high throughout the season, while HD stand had the least litter biomass and carbon stock. Also, the closed canopy and high tree density in UD stand results in litterfall throughout the year, making a thick layer of litter biomass in the forest floor (Jhariya 2017). The litter biomass reduced as the tree density decreases, as witnessed in MD stand. In HD stand, reduced canopy cover reduces the litter fall, and anthropogenic disturbances either remove or prevent the litter accumulation (Kumar and Ram, 2005). Open canopies can produce warmer microclimates that fasten decomposition (Thakrey et al., 2022), minimizing accumulation of litter.

Table 4.26: Carbon stock of under-storey vegetation and litter along the disturbance gradient.

Season	Shrubs			Herbs			Litter		
	UD	MD	HD	UD	MD	HD	UD	MD	HD
Pre-monsoon	0.034	0.344	0.168	0.014	0.038	0.084	1.157	0.43	0.103
Monsoon	0.095	0.274	0.219	0.03	0.054	0.109	0.674	0.363	0.077
Post-monsoon	0.041	0.261	0.285	0.028	0.05	0.108	0.997	0.477	0.07

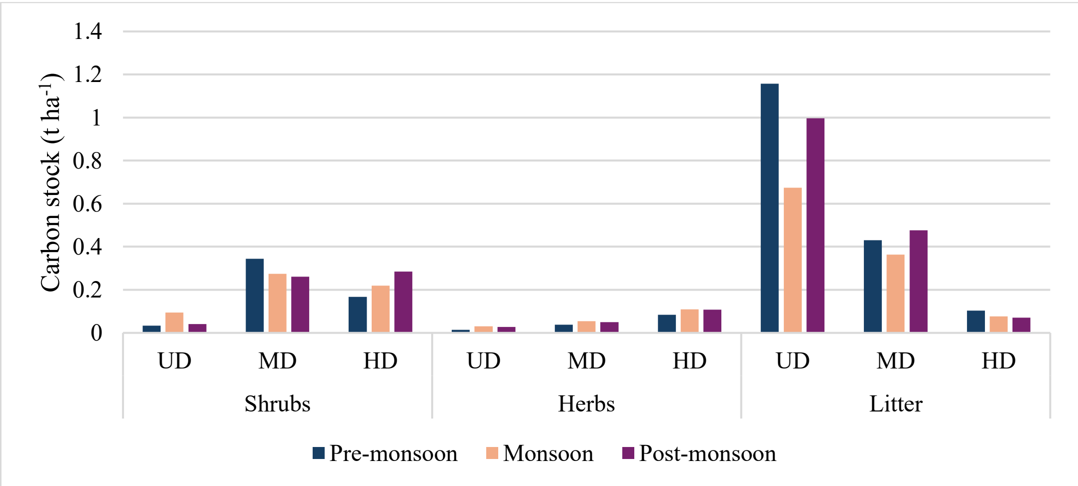

Figure 4.24: Carbon stock of under-storey vegetation and litter along the disturbance gradient.

4.5.5 Carbon to Nitrogen ratio (C:N) in different forest stands

The Carbon-to-Nitrogen (C:N) ratio was seen to be directly proportional to disturbance (Table 4.27, Figure 4.25), ranging between 10.77 (post-monsoon season at 0-10cm depth in UD stand) and 18.40 (monsoon season at 10-20cm in HD stand).

In the UD stand, the C:N ratio was low, ranging from 10.77 to 12.91, indicating that there was active breakdown of organic matter thereby releasing good amount of nitrogen (Mishra, 2012). The MD stand had slightly higher values ranging between

12.42 and 13.67, while HD stand had the maximum value ranging from 14.69 to 18.40 which may be due to slower breakdown of organic matter and loss of nitrogen due to leaching or erosion. The maximum values were found during the monsoon season across all stands and depths, indicating that heavy rains tend to wash away the nitrogen from the soil (Mishra, 2011; Mishra, 2012; Mishra and Laloo, 2006).

Table 4.27: C:N ratio along the disturbance gradient.

Forest stands	Soil depth (cm)	Seasons		
		Pre-monsoon	Monsoon	Post-monsoon
Undisturbed	0-10	11	11.83	10.77
	10-20	12.24	12.91	11.77
Moderately disturbed	0-10	12.57	13.16	12.42
	10-20	13.37	13.67	13.18
Highly disturbed	0-10	15.1	15.13	14.69
	10-20	15.67	18.4	14.75

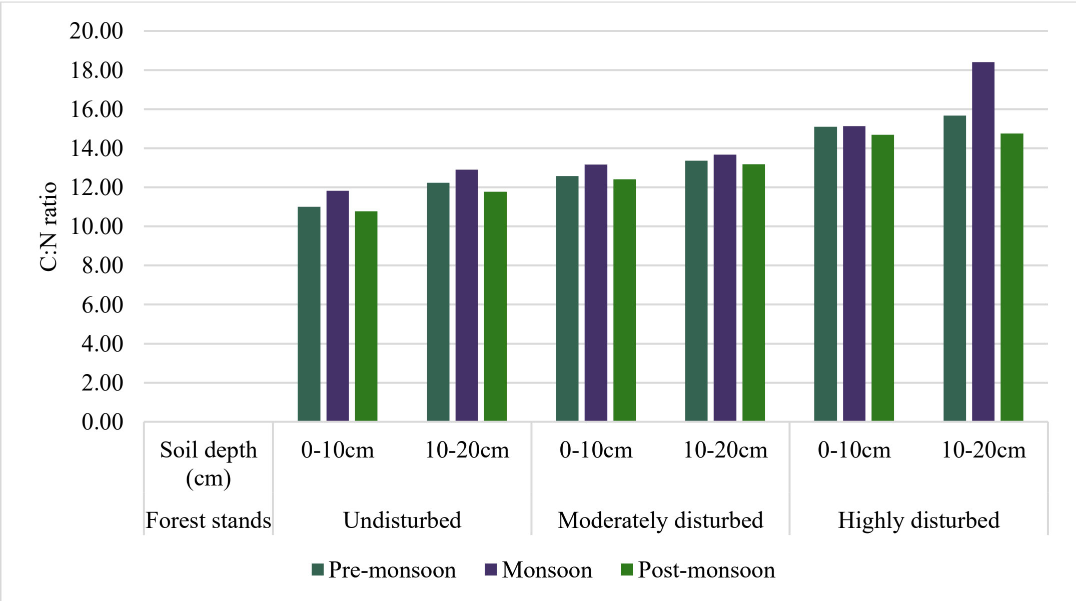

Figure 4.25: C:N ratio along the disturbance gradient.

The C:N ratio was the highest in the HD stand, followed by the MD stand and lowest in the UD stand. Also, the value in the subsoil was consistently higher than the topsoil across all stands. The increase in the C:N ratio along the disturbance gradient indicates a decline in soil fertility. The UD stand is more fertile as it consistently receives fresh litter and promotes active nutrient cycling while the HD stand was less fertile due to lower litter input, reduced nitrogen supply, and also slow decomposition rate.

4.5.6 Total biomass and carbon stock

The total biomass and carbon stock was seen to decrease with increase in disturbance level across the forest stands (Table 4.28).

Table 4.28: Total biomass and Total carbon stock along the disturbance gradient.

Components	Undisturbed stand		Moderately disturbed stand		Highly disturbed stand	
	Biomass (t ha^{-1})	Carbon stock (t ha^{-1})	Biomass (t ha^{-1})	Carbon stock (t ha^{-1})	Biomass (t ha^{-1})	Carbon stock (t ha^{-1})
Trees	364.976	182.488	225.207	112.604	47.476	23.738
Shrubs	0.119	0.06	0.617	0.309	0.472	0.236
Herbs	0.0507	0.025	0.099	0.05	0.211	0.106
Litter	1.986	0.993	0.892	0.446	0.174	0.087
Soil		57.694		52.866		36.5
Total	367.132	241.26	226.815	166.275	48.333	60.667

The total biomass was highest in UD stand at 367.13 t ha^{-1}, followed by MD stand at 226.815 t ha^{-1} and lowest in HD stand at 48.33 t ha^{-1}. Simultaneously, the total carbon stock was highest in UD stand at 241.26 t ha^{-1} and lowest in HD stand at 60.67 t ha^{-1}. The total biomass in UD and MD stand falls within the range of 129 and 533 t ha^{-1} for the Himalayan forest (Sharma et al., 2010) and the range for carbon stock was also within the range of 163 and 258 t ha^{-1} for the forests in Asia (Sharma et al., 2010; Lu et al., 2010).

The trees made up the largest carbon reservoir or sink. The amount of tree biomass and carbon stock was found to be highest in UD stand, followed by MD stand and HD stand respectively. This big drop from UD to HD stand is due to the presence of fewer big trees and weak stand structure in HD stand. Shrubs and herbs contributed very little to the forest biomass and carbon stock. For shrubs, the MD stand held the highest biomass and carbon, followed by HD stand and UD stand respectively, but when it comes to herbs, the biomass and carbon was found to be highest in HD stand, followed by MD and UD stands respectively. A decrease in the litter biomass and carbon was observed with increase in disturbance, with UD stand holding maximum litter biomass and carbon and HD holding the least. Similar trend was found in SOC where the amount decreased with increase in disturbance along the forest stands.

When the total carbon stock was calculated for every component, viz., tree, shrub, herb, litter, and soil, the value declined from UD to MD and finally to HD stand. The pattern UD>MD>HD shows how anthropogenic activities has a big effect on both biomass and carbon stock in forest ecosystems. In undisturbed forest stand, maximum carbon is stored in trees, as the forest is stable, but as the disturbance increase, the contribution made by trees drops and soil becomes the carbon pool to store the most carbon (Sahoo et al., 2021; Kumar et al, 2021). This does not imply that soil starts storing more carbon, it just shows how much vegetation is being lost due to the disturbance. According to Erb et al. (2018), anthropogenic activities like grazing, extraction of non-timber forest products and small-scale wood extraction results contribute almost half of the global carbon losses, though these do not seem as severe as deforestation. When disturbances continue through anthropogenic activities like collection of fuelwoods, grazing and shifting cultivation, the forest slowly loses its ability to recover (Kumar and Ram, 2005).

The forests stand that were disturbed can only regain their lost carbon when disturbance reduces or stops totally. A study from Northeast India demonstrates that following shifting cultivation, forest recover carbon through natural regeneration (Gogoi et al., 2020). It takes about 25 years on an average, for regenerating the forest to replenish about 50% of carbon from the old-growth forests. This means that full recovery will take around 50 to 100 more years, depending on the location and past disturbance. The HD stand contribute just one-fourth of the carbon that UD stand hold, indicating the need of good management practices for restoration of the disturbed forest stands (Sahoo et al., 2021).

Chapter 5

SUMMARY AND CONCLUSION

Forests are among the most vital and dynamic ecosystems on earth. Nearly 80% of the terrestrial biodiversity is found in forests (Watson et al., 2000). The forests in Mizoram are rich in biodiversity as they are a part of the Indo-Burma Biodiversity Hotspot. Though most of the forest areas which are inaccessible are rich still rich in biodiversity, those that are closer to human settlements are undergoing high level of pressure due to various activities like collection of fuelwood and non-timber forest products, grazing, and shifting cultivation by the locals. These anthropogenic activities have not only resulted in loss of biodiversity in the study area, but also affected other ecological processes like productivity, carbon stock, and regeneration.

According to Pandey and Bardsley (2015), forests are extremely vulnerable, which is exacerbated by stress caused by both natural and anthropogenic factors that are beyond their ability to adapt. The vulnerability of forest vegetation to disturbances is reflected by examining the variation in forest type distribution (Chaturvedi et al., 1994). Disturbance plays a significant role in determining the type of plant communities in natural ecosystems. Forest disturbance has a strong impact on plant structure (Armesto and Pickett, 1985). Forest vulnerability reflects alteration in the relative carbon characteristics and carbon distribution in the forest. It is clear that change in habitat and fragmentation, as well as the loss of plant adaptability due to disturbance, would make them vulnerable, resulting in the transformation of forest vegetation.

Forests serve a significant part in the global carbon cycle because they store large amounts of carbon in vegetation and soil, serve as an atmospheric carbon sink during regrowth after disturbance, and can be managed to sequester or store significant amounts of carbon in the land (Sharma et al., 2011). Forest stores about 62% to 78% of the terrestrial carbon which is much more than any other terrestrial ecosystems (Zhu et al., 2010). There is a growing demand for information on the carbon stock at both the national and global levels. This suggests that monitoring the state and evolution of forest carbon reservoirs is critical. The key carbon pools to be quantified in forest carbon assessment are plant biomass, soil organic carbon, litter, shrubs, herbs and grasses (Dhakal et al., 2010). In view of the growing threats to the existing forests, it is important to understand how natural forests and their ecological attributes are affected by the degradation caused due to anthropogenic activities, and relationships between such attributes and carbon stock for developing suitable management plans (Srivastava and Vellend, 2005).

The study aims to assess the impact of anthropogenic disturbance on tree community characteristics and carbon stock in the forests of Aizawl district of Mizoram. The study site was selected based on several criteria, viz., the area must represent broader ecological and disturbance patterns that are common to Mizoram's forests, it should contain forest stands along a clear level of anthropogenic disturbance from untouched to severely degraded stands, and the practical possibility and accessibility for frequent field visits.

The thesis is made up of 5 chapters. The first chapter is the "Introduction" which starts with an overview and gives idea about biodiversity and forest ecosystem, soil characteristics, forest carbon stock, anthropogenic disturbance in forest ecosystems, importance of sustainable forest management, significance and scope of the study, and objectives. The second chapter is the "Review of literature" which gives reviews at the international, national (India), regional (Northeast India), and local level (Mizoram). The third chapter is the "Methodology" which deals with the site selected for the study and the methods applied for the analysis of the plant communities, soil characteristics and forest carbon stock along different levels of anthropogenic disturbance. The fourth chapter is the "Results and discussion" where all the findings are discussed.

The present study was carried out for 2 successive years, i.e., from the post-monsoon season of 2022 to the monsoon season of 2024, covering all the three seasons i.e., pre-monsoon, monsoon and post-monsoon. To quantify the degree of disturbance caused by anthropogenic activities, disturbance index (DI), canopy cover and light interception were analysed (Pandey and Shukla, 1999). Depending on the disturbance level, the area of research was categorised into 3 stands viz., undisturbed (UD), moderately disturbed (MD) and highly disturbed (HD) forest stands, were selected in and around Hmuifang, Aizawl district, Mizoram. A total of 3 ha (1 ha for each stand) was surveyed during the study.

For the present study, the method as outlined by Misra (1968) was followed for vegetation analysis. The quadrat size of 10m x 10m for trees, 5m x 5m for shrubs, and 1m x 1m for herbs were laid randomly. In case of trees, all individuals having more than 30 cm girth at breast height (1.37 m) above ground were measured. Identification of species were done using the books, “The book of Mizoram Plants” (Sawmliana, 2003) and “Flora of Mizoram Vol. 1” (Singh et al., 2002). The species identified were then cross-checked with the herbarium records of the Department of Environmental Science, Mizoram University. Since the primary focus of the study was on trees, quantitative analysis was done for such species only. However, the list of shrub and herb species along with their presence or absence in the UD, MD and the HD stands were recorded.

The quantitative analysis viz., abundance, density and frequency, were calculated for trees using the methods proposed by Curtis and McIntosh (1950). The Importance Value Index (IVI) was calculated following the method proposed by Phillips (1959). The Whitford index, Shannon-Wiener diversity index, Pielou evenness index, Simpson dominance index, Margalef diversity index, and Sorensen similarity were also calculated for comparative assessment among the selected forest stands (Whitford, 1949; Shannon and Weiner, 1963; Pie Lou, 1969; Simpson, 1949; Margalef, 1958); Sorensen, 1948). The soil samples were collected from two depths, i.e., topsoil (0 – 10 cm) and subsoil (10 – 20 cm). The soil samples were collected from the sites by inserting a 10 cm scaled soil corer with 5.2 cm inner diameter. The soil pH, soil temperature, soil moisture content (SMC), ant the bulk density (BD) were analysed using the methods described by Allen et al. (1974) and Anderson and Ingram (1993). The soil organic carbon (SOC) was calculated following the Walkey and Black’s titration method (1934). The total nitrogen (TN) was analysed using the Kjeldahl Digestion method developed by Walkey and Black (1934). The available phosphorus ($P_{avail.}$) was determined using spectrophotometer method of Bray and Kurtz (1945). The available potassium ($K_{avail.}$) was determined using the flame photometer method of Jackson (1973). For the estimation of biomass of trees, a non-destructive approach was followed where the aboveground biomass (AGB_{trees}) was calculated using the allometric equation developed for trees in northeast part of India (Nath et al., 2019), and the belowground biomass (BGB_{trees}) was calculated following Cairns et al. (1997). The specific wood gravity of trees was derived from the global wood density database developed by Zanne et al. (2009). A destructive approach was taken for estimation of biomass of the understorey vegetation (shrubs and herbs). The method proposed by Pearson et al. (2005) was used for calculating the amount of biomass in understorey vegetation and litter. The carbon stock was considered as 50% of the total biomass following Brown et al. (1989).

In the UD stand the DI was 0%, the canopy was dense at 74% and the light interception was at 85%. This revealed that the forest stand was stable and well-preserved. The MD stand was slightly disturbed, with DI of 26.80%, canopy cover of 49% and light interception of 64%, showing some signs of anthropogenic disturbance while still maintaining so part of its natural structure. In the HD stand the DI was 71.89%, the canopy cover was 9% and light interception was 32%, indicating that the stand was severely disrupted due to anthropogenic disturbance which caused alteration in its structure.

The microclimate changed across the disturbance gradient, mainly because the canopy either covers or exposes the ground. Relative humidity was seen to be ranging between 69.1±0.35% (pre-monsoon season in HD stand) and 98.6±0.46% (monsoon season in UD stand) while the air temperature was seen to be ranging between 17.5±0.53°C (post-monsoon season in UD stand) and 28.2±0.84°C (pre-monsoon season in HD stand). Canopy opening allowed more sunlight and wind to reach the ground, making the air warmer and drier.

Anthropogenic disturbances played a big role in floral diversity. The UD stand documented 137 species, 11 genera, and 72 families of plants, but maximum plant species was observed in MD stand with 170 species, 141 genera, and 86 families. The HD stand comprised of 142 species, 125 genera, and 76 families, where most of the species are herbaceous. The MD stand had the most diversity, thereby supporting the Intermediate Disturbance Hypothesis (IDH) which states that mild disturbance allows more diversity.

The tree diversity tends to decrease with increase in disturbance. A total of 128 tree species were documented in all the forest stands. The UD stand had the highest diversity, with 99 species, 75 genera and 45 families, pointing towards a healthy ecosystem with tree species that are firm and typical of mature forests. As the forest experienced moderate disturbance, the tree diversity also decreased with 78 species, 58 genera and 37 families. The HD stand experienced maximum disturbance, thereby only included 35 species, 26 genera and 22 families. The sudden decrease in tree diversity shows a shift from well structured, diverse, and mature community to a simpler vegetation type which is dominated by fast growing, shade-intolerant and disturbance tolerant species.

The tree density and basal area decreased with increase in disturbance. The UD stand documented tree density of 1275 individuals ha^{-1}, the MD stand had 955 individuals ha^{-1}, and the HD stand had only 314 individuals ha^{-1}. This decline in density showed the impact of logging, shifting cultivation, and repeated extraction of forest products. The basal area was highest in UD stand at 40.196 m^2 ha^{-1}. The MD and HD stands recorded a basal area of 25.997 m^2 ha^{-1} and 5.787 m^2 ha^{-1} respectively, indicating that large mature trees were the first to be cut down in disturbed areas.

The diversity indices show how disturbance reshaped the forest community. The Shannon-Wiener index (H′) in the UD stand had the highest value (4.15) which is followed by MD stand (4.00) and HD stand (3.23). Margalef's species richness index (Dmg) ranged from 13.71 in UD stand to 11.22 in MD stand and 5.91 in HD stand. These show a gradual loss of both richness and balance among the species. Pielou's evenness index (J) was recorded at 0.91, 0.90, and 0.88 in the UD, the MD and the HD stand respectively, showing some signs of dominance in the HD stand. In the Simpson's dominance index (D), the value slowly increased from 0.02 in UD stand to 0.03 in MD stand and highest in HD stand at 0.05, indicating a shift in community structure from a more even to a more dominant composition. The Sorensen similarity index (S_E) revealed the similarity in species in different forest stands. The UD and MD stands was the most similar (0.62), with 55 common species, indicating that the level of disturbance was not too high to change the forest structure completely. The MD and HD stand had lower similarity (0.44) with 25 common species. The UD and HD stands had the least similarity (0.39), with only 26 common species. These indicate how disturbance can affect the species composition.

The trees in the different forest stands were divided into groups based on their girth sizes. There were trees of all girth sizes on the UD stand from younger trees (30-60cm) to medium sized (60-90cm) and older trees (>150cm) girth sizes, which is typical of a mature and stable forest stand. Maximum trees fall in the 30-60cm girth class category in the HD forest stand with just a single tree between 120-150cm and none in the higher girth class, indicating that the forest is unstable.

The IVI showed shift in dominance of species. In the UD stand, *Engelhardia spicata* was the most dominant species with IVI score of 18.89, but it was replaced by *Drimycarpus racemosus* with an IVI score of 15.67 in the MD stand, which was further replaced by *Schima wallichii* with an IVI score of 44.71 in the HD stand. There was a clear pattern of succession, going from the climax or late successional species becoming the most dominant or common in the UD stand, to early successional species or pioneer species being the most dominant in the HD stand. The MD stand still maintained species diversity, though shift in the community structure due to disturbance has been observed. The dominance-diversity curve depicts that the UD curve and the MD curve showed the log normal distribution assuming stable and complex community. However, the HD stand showed short-hooked curve depicting an unstable community.

The family dominance-distribution curve showed a clear shift in family dominance of trees along the disturbance gradient. Lauraceae was the most dominant family in both the UD and the MD stands, indicating its strong ecological presence even under mild disturbance. However, Lauraceae was replaced by Fagaceae as the most dominant species in the HD stand, indicating a shift towards species groups which can withstand disturbance as well as changed habitat conditions.

Out of the 128 species, most of them were put in the Least Concern (LC) category by IUCN. *Alseodaphnopis petiolaris* and *Memecylon grande* were classified as Vulnerable (VU), while *Dipterocarpus retusus* and *Palaquium polyanthum* were categorised as Endangered (EN), indicating their vulnerability. The species *Saurauia punduana* was listed as Critically Endangered (CR), and was present only in the UD stand, indicating its risk of extinction.

The soil temperature was seen to range from 15.22±0.44°C (post-monsoon season at 10-20 cm depth in UD stand) to 22.53±0.55°C (pre-monsoon season at 0-10 cm depth in HD stand). The soil warmed up faster in disturbed areas because of the open canopy which allowed light to hit the ground more directly. Soil moisture ranged between 17.44±0.52% (pre-monsoon season at 10-20 cm depth in HD stand) and 44.13±0.48% (monsoon season at 0-10 cm depth in UD stand). This shows that the more disturbed the forest was, the less moisture it could hold. The loss of soil moisture was because there was less vegetation and the soil structure was weaker in the disturbed area, which made it difficult for the soil to hold water.

The bulk density of soil was seen to increase with increase in disturbance, with values ranging between 0.81±0.11 g cm^{-3} (pre-monsoon season at 0-10cm depth in UD stand) and 1.38±0.01 g cm^{-3} (monsoon season at 10-20cm depth in HD stand), indicating that the soil in disturbed site is more compact and the soil is more exposed to trampling and erosion. Soil pH was moderately to slightly acidic across all forest stands, with values ranging between 5.27±0.04 (pre-monsoon season at 0-10cm depth in UD stand) and 6.20±0.05 (post-monsoon season at 10-20cm depth in MD stand. The UD stand had lower pH because of more litter organic acid buildup. The disturbed stands have slightly higher pH because the vegetation has been burnt and organic input has been lost.

Total Nitrogen was seen to decrease with increase in disturbance. The values ranged from 0.05±0.01% (monsoon season at 10-20cm depth in HD stand) to 0.34±0.02% (post-monsoon season at 0-10cm in UD stand). This big drop may be caused by the loss of organic matter, the soil's poorer ability to fix nitrogen, and more leeching as the vegetation gets thinner. The available Phosphorus was also seen to decrease along the disturbance gradient, with values ranging between 6.84±0.67 kg ha^{-1} (monsoon season at 10-20cm depth in HD stand) and 31.90±1.21 kg ha^{-1} (post-monsoon season at 0-10cm depth in UD stand). This reduction shows how erosion, slower litter breakdown and less microbial activity slowly strip nutrients from the disturbed soil.

The amount of available Potassium was seen to decrease with increase in disturbance, with values ranging between 39.33±1.75 kg ha^{-1} (monsoon season at 10-20cm depth in HD stand) and 207.41±0.80 kg ha^{-1} (post-monsoon season at 0-10cm depth in UD stand). The amount of SOC had values ranging from 0.92±0.03% (monsoon season at 10-20cm depth in HD stand) to 3.66±0.19% (post-monsoon season at 0-10cm depth in UD stand). These huge drop in potassium and organic carbon indicate how disturbance reduce the soil fertility, making it less able to support healthy forest growth and store carbon effectively.

There was a strong negative correlation between disturbance level and soil moisture content ($r=-0.762$, $p<0.01$), total Nitrogen ($r=-849$, $p<0.01$), available Phosphorus ($r=-0.880$, $p<0.01$), available Potassium ($r=-0.876$, $p<0.01$), and soil organic carbon ($r=-0.839$, $p<0.01$). Conversely, there was a positive correlation between disturbance levels and bulk density ($r=0.644$, $p<0.01$), and soil temperature ($r=0.462$, $p<0.01$). Also, there was positive correlations among nutrient parameters, indicating their interdependence in maintaining soil fertility and ecosystem functioning.

The tree aboveground biomass was highest at 238.64 t ha^{-1} in the UD stand, 145.27 t ha^{-1} in the MD stand, and lowest at 29.93 t ha^{-1} in the HD forest stand. The same pattern was seen in the belowground biomass, where biomass dropped from 126.33 t ha^{-1} in the UD stand to 79.94 t ha^{-1} in the MD stand and 17.55 t ha^{-1} in the HD stand. The total amount of tree biomass dropped from 364.98 t ha^{-1} in the UD stand to 225.21 t ha^{-1} in the MD stand and finally to 47.48 t ha^{-1} in the HD stand. It can clearly be seen that there is a drop of about 87% from UD to HD stand, indicating how disturbance takes away the forests' ability to store carbon and protect against climate change. The carbon stock pattern was like the biomass data where trees stored 182.49 t ha^{-1} in the UD stand, followed by 112.60 t ha^{-1} in the MD stand, and then dropped dramatically to23.74 t ha^{-1} in the HD stand.

The UD stand clearly demonstrated that the 60-90cm girth sized trees stored the most amount of biomass at 111.08 t ha^{-1} and carbon stock at 55.38 t ha^{-1}. In MD and HD stand the 30-60cm girth sized trees stored maximum biomass at 87.63 t ha^{-1} and 31.08 t ha^{-1} respectively, and carbon stock at 43.82 t ha^{-1} and 15.54 t ha^{-1} respectively. This change indicates that the bigger trees which store high amount of carbon are usually the first to be affected by anthropogenic activities.

The species *Ostodes paniculata* was the highest contributor of biomass and carbon stock in the UD forest stand at 30 t ha^{-1} of biomass and 15 t ha^{-1} of carbon, followed by *Quercus floribunda*, *Engelhardia spicata*, *Quercus floribunda* and *Lindera pulcherrima*. These five major species collectively contributed 33.47% of the total carbon in the UD stand. In the MD stand, *Drimycarpus racemosus* stored the maximum biomass at 18.37 t ha^{-1} and carbon at 9.19 t ha^{-1}, followed by *Quercus xylocarpus, Rapanea capitellata, Schima wallichii,* and *Engelhardia spicata.* These five major species collectively contributed 28.16% of the total carbon. In the HD stand, *Schima wallichii* was the highest contributor of biomass at 11.22 t ha^{-1} and carbon at 5.61 t ha^{-1}, followed by *Quercus xylocarpus*, *Wendlandia grandis, Carallia brachiate,* and *Macaranga denticulata*. The five major species collectively contributed 51.24% of the total carbon. This change from late-successional species with high wood density in the UD stand to fast growing pioneer species with lower wood density in the HD stand shows why the amount of carbon stored declined with increase in disturbance.

The biomass in shrubs varied along the disturbance gradient, ranging from 0.072 t ha^{-1} in UD stand to 0.724 t ha^{-1} in MD stand. Similarly, the amount of carbon stored in shrubs ranged from 0.034 t ha^{-1} in UD stand to 0.344 t ha^{-1} in MD stand, indicating that moderately disturbed forests usually have thicker shrub layer.

The biomass in herbaceous vegetation was seen to range between 0.03 t ha^{-1} in UD stand to 0.229 t ha^{-1} in HD stand, and carbon stock ranged from 0.014 t ha^{-1} UD stand to 0.109 t ha^{-1} in HD stand. Herbs were reported to grow best in disturbed area. This is because the lighter, more open canopy in disturbed areas lets more light to pass through and have fewer competitors overhead.

Litter made up an important part of the understorey biomass, ranging between 0.143 t ha^{-1} in HD stand and 2.437 t ha^{-1} in UD stand, and carbon stock was seen to be ranging from 0.070 t ha^{-1} in HD stand to 1.157 t ha^{-1} in UD stand. The closed canopy in the undisturbed regions have high litterfall throughout the year, making a thick layer of biomass in the forest floor, while open canopy can produce warmer microclimates that fasten decomposition process, thereby minimizing litter accumulation.

The Carbon-to-Nitrogen (C:N) ratio was seen to be directly proportional to disturbance, ranging between 10.77 (post-monsoon season at 0-10cm depth in UD stand) and 18.40 (monsoon season at 10-20cm in HD stand). The C:N ratio was the highest in the HD stand, followed by the MD stand and lowest in the UD stand. Also, the value in the subsoil was consistently higher than the topsoil across all stands. The increase in the C:N ratio along the disturbance gradient indicates a decline in soil fertility. The UD stand is more fertile as it consistently receives fresh litter and promotes active nutrient cycling while the HD stand was less fertile due to lower litter input, reduced nitrogen supply, and slow decomposition rate.

In the UD forest stand, most of the carbon was stored in the trees, while in HD stand the soil held more amount of carbon. This was not because the soil absorbed more carbon, but because of loss of vegetation. This indicates how vulnerable the forests carbon pools are when anthropogenic pressure increases. It also highlights the importance of conserving and protecting these forests to store carbon thereby minimizing climate change.

Anthropogenic activities have severe impact on the forest ecosystem by reducing the tree diversity, altering the community structure, and decreasing carbon storage, especially in the highly disturbed stand. With increase of degree of disturbance, there is a sharp change in microclimates, species composition, and the overall function of the ecosystem. The findings of the study highlight the importance of protecting and managing the forest stands that are undisturbed and to restore the damaged forest stands. There is an ample scope of integrated management approach involving governments, local communities, NGOs, and researchers together to conserve and manage the forests in a way that protects the diversity, stores carbon, provides ecological services, and supports local livelihoods.

Appendix-1

Correlation analysis of physico-chemical characteristics of soil along disturbance gradient.

	Disturbance level	Season	Depth (cm)	Temperature (°C)	SMC (%)	BD (g/cm3)	pH	SOC (%)	TN (%)	$P_{avail.}$ (kg/ha)	$K_{avail.}$ (kg/ha)
Disturbance level	1	0	0	.462**	-.762**	.644**	-0.092	-.839**	-.849**	-.880**	-.876**
Season		1	0	-.576**	.350**	.335*	.728**	0.197	0.143	0.192	0.155
Depth (cm)			1	-0.24	-0.07	0.136	.313*	-0.077	-0.156	-0.121	-0.144
Temperature (°C)				1	-.752**	0.017	-.498**	-.309*	-.356**	-.346*	-.304*
SMC (%)					1	-0.252	.300*	.604**	.584**	.555**	.558**
BD (g/cm3)						1	0.032	-.579**	-.681**	-.598**	-.648**
pH							1	.314*	0.238	0.191	0.198
SOC (%)								1	.833**	.884**	.857**
TN (%)									1	.875**	.870**
$P_{avail.}$ (kg/ha)										1	.899**
$K_{avail.}$ (kg/ha)											1

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

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

(Abbreviation: SMC- Soil Moisture Content, BD- Bulk Density, SOC- Soil Organic Carbon, TN- Nitrogen, $P_{avail.}$- Available Phosphorus, $K_{avail.}$- Available Potassium)

Appendix-2

One-way Anova for soil parameters along the disturbance gradient.

		Sum of Squares	df	Mean Square	F	Sig.
Season	Between Groups	0.00	2.00	0.00	0.00	1.000
	Within Groups	36.00	51.00	0.71		
Depth (cm)	Between Groups	0.00	2.00	0.00	0.00	1.000
	Within Groups	13.50	51.00	0.26		
Temperature (°C)	Between Groups	73.30	2.00	36.65	7.01	0.002
	Within Groups	266.69	51.00	5.23		
SMC (%)	Between Groups	2109.31	2.00	1054.65	36.96	0.000
	Within Groups	1455.24	51.00	28.53		
BD (g/cm3)	Between Groups	1.08	2.00	0.54	20.63	0.000
	Within Groups	1.33	51.00	0.03		
pH	Between Groups	0.26	2.00	0.13	1.70	0.193
	Within Groups	3.91	51.00	0.08		
SOC (%)	Between Groups	27.90	2.00	13.95	74.80	0.000
	Within Groups	9.51	51.00	0.19		
Total Nitrogen (%)	Between Groups	0.26	2.00	0.13	69.40	0.000
	Within Groups	0.09	51.00	0.00		
Available Phosphorus (kg/ha)	Between Groups	1953.90	2.00	976.95	93.57	0.000
	Within Groups	532.46	51.00	10.44		
Available Potassium (kg/ha)	Between Groups	131935.60	2.00	65967.80	84.03	0.000
	Within Groups	40035.37	51.00	785.01		

Abbreviation: df=degrees of freedom, F= F-statistic (ratio of between-group variance to within-group variance), Sig.= Significance level (p-value)

Appendix-3

Shrub species diversity in selected forest stands along the disturbance gradient.

Sl. No.	Species	Family	Undisturbed forest	Moderately disturbed forest	Highly disturbed forest
1	*Actephila excelsa* (Dalzell) Müll.Arg.	Phyllanthaceae	+	+	+
2	*Aeschynanthus parviflorus* Fern.-Vill.	Gesneriaceae	+	-	-
4	*Ardisia japonica* (Thunb.) Blume	Primulaceae	-	+	-
5	*Ardisia macrocarpa* Wall.	Primulaceae	+	+	+
6	*Artemisia vulgaris* Burm.f.	Asteraceae	-	-	+
9	*Benkara fasciculata* (Roxb.) Ridsdale	Rubiaceae	-	+	+
10	*Berberis napaulensis* (DC.) Spreng.	Berberidaceae	-	+	+
11	*Blumea lanceolaria* Druce	Asteraceae	-	+	-
12	*Bridelia stipularis* (L.) Blume	Phyllanthaceae	+	+	+
13	*Brugmansia suaveolens* (Willd.) Sweet	Solanaceae	+	+	+
14	*Butea parviflora* Roxb. ex G.Don	Fabaceae	+	+	+
15	*Cajanus cajan* (L.) Millsp.	Fabaceae	-	-	+
16	*Camellia oleifera* C.Abel	Theaceae	-	+	-
17	*Camellia caudata* Wall.	Theaceae	-	+	-
18	*Camellia sinensis* (L.) Kuntze.	Theaceae	-	+	-
19	*Citrus indica* Tanaka	Rutaceae	+	-	-
20	*Clerodendrum infortunatum* L.	Lamiaceae	-	+	+
22	*Colquhounia coccinea* Wall.	Lamiaceae	-	+	+
23	*Croton caudatus* Geiseler	Euphorbiaceae	-	+	+
24	*Dalbergia stipulacea* Roxb.	Fabaceae	-	+	+
25	*Debregeasia longifolia* (Burm.f.) Wedd.	Urticaceae	+	+	-
27	*Dichroa febrifuga* Lour.	Hydrangeaceae	+	+	-

28	*Drepanostachyum falcatum* (Nees) Keng f.	Poaceae	-	+	-
29	*Elaeagnus pyriformis* Hook.f.	Elaeagnaceae	-	+	+
30	*Girardinia diversifolia* (Link) Friis	Urticaceae	-	+	-
31	*Gnetum gnemon* L.	Gnetaceae	-	+	-
32	*Inula cappa* (Buch.-Ham. ex D.Don) DC.	Asteraceae	-	+	+
33	*Lantana camara* L	Verbenaceae	-	+	+
34	*Luculia gratissima* (Wall.) Sweet	Rubiaceae	-	+	+
36	*Meizotropis buteiformis* Voigt	Fabaceae	-	-	+
37	*Mussaenda roxburghii* Hook.f.	Rubiaceae	+	+	+
38	*Mussaenda fandra* Vahl	Rubiaceae	+	+	+
40	*Osbeckia crinita* Benth.	Melastomataceae	-	+	+
42	*Psychotria calocarpa* Kurz	Rubiaceae	+	+	-
43	*Rourea minor* (Gaertn.) Merr.	Connaraceae	+	+	+
44	*Rubus birmanicus* Hook.f.	Rosaceae	-	+	+
45	*Rubus rugosus* Sm.	Rosaceae	-	+	+
46	*Sarcococca pruniformis* Lindl.	Buxaceae	-	-	+
47	*Senna floribunda* (Cav.) H.S.Irwin & Barneby	Fabaceae	-	-	+
49	*Tithonia diversifolia* (Hemsl.) A.Gray	Asteraceae	-	-	+
50	*Toddalia asiatica* (L.) Lam.	Rutaceae	-	+	+
51	*Triumfetta rhomboidea* Jacq.	Malvaceae	-	-	+
52	*Urena lobata* L.	Malvaceae	-	+	+
53	*Zanthoxylum armatum* DC.	Rutaceae	-	+	-

Abbreviation: ✓: Present. -: Absent.

Appendix-4

Herbaceous species diversity in selected forest stands along the disturbance gradient.

Sl. No .	Species	Family	Undisturbed forest	Moderately disturbed forest	Highly disturbed forest
1	*Abelmoschus manihot* (L.) Medik.	Malvaceae	-	-	+
2	*Achyranthes aspera* L.	Amaranthaceae	-	+	+
3	*Acmella paniculata* (Wall. ex DC.) R.K.Jansen	Asteraceae	-	-	+
4	*Adiantum caudatum* Linn	Pteridaceae	+	+	+
5	*Adiantum philippense* L.	Pteridaceae	+	+	+
6	*Aeginetia indica* L.	Orobanchaceae	-	+	+
8	*Ageratum conyzoides* L.	Asteraceae	-	+	+
9	*Aglaomorpha coronans* (Wall.) Copel.	Polypodiaceae	+	+	+
10	*Aglaonema hookerianum* Schott	Araceae	+	-	-
11	*Alocasia fallax* Schott	Araceae	-	+	+
12	*Alternanthera philoxeroides* (Mart.) Griseb.	Amaranthaceae	-	-	+
13	*Alternanthera sessilis* (L.) DC.	Amaranthaceae	-	-	+
14	*Amaranthus spinosus* L.	Amaranthaceae	-	+	+
15	*Amomum dealbatum* Roxb.	Zingiberaceae	-	+	+
16	*Anaphalis adnata* DC.	Asteraceae	-	-	+
17	*Andrographis paniculata* (Burm.f.) Wall. ex Nees	Acanthaceae	-	+	+
18	*Angiopteris evecta* (Forst.) Hoffm.	Marattiaceae	+	-	-
19	*Apluda mutica* L.	Poaceae	-	-	+
20	*Bidens pilosa* L.	Asteraceae	-	+	+
21	*Blumea laciniata* DC.	Asteraceae	-	+	+
22	*Blumeopsis falcata* (D.Don) Merr.	Asteraceae	-	+	-
23	*Brachiaria ruziziensis* R.Germ. & C.M.Evrard	Poaceae	-	-	+

24	*Chlorophytum nepalense* (Lindl.) Baker	Asparagaceae	+	+	+
25	*Cirsium verutum* Spreng.	Asteraceae	-	+	-
26	*Colocasia affinis* Schott	Araceae	-	+	+
27	*Colocasia esculenta* (L.) Schott	Araceae	+	-	-
28	*Conyza leucantha* (D.Don) Ludlow & P.H.Raven	Asteraceae	-	+	-
29	*Crassocephalum crepidioides* S.Moore	Asteraceae	-	-	+
30	*Cyanotis cristata* (L.) D.Don	Commelinaceae	-	-	+
31	*Cyanthillium cinereum* (L.) H.Rob.	Asteraceae	-	-	+
32	*Cynodon dactylon* (L.) Pers.	Poaceae	+	+	+
33	*Cynoglossum zeylanicum* (Sw. ex Lehm.) Thunb. ex Brand	Boraginaceae	-	-	+
34	*Cyperus rotundus* L.	Cyperaceae	-	+	+
35	*Dichrocephala integrifolia* (L.f.) Kuntze	Asteraceae	-	-	+
36	*Dicranopteris linearis* (Burm.f.) Underw.	Gleicheniaceae	+	+	+
37	*Digitaria radicosa* (J.Presl) Miq.	Poaceae	-	+	+
38	*Diplazium esculentum* (Retz.) Sw.	Athyriaceae	+	+	+
39	*Drymaria cordata* Willd. ex Schult.	Caryophyllaceae	-	-	+
40	*Drymaria quercifolia* (L.) J.Sm.	Polypodiaceae	+	+	-
41	*Duchesnea indica* (Andrews) Fock	Rosaceae	-	-	+
42	*Dysphania ambrosioides* (L.) Mosyakin & Clemants	Amaranthaceae	-	-	+
43	*Elatostema sessile* J.R.Forst. & G.Forst.	Urticaceae	+	+	-
44	*Eragrostis nutans* (Retz.) Nees ex Steud.	Poaceae	-	+	+
45	*Euphorbia hirta* L.	Euphorbiaceae	-	-	+
46	*Fagopyrum acutatum* Mansf. ex K.Hammer	Polygonaceae	-	+	+
47	*Galinsoga parviflora* Cav.	Asteraceae	-	-	+

48	*Glinus oppositifolius* Aug.DC.	Molluginaceae	-	+	+
49	*Hedychium villosum* Wall.	Zingiberaceae	+	+	-
50	*Hydrocotyle javanica* Thunb.	Araliaceae	+	+	+
51	*Impatiens drepanophora* Hook.f.	Balsaminaceae	+	-	-
52	*Imperata cylindrica* (L.) Raeusch.	Poaceae	-	-	-
53	*Laggera alata* (DC.) Sch.Bip. ex Oliv.	Asteraceae	-	+	+
54	*Lepidagathis rigida* Dalzell	Acanthaceae	-	+	+
55	*Leucas decemdentata* (Willd.) Sm.	Lamiaceae	-	+	+
56	*Lobelia angulata* G.Forst.	Goodeniaceae	-	-	+
57	*Lycopodium clavatum* L.	Lycopodiaceae	+	+	+
58	*Lygodium flexuosum* Prantl	Lygodiaceae	+	-	-
59	*Medicago sativa* L.	Fabaceae	-	-	+
60	*Merremia vitifolia* Hallier f.	Convolvulaceae	-	+	+
61	*Microlepia strigosa* Prantl	Dennstaedtiaceae	+	+	+
62	*Mirabilis jalapa* L.	Nyctaginaceae	-	+	+
63	*Molineria capitulata* (Lour.) Herb.	Hypoxidaceae	+	+	-
64	*Mollugo pentaphylla* L.	Molluginaceae	-	-	+
65	*Musa acuminata* Colla	Musaceae	-	+	-
66	*Nervilia plicata* (Andrews) Schltr.	Orchidaceae	+	+	-
67	*Neyraudia reynaudiana* (Kunth) Keng ex Hitchc.	Poaceae	-	+	-
68	*Oldenlandia verticillata* L.	Rubiaceae	-	-	+
69	*Onychium siliculosum* (Desv.) C.Chr.	Pteridaceae	-	+	+
70	*Oxalis corniculata* L.	Oxalidaceae	-	-	+
71	*Passiflora edulis* Sims	Passifloraceae	-	-	+
72	*Persicaria glabra* (Willd.) M.Gómez	Polygonaceae	-	+	+
73	*Persicaria hydropiper* Opiz	Polygonaceae	-	+	+

74	*Persicaria nepalensis* (Meisn.) Miyabei	Polygonaceae	-	-	+
75	*Picria fel-terrae* Lour.	Linderniaceae	-	+	-
76	*Plantago major* L.	Plantaginaceae	-	-	+
77	*Pogostemon cablin* (Blanco) Benth.	Lamiaceae	-	-	+
78	*Portulaca oleracea* L.	Portulacaceae	-	-	+
79	*Pothos chinensis* (Raf.) Merr.	Araceae	+	+	-
80	*Pseudognaphalium luteoalbum* (L.) Hilliard & B.L.Burtt	Asteraceae	-	+	+
81	*Pteridium aquilinum* (L.) Kuhn	Dennstaedtiaceae	+	+	+
82	*Pteris vittata* L.	Pteridaceae	+	+	-
83	*Pueraria montana* (Lour.) Merr.	Fabaceae	-	+	+
84	*Saccharum arundinaceum* Retz.	Poaceae	-	+	+
85	*Saccharum longisetosum* (Anderson)	Poaceae	+	+	+
86	*Scutellaria discolor* Colebr.	Lamiaceae	-	-	+
87	*Setaria palmifolia* (J.Koenig) Stapf	Poaceae	+	+	+
88	*Solanum nigrum* Tausch ex Dunal	Solanaceae	-	-	+
89	*Sonchus arvensis* L.	Asteraceae	-	-	+
90	*Sonerila maculata* Roxb.	Melastomataceae	-	+	+
91	*Spermacoce ocymoides* Burm.f.	Rubiaceae	-	-	+
92	*Tagetes patula* L.	Asteraceae	-	-	+
93	*Thalictrum punduanum* Wall.	Ranunculaceae	-	-	+
94	*Themeda villosa* (Poir.) A.Camus	Poaceae	-	+	+
95	*Thysanolaena latifolia* (Roxb. ex Hornem.) Honda	Poaceae	-	+	+
96	*Thysanolaena maxima* Roxb.	Poaceae	-	+	+
97	*Torenia violacea* (Azaola) Pennell	Linderniaceae	-	-	+

Abbreviation: ✓: Present. -: Absent.

PHOTO PLATES

(1)

(2)

Photo plate 1 and 2: Bird eye view of the study site.

(3)

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Photo plate 3, 4, 5, and 6: Glimpses of the Undisturbed forest stand.

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Photo plate 7, 8, 9, and 10: Glimpses of the Moderately disturbed forest stand.

(11)

(12)

(13)

(14)

Photo plate 11, 12, 13, and 14: Glimpses of Highly disturbed forest stand.

(15)

(16)

Photo plate 15 and 16: Field work for tree community characteristics.

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(21)

Photo plate 17, 18, 19, 20, and 21: Glimpses of soil sample laboratory analysis.

REFERENCES

Adhikari, K., and Hartemik, A. E. (2016). Linking soils to ecosystem services- A global review. *Geoderma*, *262*, 101-111.

Alamgir, M., Turton, S. M., Macgregor, C. J., and Pert, P. L. (2016). Assessing regulating and provisioning ecosystem services in a contrasting tropical forest landscape. *Ecological Indicators*, *64*, 319-334.https://doi.org/10.1016/j.ecolind.2016.01.016

Alexander, M. (1978). Introduction to soil microbiology. *Soil Science*, *125*(5), 331.

Allen, S. E., Grimshaw, H. M., Parkinson, J. A., Quarmby, C., and Roberts, J. D. (1974). Chemical Analysis of Ecological Materials. *Blackwell Scientific Publications. Oxford.*

Amankwah, A. A., Quaye-Ballard, J. A., Kouassi, E. K., Porembski, S., Manu, E. A., and Adu-Bredu, S. (2024). Effect of anthropogenic activities on carbon stocks in protected areas within Ghana's forest-Savannah transition zone. *Trees, Forests and People*, *17*, 100641. https://doi.org/10.1016/j.tfp.2024.100641

Anbarashan, M., and Parthasarathy, N. (2012). Tree diversity and forest stand structure along disturbance gradients in Indian tropical dry evergreen forest. Ecotropica, 18(2), 119-136.

Anderson, J. M., and Ingram, J. S. I. (1993). Tropical soil biology and fertility. *A handbook of methods. 2nd ed. CAB Int., Wallingford, UK*.

Ao, A., Changkija, S., and Tripathi, S. K. (2021). Stand structure, community composition and tree species diversity of sub-tropical forest of Nagaland, Northeast India. *Tropical Ecology*, *62*(4), 549-562.

Ao, A., Changkija, S., and Tripathi, S. K. (2024). Patterns of forest community diversity, regeneration potential and carbon storages along an altitudinal gradient in Eastern Himalaya, India. *Environmental and Sustainability Indicators*, *22*, 100399.

Ao, A., Mere, K., and Tripathi, S. K. (2023). Stand structure, regeneration potential and biomass carbon stock of subtropical forest of Mizoram, northeast India. *Indian Journal of Ecology*, *50*(6), 1972-1979. https://doi.org/10.55362/IJE/2023/4162

Arroyo-Rodríguez, V., Fahrig, L., Tabarelli, M., Watling, J. I., Tischendorf, L., Benchimol, M., ... and Tscharntke, T. (2020). Designing optimal human-modified landscapes for forest biodiversity conservation. *Ecology letters*, *23*(9), 1404-1420. https://doi.org/10.1111/ele.13535

Arunachalam, A., and Arunachalam, K. (2000). Influence of gap size and soil properties on microbial biomass in a subtropical humid forest of north-east India. *Plant and soil*, *223*(1), 187-195.

Arunachalam, A., Maithani, K., Pandey, H. N., and Tripathi, R. S. (1996). The impact of disturbance on detrital dynamics and soil microbial biomass of a Pinus kesiya forest in north-east India. *Forest Ecology and Management*, *88*(3), 273-282.

Asner, G. P., Broadbent, E. N., Oliveira, P. J., Keller, M., Knapp, D. E., and Silva, J. N. (2006). Condition and fate of logged forests in the Brazilian Amazon. *Proceedings of the National Academy of Sciences*, *103*(34), 12947-12950.

Baldrian, P. (2017). Forest microbiome: diversity, complexity and dynamics. *FEMS Microbiology reviews*, *41*(2), 109-130. https://doi.org/10.1093/femsre/fuw040

Barbhuyan, H. S. A., Upadhaya, K., Chaudhury, G., and Mir, A. H. (2024). Effect of Disturbance on Micro-environment, Soil Properties and Microbial Biomass in Subtropical Broadleaved Forests of Meghalaya, India. *Anthropocene Science*, *3*(1), 50-62.

Bardgett, R. D., and Van Der Putten, W. H. (2014). Belowground biodiversity and ecosystem functioning. *Nature*, *515*(7528), 505-511.

Basumatary, A., and Bordoloi, P. K. (1992). Forms of potassium in some soils of Assam in relation to soil properties. *Journal of the Indian Society of Soil Science*, *40*(3), 443-446.

Behera, M. C., Sahoo, U. K., Mohanty, T. L., Prus, P., Smuleac, L., and Pascalau, R. (2023). Species composition and diversity of plants along human-induced disturbances in tropical moist Sal forests of Eastern Ghats, India. *Forests*, *14*(10), 1931.

Bellassen, V., and Luyssaert, S. (2014). Carbon sequestration: Managing forests in uncertain times. *Nature*, *506*(7487), 153-155.

Bentsi-Enchill, F., Damptey, F. G., Pappoe, A. N. M., Ekumah, B., and Akotoye, H. K. (2022). Impact of anthropogenic disturbance on tree species diversity, vegetation structure and carbon storage potential in an upland evergreen forest of Ghana, West Africa. *Trees, Forests and People, 8*, 100238.

Bentsi-Enchill, F., Ekumah, B., and Komla Akotoye, H. (2020). Assessment of Anthropogenic Impacts on Carbon Sequestration Potential of a Moist Semi-Deciduous Forest in Eastern Ghana.

Bhat Jahangeer, A., Negi, K. M., Ajeet, K., and Todaria, N. P. (2012). Anthropogenic pressure along altitudinal gradient in a protected area of Garhwal Himalaya, India. *J. Environ. Res. Develop*, *7*(1), 62-65.

Bhattacharyya, T. (2016). Soil diversity in India. *Journal of the Indian Society of Soil Science*, *64*, S41-S52.

Bhuyan, N., and Sharma, S. (2017). Physico-chemical analysis of soil status of various degraded sites in an around Dimoria tribal belt of Assam, India. *International Journal of Science and Research (IJSR)*, *8*(6), 849-852.

Bhuyan, P., Khan, M. L., and Tripathi, R. S. (2003). Tree diversity and population structure in undisturbed and human-impacted stands of tropical wet evergreen forest in Arunachal Pradesh, Eastern Himalayas, India. *Biodiversity and Conservation*, *12*(8), 1753-1773.

Binkley, D., and Fisher, R. F. (2019). *Ecology and management of forest soils*. John Wiley and Sons.

Bitew, G., and Tesfaye, A. (2017). Patterns of woody species diversity along disturbance gradient in Gumdri Abo natural forest, Dangila District, North Western Ethiopia. *J. Nat. Sci. Res*, *9*, 32-46.

Bol, E. T., and Tokuchi, N. (2018). Impact of forest disturbances on soil properties: a case study in Mon State, Myanmar. *Tropics*, *26*(4), 99-109.

Bora, N., Nath, A. J., and Das, A. K. (2013). Aboveground biomass and carbon stocks of tree species in tropical forests of Cachar District, Assam, Northeast India. *International Journal of Ecology and Environmental Sciences*, *39*(2), 97-106.

Borah, M., Das, R. J., Baruah, R., Konwar, P. B., Dutta, S. C., and Boruah, H. D. (2013). Assessment of soil and above ground biomass carbon stock in two forests of Himalayan foot hills of Assam and their carbon sequestration potential. *Climate Change & Himalayan Ecosystem-Indicator, Bio & Water Resources*, 166.

Borah, N., and Garkoti, S. C. (2011). Tree Species composition, diversity, and regeneration patterns in undisturbed and disturbed forests of Barak Valley, South Assam, India. *International Journal of Ecology and Environmental Sciences*, *37*(3), 131-141.

Borah, N., Athokpam, F. D., Das, A. K., and Garkoti, S. C. (2019). Aboveground tree carbon stocks along a disturbance gradient in wet tropical forests of South Assam, India. In *Tropical ecosystems: Structure, functions and challenges in the face of global change* (pp. 111-128). Singapore: Springer Singapore.

Borah, N., Athokpam, F. D., Garkoti, S. C., Das, A. K., and Hore, D. K. (2014). Structural and compositional variations in undisturbed and disturbed tropical forests of Bhuban hills in south Assam, India. *International Journal of Biodiversity Science, Ecosystem Services and Management*, *10*(1), 9-19.

Bot, A., and Benites, J. (2005). *The importance of soil organic matter: Key to drought-resistant soil and sustained food production* (Vol. 80). Food and Agriculture Organization.

Bray, R. H., and Kurtz, L. T. (1945). Determination of total, organic, and available forms of phosphorus in soils. *Soil science*, *59*(1), 39-46.

Brienen, R. J., Phillips, O. L., Feldpausch, T. R., Gloor, E., Baker, T. R., Lloyd, J., ... and Zagt, R. J. (2015). Long-term decline of the Amazon carbon sink. *Nature*, *519*(7543), 344-348. https://doi.org/10.1038/nature14283

Brockerhoff, E. G., Barbaro, L., Castagneyrol, B., Forrester, D. I., Gardiner, B., González-Olabarria, J. R., ... and Jactel, H. (2017). Forest biodiversity, ecosystem functioning and the provision of ecosystem services. *Biodiversity and Conservation*, *26*(13), 3005-3035. https://doi.org/10.1007/s10531-017-1453-2

Brooks, T. M., Mittermeier, R. A., Mittermeier, C. G., Da Fonseca, G. A., Rylands, A. B., Konstant, W. R., ... and Hilton-Taylor, C. (2002). Habitat loss and extinction in the hotspots of biodiversity. *Conservation biology*, *16*(4), 909-923. https://doi.org/10.1046/j.1523-1739.2002.00530.x

Brown, S. A. N. D. R. A., and Lugo, A. E. (1992). Aboveground biomass estimates for tropical moist forests of the Brazilian Amazon. *Interciencia. Caracas*, *17*(1), 8-18.

Brown, S., Gillespie, A. J., and Lugo, A. E. (1989). Biomass estimation methods for tropical forests with applications to forest inventory data. *Forest science*, *35*(4), 881-902. https://doi.org/10.1093/forestscience/35.4.881

Buragohain, M. K., Dar, A. A., Babu, K. N., and Parthasarathy, N. (2023). Tree community structure, carbon stocks and regeneration status of disturbed lowland tropical rain forests of Assam, India. *Trees, Forests and People*, *11*, 100371.

Cairns, M. A., Brown, S., Helmer, E. H., and Baumgardner, G. A. (1997). Root biomass allocation in the world's upland forests. *Oecologia*, *111*(1), 1-11.

Cardelús, C. L., Scull, P., Hair, J., Baimas-George, M., Lowman, M. D., and Wassie Eshete, A. (2013). A preliminary assessment of Ethiopian sacred grove status at the landscape and ecosystem scales. *Diversity*, *5*(2), 320-334.

Cazzolla Gatti, R., Reich, P. B., Gamarra, J. G., Crowther, T., Hui, C., Morera, A., ... and Liang, J. (2022). The number of tree species on Earth. *Proceedings of the National Academy of Sciences*, *119*(6), e2115329119.

Champion, H. G., and Seth, S. K. (1968). *A revised survey of the forest types of India*. Manager of publications.

Chaturvedi, R. K., Raghubanshi, A. S., and Singh, J. S. (2011). Carbon density and accumulation in woody species of tropical dry forest in India. *Forest Ecology and Management*, *262*(8), 1576-1588.

Chaudhury, G., Darji, C. B., Basumatari, M., Dutta, G., Devi, A., and Bharadwaj, N. (2022). Stand structure, biomass and carbon stock along disturbance gradients in differently managed tropical forests of Assam, northeast India. *Trees, Forests and People*, *9*, 100296. https://doi.org/10.1016/j.tfp.2022.100296

Chazdon, R. L. (2017). Landscape restoration, natural regeneration, and the forests of the Future1. *Annals of the Missouri Botanical Garden*, *102*(2), 251-257.

Chhabra, A., Palria, S., and Dadhwal, V. K. (2002). Growing stock-based forest biomass estimate for India. *Biomass and bioenergy*, *22*(3), 187-194.

Clark, D. B., and Clark, D. A. (1996). Abundance, growth and mortality of very large trees in neotropical lowland rain forest. *Forest Ecology and Management*, *80*(1-3), 235-244.

Connell, J. H., and Slatyer, R. O. (1977). Mechanisms of succession in natural communities and their role in community stability and organization. *The american naturalist*, *111*(982), 1119-1144.

Convention on Biological Diversity. (1992). *Convention on Biological Diversity: Text and annexes.* United Nations, Rio de Janeiro. https://www.cbd.int/doc/legal/cbd-en.pdf

Curtis, J. T., and McIntosh, R. P. (1950). The interrelations of certain analytic and synthetic phytosociological characters. *Ecology*, *31*(3), 434-455.

Daddow, R. L. (1983). *Growth-limiting soil bulk densities as influenced by soil texture*. Watershed Systems Development Group, USDA Forest Service.

Daniel, T. C., Muhar, A., Arnberger, A., Aznar, O., Boyd, J. W., Chan, K. M., ... and Von Der Dunk, A. (2012). Contributions of cultural services to the ecosystem services agenda. *Proceedings of the National Academy of Sciences*, *109*(23), 8812-8819. https://doi.org/10.1073/pnas.1114773109

Dar, A. A., and Parthasarathy, N. (2022). Tree species composition, stand structure and distribution patterns across three Kashmir Himalayan forests, India. *Écoscience*, *29*(4), 311-324.

Dar, G. H., and Khuroo, A. A. (2020). An introduction to biodiversity of the Himalaya: Jammu and Kashmir state. In *Biodiversity of the Himalaya: Jammu and Kashmir* *state* (pp. 3-26). Singapore: Springer Singapore. https://doi.org/10.1007/978-981-32-9174-4_1

Dar, J. A., and Sundarapandian, S. (2016). Patterns of plant diversity in seven temperate forest types of Western Himalaya, India. *Journal of Asia-Pacific Biodiversity*, *9*(3), 280-292.

Dar, J. A., and Sundarapandian, S. M. (2013). Soil organic carbon stock assessment in two temperate forest types of Western Himalaya of Jammu and Kashmir. *India. Forest Res*, *3*(114), 2. http://dx.doi.org/10.4172/2168-9776.1000114

Das, G. K. (2021). Soil characteristics in the forest patches of Jungle Mahal in WB, India. *International Research Journal of Environmental Sciences*, *10*(1), 81-85.

Das, S., and Deb, S. (2022). Assessment of Carbon Stock and Carbon Sequestration Potential in three major density-based forest ecosystems of Tripura, North-East India. *International Journal of Ecology and Environmental Sciences*, *48*(2), 229-241.

Datta, A., and Rawat, G. S. (2008). Dispersal modes and spatial patterns of tree species in a tropical forest in Arunachal Pradesh, northeast India. *Tropical Conservation Science*, *1*(3), 163-185.

De Frenne, P., Lenoir, J., Luoto, M., Scheffers, B. R., Zellweger, F., Aalto, J., ... and Hylander, K. (2021). Forest microclimates and climate change: Importance, drivers and future research agenda. *Global change biology*, *27*(11), 2279-2297.

Deb, D. B., and Dutta, R. M. (1987). A contribution to the flora of Mizoram. *Journal of Economic and Taxonomic Botany*, *10*(1), 21-61.

Deb, D., Deb, S., Debbarma, P., and Banik, B. (2020). Impact of disturbance on vegetation, biomass and carbon stock in tropical forests of Tripura, Northeast India. *Vegetos*, *33*(1), 187-193. https://doi.org/10.1007/s42535-019-00093-6

Deb, D., Jamatia, M., Debbarma, J., Ahirwal, J., Deb, S., and Sahoo, U. K. (2021). Evaluating the role of community-managed forest in carbon sequestration and climate change mitigation of Tripura, India. *Water, Air, and Soil Pollution*, *232*(5), 166.

Devi, L. S., and Yadava, P. S. (2006). Floristic diversity assessment and vegetation analysis of tropical semievergreen forest of Manipur, north east India. *Tropical Ecology*, *47*(1), 89-98.

Devi, N. L., Singha, D., and Tripathi, S. K. (2018). Tree species composition and diversity in tropical moist forests of Mizoram, Northeast India. *Indian Journal of Ecology*, *45*(3), 454-461.

Dexter, A. R. (2004). Soil physical quality: Part I. Theory, effects of soil texture, density, and organic matter, and effects on root growth. *Geoderma*, *120*(3-4), 201-214. https://doi.org/10.1016/j.geoderma.2003.09.004

Dupuy, J. M., and Chazdon, R. L. (2006). Effects of vegetation cover on seedling and sapling dynamics in secondary tropical wet forests in Costa Rica. *Journal of Tropical Ecology*, *22*(1), 65-76.

Edwards, D. P., Massam, M. R., Haugaasen, T., and Gilroy, J. J. (2017). Tropical secondary forest regeneration conserves high levels of avian phylogenetic diversity. *Biological Conservation*, *209*, 432-439. https://doi.org/10.1016/j.biocon.2017.03.006

Ellison, D., Morris, C. E., Locatelli, B., Sheil, D., Cohen, J., Murdiyarso, D., ... and Sullivan, C. A. (2017). Trees, forests and water: Cool insights for a hot world. *Global environmental change*, *43*, 51-61.

Eshaghi Rad, J., Valadi, G., and Salehzadeh, O. (2018). Effects of anthropogenic disturbance on plant composition, plant diversity and soil properties in oak forests, Iran. *Journal of Forest Science*, 64(8), 358–370. https://doi.org/10.17221/13/2018-JFS

FAO. (2020). *Global Forest Resources Assessment 2020: Main report*. Food and Agriculture Organization of the United Nations. https://doi.org/10.4060/ca9825en

Forest Survey of India (FSI). (2023). *India State of Forest Report 2023*. Volume I. https://fsi.nic.in/uploads/isfr2023/isfr_book_eng-vol-1_2023.pdf

Frankham, R., Ballou, J.D. and Briscoe, D.A. (2002) Introduction to Conservation Genetics. Cambridge University Press, Cambridge.

Franklin, J. F., Spies, T. A., Van Pelt, R., Carey, A. B., Thornburgh, D. A., Berg, D. R., ... and Chen, J. (2002). Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. *Forest ecology and management*, *155*(1-3), 399-423.

Friedlingstein, P., O'sullivan, M., Jones, M. W., Andrew, R. M., Hauck, J., Olsen, A., ... and Zaehle, S. (2020). Global carbon budget 2020. *Earth System Science Data Discussions*, *2020*, 1-3. https://doi.org/10.5194/essd-12-3269-2020

Gairola, S., Sharma, C. M., Ghildiyal, S. K., and Suyal, S. (2011). Tree species composition and diversity along an altitudinal gradient in moist tropical montane valley slopes of the Garhwal Himalaya, India. *Forest Science and Technology*, *7*(3), 91-102. https://doi.org/10.1080/21580103.2011.597109

Gamfeldt, L., Snäll, T., Bagchi, R., Jonsson, M., Gustafsson, L., Kjellander, P., ... and Bengtsson, J. (2013). Higher levels of multiple ecosystem services are found in forests with more tree species. *Nature communications*, *4*(1), 1340.

García-García, A., Cuesta-Valero, F. J., Miralles, D. G., Mahecha, M. D., Quaas, J., Reichstein, M., ... and Peng, J. (2023). Soil heat extremes can outpace air temperature extremes. *Nature Climate Change*, *13*(11), 1237-1241.

Gautam, T. P., and Mandal, T. N. (2016). Effect of disturbance on biomass, production and carbon dynamics in moist tropical forest of eastern Nepal. *Forest Ecosystems*, *3*(1), 11.

Gebeyehu, G., Soromessa, T., Bekele, T., and Teketay, D. (2019). Carbon stocks and factors affecting their storage in dry Afromontane forests of Awi Zone, northwestern Ethiopia. *Journal of Ecology and Environment*, *43*(1), 7. https://doi.org/10.1186/s41610-019-0105-8

Gibson, L., Lee, T. M., Koh, L. P., Brook, B. W., Gardner, T. A., Barlow, J., ... and Sodhi, N. S. (2011). Primary forests are irreplaceable for sustaining tropical biodiversity. *Nature*, *478*(7369), 378-381.

Giri, N., Rawat, L., and Kumar, P. (2014). Assessment of biomass carbon stock in a Tectona grandis Linn. f. plantation ecosystem of Uttarakhand, India. *International Journal of Engineering, Science and Technology*, *3*(5), 46-53.

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. https://doi.org/10.1016/j.jenvman.2021.113972

Gogoi, A., and Sahoo, U. K. (2018). Impact of anthropogenic disturbance on species diversity and vegetation structure of a lowland tropical rainforest of eastern Himalaya, India. *Journal of Mountain Science*, *15*(11), 2453-2465.

Gogoi, A., and Sahoo, U. K. (2018). Impact of anthropogenic disturbance on species diversity and vegetation structure of a lowland tropical rainforest of eastern Himalaya, India. *Journal of Mountain Science*, *15*(11), 2453-2465. https://doi.org/10.1007/s11629-017-4713-4

Gogoi, A., Sahoo, U. K., and Saikia, H. (2020). Vegetation and ecosystem carbon recovery following shifting cultivation in Mizoram-Manipur-Kachin rainforest eco-region, Southern Asia. *Ecological processes*, *9*(1), 21.

Gogoi, A., Sahoo, U. K., and Singh, S. L. (2017). Assessment of biomass and total carbon stock in a tropical wet evergreen rainforest of Eastern Himalaya along a disturbance gradient. *Journal of Plant Biology & Soil Health, 4*(1), 8.

Gogoi, R. R., Adhikari, D., Upadhaya, K., and Barik, S. K. (2020). Tree diversity and carbon stock in a subtropical broadleaved forest are greater than a subtropical pine forest occurring in similar elevation of Meghalaya, north-eastern India. *Tropical Ecology*, *61*(1), 142-149.

Gopalakrishna, S. P., Kaonga, M. L., Somashekar, R. K., Suresh, H. S., and Suresh, R. (2015). Tree diversity in the tropical dry forest of Bannerghatta National Park in Eastern Ghats, Southern India. *European Journal of Ecology*, *1*(2), 12-27.

Gottardini, E., Cristofolini, F., Cristofori, A., and Ferretti, M. (2023). Forests Attenuate Temperature and Air Pollution Discomfort in Montane Tourist Areas. *Forests*, *14*(3), 545.

Government of Mizoram. (2021). *Statistical handbook of Mizoram 2021*. Directorate of Economics & Statistics, Government of Mizoram. https://des.mizoram.gov.in

Grant, T. A., Madden, E. M., Shaffer, T. L., and Dockens, J. S. (2010). Effects of prescribed fire on vegetation and passerine birds in northern mixed-grass prairie. *The Journal of Wildlife Management*, *74*(8), 1841-1851.

Hanway, J. J. (1952). Soil analysis methods as used in the Iowa state college soil testing laboratory. *Iowa agriculture*, *57*, 1.

Haq, S. M., Calixto, E. S., Rashid, I., Srivastava, G., and Khuroo, A. A. (2022). Tree diversity, distribution and regeneration in major forest types along an extensive elevational gradient in Indian Himalaya: Implications for sustainable forest management. *Forest Ecology and Management*, *506*, 119968. https://doi.org/10.1016/j.foreco.2021.119968

Haq, S. M., Rashid, I., Khuroo, A. A., Malik, Z. A., and Malik, A. H. (2019). Anthropogenic disturbances alter community structure in the forests of Kashmir Himalaya. *Tropical Ecology*, *60*(1), 6-15. https://doi.org/10.1007/s42965-019-00001-8

Haq, S. M., Waheed, M., Khoja, A. A., Amjad, M. S., Bussmann, R. W., Ali, K., and Jones, D. A. (2023). Measuring forest health at stand level: A multi-indicator evaluation for use in adaptive management and policy. *Ecological Indicators*, *150*, 110225. https://doi.org/10.1016/j.ecolind.2023.110225

Hauchhum, R. (2017). Aboveground biomass and carbon stock assessment in forest stands of Gmelinaarborea Roxb. in Mizoram, North-East India.

Hauchhum, R. (2022). Rhizosphere effects of Melocanna baccifera on soil microbial properties under different fallow phases following shifting cultivation. *International Journal of Plant & Soil Science*.

Hauchhum, R., and Singson, M. Z. (2020). Tree species composition and diversity in abandoned Jhum lands of Mizoram, North East India. *Tropical Ecology*, *61*(2), 187-195. https://doi.org/10.1007/s42965-020-00079-5

Houghton, R. A., and Nassikas, A. A. (2017). Global and regional fluxes of carbon from land use and land cover change 1850–2015. *Global Biogeochemical Cycles*, *31*(3), 456-472. https://doi.org/10.1002/2016GB005546

Hrahsel, L., Sahoo, S. S., Singh, S. L., and Sahoo, U. K. (2019). Assessment of plant diversity and carbon stock of a sub-tropical forest stand of Mizoram, India.

Hunter Jr, M. L., and Gibbs, J. P. (2006). *Fundamentals of conservation biology*. John Wiley and Sons.

IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

ISFR. (2021). India State of Forest Report 2021. Dehradun: Forest Survey of India. Government of India.

Jackson, M. L. (1973). Soil chemical analysis, pentice hall of India Pvt. *Ltd., New Delhi, India*, *498*, 151-154.

Jhariya, M. K. (2017). Influences of forest fire on forest floor and litterfall in Bhoramdeo wildlife sanctuary (CG), India.

Joshi, R. K. (2020). Tree species diversity and biomass carbon assessment in undisturbed and disturbed tropical forests of Dibru-Saikhowa biosphere reserve in Assam North-East India. *Vegetos*, *33*(3), 516-537. https://doi.org/10.1007/s42535-020-00135-4

Jucker, T., Bouriaud, O., and Coomes, D. A. (2015). Crown plasticity enables trees to optimize canopy packing in mixed-species forests. *Functional Ecology*, *29*(8), 1078-1086. https://doi.org/10.1111/1365-2435.12428

Kalita, P., and Yumnam, J. Y. (2025). Tree diversity and community characteristics of a tropical moist deciduous forest of Assam, India. *Vegetos*, *38*(2), 660-667. https://doi.org/10.1007/s42535-023-00799-8

Kamimura, V. D. A., de Paula Loiola, P., de Mesquita Neves, D. R., Marcusso, G. M., Sabino, G. P., Assis, M. A., ... and Pinheiro, F. (2025). Unveiling anthropogenic disturbance effects on tropical tree communities: clade-based insights across elevations. *Trees, Forests and People*, 100894.

Kassahun, A. A., Abate, D. F., and Belete, D. A. (2024). The effects of disturbance on woody species composition, structure and regeneration status in the ura natural forest, Guangua district, Awi Zone, Ethiopia. *Heliyon*, *10*(18).

Kaushal, S., and Baishya, R. (2021). Stand structure and species diversity regulate biomass carbon stock under major Central Himalayan forest types of India. *Ecological Processes*, *10*(1), 14. https://doi.org/10.1186/s13717-021-00283-8

Kaushal, S., Siwach, A., and Baishya, R. (2021). Diversity, regeneration, and anthropogenic disturbance in major Indian Central Himalayan forest types: implications for conservation. *Biodiversity and Conservation*, *30*(8), 2451-2480.

Kaushal, S., Siwach, A., and Baishya, R. (2021). Diversity, regeneration, and anthropogenic disturbance in major Indian Central Himalayan forest types: implications for conservation. *Biodiversity and Conservation*, *30*(8), 2451-2480. https://doi.org/10.1007/s10531-021-02203-w

Kenye, A., Sahoo, U. K., Singh, S. L., and Anudip Gogoi, A. G. (2019). Effect of four land uses on soil edaphic properties and soil organic carbon stock in Mizoram, North-East India.

Khadanga, S. S., and Jayakumar, S. (2020). Tree biomass and carbon stock: understanding the role of species richness, elevation, and disturbance. *Tropical Ecology*, *61*(1), 128-141. https://doi.org/10.1007/s42965-020-00070-0

Khan, M. L., Menon, S., and Bawa, K. S. (1997). Effectiveness of the protected area network in biodiversity conservation: a case-study of Meghalaya state. *Biodiversity and conservation*, *6*(6), 853-868.

Köhl, M., Lasco, R., Cifuentes, M., Jonsson, Ö., Korhonen, K. T., Mundhenk, P., ... and Stinson, G. (2015). Changes in forest production, biomass and carbon: Results from the 2015 UN FAO Global Forest Resource Assessment. *Forest Ecology and Management*, *352*, 21-34. https://doi.org/10.1016/j.foreco.2015.05.036

Körner, C. (2017). A matter of tree longevity. *Science*, *355*(6321), 130-131. https://doi.org/10.1126/science.aal2449

Kothandaraman, S., Dar, J. A., Sundarapandian, S., Dayanandan, S., and Khan, M. L. (2020). Ecosystem-level carbon storage and its links to diversity, structural and environmental drivers in tropical forests of Western Ghats, India. *Scientific Reports*, *10*(1), 13444.

Kumar, A., and Ram, J. (2005). Anthropogenic disturbances and plant biodiversity in forests of Uttaranchal, central Himalaya. *Biodiversity and Conservation*, *14*(2), 309-331.

Kumar, A., Kumar, P., Patil, M., Hussain, S., Yadav, R., Sharma, S., ... and Singh, A. N. (2024). Disturbance and vegetational structure in an urban forest of Indian Siwaliks: an ecological assessment. *Environmental Monitoring and Assessment*, *196*(8), 691. https://doi.org/10.1007/s10661-024-12801-0

Kumar, B. M., and Balasubramanian, D. (2024). Carbon stocks of forests and tree plantations along an elevational gradient in the Western Ghats: Does plant diversity impact forest carbon stocks?. *Anthropocene Science*, *3*(1), 63-80. https://doi.org/10.1007/s42965-020-00070-0

Kumar, B. M., Kumar, S. S., and Fisher, R. F. (1998). Intercropping teak with Leucaena increases tree growth and modifies soil characteristics. Agroforestry Systems, 42(1), 81-89.

Kumar, J. N., Kumar, R. N., Bhoi, R. K., and Sajish, P. R. (2010). Tree species diversity and soil nutrient status in three sites of tropical dry deciduous forest of western India. *Tropical Ecology*, *51*(2), 273-279.

Kumar, J., Bhardwaj, D. R., Thakur, C. L., Sharma, P., and Sharma, P. (2024). Soil organic carbon dynamics under different land use systems in dry temperate ecosystem of north-western Himalayas. *Catena*, *240*, 108022.

Kumar, M., and Singh, H. (2020). Agroforestry as a nature-based solution for reducing community dependence on forests to safeguard forests in rainfed areas of India. In *Nature-based solutions for resilient ecosystems and societies* (pp. 289-306). Singapore: Springer Singapore.

Lal, R. (2005). Forest soils and carbon sequestration. *Forest ecology and management*, *220*(1-3), 242-258. https://doi.org/10.1016/j.foreco.2005.08.015

Lalfakwma, Sahoo U. K., Roy S., Vanlalhritpuia K. and Vanlalhluna P. C. (2009). Community composition and tree population structure in undisturbed and disturbed tropical semi-evergreen forest stands of North-East India. *Applied Ecology and Environmental Research*, 7: 303-318

Lalramnghinglova, H. (1997). Handbook of Common Trees of Mizoram. *Lalhluna, Zarkawt, Aizawl, Mizoram*.

Lalramnghinglova, H., and Lalnunmawia, F. (Eds.). (2011). *Forest Resources of Mizoram: Conservation and Management*. Department of Environmental Science, Mizoram University in collaboration with Regional Centre, National Afforestation and Eco-development Board (RCNAEB), North Eastern Hill University.

Lalthakimi, C., Joshi, M., Monsang, N. P., Singh, N. S., Vanlalfakawma, D. C., Upadhyay, K. K., and Tripathi, S. K. (2023). Ecological analysis of climate change on soil characteristics under shifting cultivation practice in tropical moist regions. *Environ Ecol*, *41*(4B), 2701-2712. https://doi.org/10.60151/envec/IHXW4077

Lalthakimi, C., Singh, N. S., Vanlalfakawma, D. C., Upadhyay, K. K., and Tripathi, S. K. (2023). Land use change effects on soil physical and biochemical properties during wet and dry season in forest and shifting cultivation (Jhum) sites in Northeast India. *Environment and Ecology*, *41*(4A), 2584-2594.

Lamare, E., Ao, A., and Tripathi, S. K. (2024). Tree Species Diversity and Carbon Stock of Tropical and Sub-Tropical Forests of Mizoram, Northeast India. *Environment and Ecology*, *42*(4), 1473-1482. https://doi.org/10.60151/envec/IINN9593

Laurance, W. F., Camargo, J. L., Luizão, R. C., Laurance, S. G., Pimm, S. L., Bruna, E. M., ... and Lovejoy, T. E. (2011). The fate of Amazonian forest fragments: a 32-

year investigation. *Biological conservation*, *144*(1), 56-67. https://doi.org/10.1016/j.biocon.2010.09.021

Lü, X. T., Yin, J. X., Jepsen, M. R., and Tang, J. W. (2010). Ecosystem carbon storage and partitioning in a tropical seasonal forest in Southwestern China. *Forest Ecology and Management*, *260*(10), 1798-1803.

Lung, M., and Espira, A. (2015). The influence of stand variables and human use on biomass and carbon stocks of a transitional African forest: Implications for forest carbon projects. *Forest Ecology and Management*, *351*, 36-46. https://doi.org/10.1016/j.foreco.2015.04.032

Luyssaert, S., Schulze, E. D., Börner, A., Knohl, A., Hessenmöller, D., Law, B. E., ... and Grace, J. (2008). Old-growth forests as global carbon sinks. *Nature*, *455*(7210), 213-215.

Ma, T., Li, J., Smith, A., Yan, X., Su, Y., Huo, J., ... and Yu, H. (2025). A dual-pathway framework for mapping forest age in complex mining landscapes by multi-source remote sensing data and tree growth patterns. *GIScience & Remote Sensing*, *62*(1), 2565858.

Madhurima and Mishra, B. P. (2023). Assessment of impact of anthropogenic disturbances on soil characteristics in the sub-tropical forests of Aizawl, Mizoram. *Indian Journal of Science and Technology, 16*(SP1), 158-164.

Magurran, A. E. (2003). *Measuring biological diversity*. John Wiley & Sons.

Malik, Z. A., and Bhatt, A. B. (2016). Regeneration status of tree species and survival of their seedlings in Kedarnath Wildlife Sanctuary and its adjoining areas in Western Himalaya, India. *Tropical Ecology*, *57*(4), 677-690.

Manpoong, C., and Tripathi, S. K. (2019). Soil properties under different land use systems of Mizoram, North East India. *Journal of Applied & Natural Science*, *11*(1).

Manpoong, C., Tripathi, S. K., Aravindakshan, S., and Krupnik, T. J. (2025). Digging in: Impact of land use changes on soil aggregation patterns and carbon stocks in the moist tropics of the Mizoram in the Indomalayan realm. *Total Environment Advances*, *13*, 200119.

Manral, V., Bargali, K., Bargali, S. S., and Shahi, C. (2020). Changes in soil biochemical properties following replacement of Banj oak forest with Chir pine in Central Himalaya, India. *Ecological Processes*, *9*(1), 30. https://doi.org/10.1186/s13717-020-00235-8

Mansingh, A., Pradhan, A., Sahoo, S. R., Cherwa, S. S., Mishra, B. P., Rath, L. P., ... and Panda, B. P. (2025). Tree diversity, population structure, biomass accumulation, and carbon stock dynamics in tropical dry deciduous forests of Eastern India. *BMC Ecology and Evolution*, *25*(1), 48. https://doi.org/10.1186/s12862-025-02385-9

Måren, I. E., and Sharma, L. N. (2021). Seeing the wood for the trees: Carbon storage and conservation in temperate forests of the Himalayas. *Forest Ecology and Management*, *487*, 119010. https://doi.org/10.1016/j.foreco.2021.119010

Margalef, R. (1958). Information theory in ecology. *General Systematics,* 3, 533-536.

Martin, P. A., Newton, A. C., and Bullock, J. M. (2013). Carbon pools recover more quickly than plant biodiversity in tropical secondary forests. *Proceedings of the Royal Society B: Biological Sciences*, *280*(1773), 20132236. https://doi.org/10.1098/rspb.2013.2236

Mehta, J. P., and Shreshthamani, B. (2014). Analysis of the physic-chemical properties of the soil and climatic attribute on vegetation in Central Himalaya. *Nature and Science*, *12*(11), 46-54.

Mehta, P., Baweja, P. K., and Aggarwal, R. K. (2017). Impact of Micro-climatic variations on forest ecosystem in Mid Hills of Himachal Pradesh. *Current World Environment*, *12*(1), 97.

Mehta, V. K., Sullivan, P. J., Walter, M. T., Krishnaswamy, J., and DeGloria, S. D. (2008). Impacts of disturbance on soil properties in a dry tropical forest in Southern India. *Ecohydrology: Ecosystems, Land and Water Process Interactions, Ecohydrogeomorphology*, *1*(2), 161-175.

Mir, A. H., Chaudhury, G., Barbhuyan, H. S. A., Sarma, K., and Upadhaya, K. (2021). Impact of disturbance on community structure, biomass and carbon stock in montane evergreen forests of Meghalaya, northeast India. *Carbon Management*, *12*(2), 215-233. https://doi.org/10.1080/17583004.2021.1899752

Mishra, B. P. (2011). Vegetation composition and soil nutrients status from polyculture to monoculture. *African Journal of Environmental Science and Technology*, *5*(5), 363-366.

Mishra, B. P. (2012). Effect of anthropogenic activities on micro-environment and soil characteristics along disturbance gradient in the sub-tropical forest of Mizoram, North East India. *Indian Journal of Plant Sciences*, 1(2-3). 208-212.

Mishra, B. P., and Jeeva, S. (2012). Plant diversity and community attributes of woody plants in two climax subtropical humid forests of Meghalaya, Northeast India. *Applied Ecology and Environmental Research*, *10*(4), 417-436.

Mishra, B. P., and Laloo, R. C. (2006). A comparative analysis of vegetation and soil characteristics of montane broad-leaved, mixed pine and pine forests of northeast India. *Advances in Plant Physiology. IK International Publishing House, New Delhi*, 185-197.

Mishra, B. P., Tripathi, O. P., and Laloo, R. C. (2005). Community characteristics of a climax subtropical humid forest of Meghalaya and population structure of ten important tree species. *Tropical Ecology*, *46*(2), 241-252.

Mishra, B. P., Tripathi, O. P., Tripathi, R. S., and Pandey, H. N. (2004). Effects of anthropogenic disturbance on plant diversity and community structure of a sacred grove in Meghalaya, northeast India. *Biodiversity & Conservation*, *13*(2), 421-436.

Misra, R. (1968). Ecology Work Book Oxford and IBH Publishing Company. *New Delhi*, *426*, 427.

Monsang, N. P., Singh, N. S., Upadhyay, K. K., and Tripathi, S. K. (2023). Changes in soil physico-chemical properties in different land use systems of Manipur, Northeast India. *Indian Journal of Ecology*, *50*(4), 918-925.

Muhati, G. L., Olago, D., and Olaka, L. (2018). Land use and land cover changes in a sub-humid Montane forest in an arid setting: A case study of the Marsabit forest reserve in northern Kenya. *Global Ecology and Conservation*, *16*, e00512. https://doi.org/10.1016/j.gecco.2018.e00512

Mukul, S. A., Herbohn, J., and Firn, J. (2016). Tropical secondary forests regenerating after shifting cultivation in the Philippines uplands are important carbon sinks. *Scientific Reports*, *6*(1), 22483. https://doi.org/10.1038/srep22483

Myers, N. (1988). Threatened biotas:" hot spots" in tropical forests. *Environmentalist*, *8*(3), 187-208. https://doi.org/10.1007/BF02240252

Myers, N., Mittermeier, R. A., Mittermeier, C. G., Da Fonseca, G. A., and Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature*, *403*(6772), 853-858. https://doi.org/10.1038/35002501

Nang B.D. (2016). Impacts of Anthropogenic activities on physical and selected chemical properties of soils in the natural forest-savanna of Northern Ganna*. Journal of Soil Science and Environmental Management*, 7(5), 55-63.

Nath, A. J., Tiwari, B. K., Sileshi, G. W., Sahoo, U. K., Brahma, B., Deb, S., ... and Gupta, A. (2019). Allometric models for estimation of forest biomass in North East India. *Forests*, *10*(2), 103. https://doi.org/10.3390/f10020103

Naudiyal, N., and Schmerbeck, J. (2018). Impacts of anthropogenic disturbances on forest succession in the mid-montane forests of Central Himalaya. *Plant Ecology*, *219*(2), 169-183.

Nautiyal, D. C., and Manish, K. (2024). Anthropogenic disturbance produces divergent effects in the community structure and composition of tropical semi-evergreen forests in the Eastern Himalaya. *BioRisk*, *22*, 1-15. https://doi.org/10.3897/biorisk.22.120802

Neina, D. (2019). The role of soil pH in plant nutrition and soil remediation. *Applied and environmental soil science*, *2019*(1), 5794869.

Nemhoihkim, E., Enmuanliana, T. N. L., Basumatary, L. S., and Mishra, B. P. (2025). Effects of Anthropogenic Disturbance on Soil Characteristics in a Forest of Aizawl District, Mizoram. *Indian Journal of Science and Technology*, *18*(21), 1696-1702.

Ngaihte, L. K., Nemhoihkim, E., Tripathi, O. P., and Mishra, B. P. (2024). Impact of Altitude on Soil Quality in Current Jhum Fields of Churachandpur, Manipur, India. *Ecology, Environment & Conservation (0971765X)*, *30*.

Niirou, N., Gupta, A., and Singh, T. B. (2015). Soil organic carbon stock in natural and human impacted ecosystems of Senapati District, Manipur. *International Journal of Science and Research*, *6*(7), 1279-1285.

NITI Aayog. (2025). *A Macro and Fiscal Landscape of the State of Mizoram.* Government of India. https://www.niti.gov.in/sites/default/files/2025-07/Macro-and-Fiscal-Landscape-of-the-State-of-Mizoram-1.pdf

Noble, I. R., and Dirzo, R. (1997). Forests as human-dominated ecosystems. *Science*, *277*(5325), 522-525.

Noss, R. F. (1990). Indicators for monitoring biodiversity: a hierarchical approach. *Conservation biology*, *4*(4), 355-364. https://doi.org/10.1111/j.1523-1739.1990.tb00309.x

O'Connor, T. G. (2005). Influence of land use on plant community composition and diversity in Highland Sourveld grassland in the southern Drakensberg, South Africa. *Journal of Applied Ecology, 42*(5), 975–988. https://doi.org/10.1111/j.1365-2664.2005.01065.x

Opeyemi, A. O., Adewunmi, B. I., and Oluwaseyi, A. I. (2020). Physical and Chemical Properties of Soils in Gambari Forest Reserve Near Ibadan, South Western Nigeria. *Journal of Bioresource Management*, *7*(2), 7.

Osman, K. T. (2012). *Soils: principles, properties and management*. Springer Science & Business Media.

Osuri, A. M., Kasinathan, S., Siddhartha, M. K., Mudappa, D., and Raman, T. S. (2019). Effects of restoration on tree communities and carbon storage in rainforest fragments of the Western Ghats, India. *Ecosphere*, *10*(9), e02860.

Ovung, E. Y., and Tripathi, S. K. (2021). Assessment of tree diversity in tropical moist deciduous forest of Mizoram University, Northeast India. *Journal of Applied & Natural Science*, *13*(1).

Ovung, E. Y., Tripathi, S. K., and Brearley, F. Q. (2021). Changes in soil exchangeable nutrients across different land uses in steep slopes of Mizoram, North-east India. *Journal of Applied and Natural Science*, *13*(3), 929-936.

Pan, Y., Birdsey, R. A., Fang, J., Houghton, R., Kauppi, P. E., Kurz, W. A., ... and Hayes, D. (2011). A large and persistent carbon sink in the world's forests. *Science*, *333*(6045), 988-993. https://doi.org/10.1126/science.1201609

Pan, Y., Birdsey, R. A., Phillips, O. L., and Jackson, R. B. (2013). The structure, distribution, and biomass of the world's forests. *Annual Review of Ecology, Evolution, and Systematics*, *44*(1), 593-622. https://doi.org/10.1146/annurev-ecolsys-110512-135914

Pandey, H. P. (2021). Implications of anthropogenic disturbances for species diversity, recruitment and carbon density in the mid-hills forests of Nepal. *Journal of Resources and Ecology*, *12*(1), 1-10. https://doi.org/10.5814/j.issn.1674-764x.2021.01.001

Pandey, S. K., and Shukla, R. P. (1999). Plant diversity and community patterns along the disturbance gradient in plantation forests of sal (Shorea robusta Gaertn.). *Current Science*, 814-818.

Parthasarathy, N., and Karthikeyan, R. (1997). Plant biodiversity inventory and conservation of two tropical dry evergreen forests on the Coromandel coast, south India. *Biodiversity & Conservation*, *6*(8), 1063-1083.

Pawar, G. V., Singh, L., Jhariya, M. K., and Sahu, K. P. (2014). Effect of anthropogenic disturbances on biomass and carbon storage potential of a dry tropical forest in India. *Journal of Applied and Natural Science*, *6*(2), 383.

Pearson, T., Walker, S., and Brown, S. (2005). *Sourcebook for land use, land-use change and forestry projects*. Winrock International and the BioCarbon.

Pelletier, J., Ramankutty, N., and Potvin, C. (2011). Diagnosing the uncertainty and detectability of emission reductions forREDD+ under current capabilities: an example for Panama. *Environmental Research Letters*, *6*(2), 024005.

Phillips, E.A. 1959. Methods of Vegetation Study. Henry Holt and Co., New York.

Pickett, S. T., Pickett, S. T., and White, P. S. (Eds.). (1985). *The ecology of natural disturbance and patch dynamics*. Academic press.

Pielou, E. C. (1969). *An introduction to mathematical ecology*.Wiley, New York.

Poorter, L., Craven, D., Jakovac, C. C., Van Der Sande, M. T., Amissah, L., Bongers, F., ... and Hérault, B. (2021). Multidimensional tropical forest recovery. *Science*, *374*(6573), 1370-1376.

Poorter, L., van der Sande, M. T., Thompson, J., Arets, E. J., Alarcón, A., Álvarez-Sánchez, J., ... and Peña-Claros, M. (2015). Diversity enhances carbon storage in tropical forests. *Global Ecology and Biogeography*, *24*(11), 1314-1328. https://doi.org/10.1111/geb.12364

Putz, F. E., Dykstra, D. P., and Heinrich, R. (2000). Why poor logging practices persist in the tropics. *Conservation Biology*, *14*(4), 951-956. https://doi.org/10.1046/j.1523-1739.2000.99137.x

Putz, F. E., Zuidema, P. A., Synnott, T., Peña-Claros, M., Pinard, M. A., Sheil, D., ... and Zagt, R. (2012). Sustaining conservation values in selectively logged tropical forests: the attained and the attainable. *Conservation letters*, *5*(4), 296-303. https://doi.org/10.1111/j.1755-263X.2012.00242.x

Rabha, D., Borah, N., and Das, A. K. (2014). Assessment of aboveground and soil organic carbon stocks in Dipterocarpus forests of Barak Valley, Assam, Northeast India. *International Journal of Ecology and Environmental Sciences*, *40*(1), 29-40.

Ramachandran, A., Jayakumar, S., Haroon, R. M., Bhaskaran, A., and Arockiasamy, D. I. (2007). Carbon sequestration: estimation of carbon stock in natural forests using geospatial technology in the Eastern Ghats of Tamil Nadu, India. *Current science*, 323-331.

Ramankutty, N., Gibbs, H. K., Achard, F., Defries, R., Foley, J. A., and Houghton, R. A. (2007). Challenges to estimating carbon emissions from tropical deforestation. *Global change biology*, *13*(1), 51-66.

Rao, P., Barik, S. K., Pandey, H. N., and Tripathi, R. S. (1990). Community composition and tree population structure in a sub-tropical broad-leaved forest along a disturbance gradient. *Vegetatio*, *88*(2), 151-162.

Rao, R. S., and Panigrahi, G. (1961). Distribution of vegetation types and their dominant species in Eastern India.

Rashid, I., Bhat, M. A., and Romshoo, S. A. (2017). Assessing changes in the above ground biomass and carbon stocks of Lidder valley, Kashmir Himalaya, India. *Geocarto international*, *32*(7), 717-734. https://doi.org/10.1080/10106049.2016.1188164

Rasingam, L., and Parathasarathy, N. (2009). Tree species diversity and population structure across major forest formations and disturbance categories in Little Andaman Island, India. *Tropical Ecology*, *50*(1), 89.

Rawat, D. S., Tiwari, P., Das, S. K., and Tiwari, J. K. (2020). Tree species composition and diversity in montane forests of Garhwal Himalaya in relation to environmental and soil properties. *Journal of Mountain Science*, *17*(12), 3097-3111.

Russell, M. B., Fraver, S., Aakala, T., Gove, J. H., Woodall, C. W., D'Amato, A. W., and Ducey, M. J. (2015). Quantifying carbon stores and decomposition in dead wood: A review. *Forest Ecology and Management*, *350*, 107-128. https://doi.org/10.1016/j.foreco.2015.04.033

Saatchi, S. S., Harris, N. L., Brown, S., Lefsky, M., Mitchard, E. T., Salas, W., ... and Morel, A. (2011). Benchmark map of forest carbon stocks in tropical regions across three continents. *Proceedings of the national academy of sciences*, *108*(24), 9899-9904. https://doi.org/10.1073/pnas.1019576108

Sagar, R., and Devy, M. S. (2022). The Impact of Anthropogenic Disturbance to the Canopy Microclimate of Tropical Forests in the Southern Western Ghats, India. *Frontiers in Forests and Global Change*, *5*, 734448.

Sagar, R., Raghubanshi, A. S., and Singh, J. S. (2003). Tree species composition, dispersion and diversity along a disturbance gradient in a dry tropical forest region of India. *Forest ecology and Management*, *186*(1-3), 61-71.

Saha, S., Rajwar, G. S., and Kumar, M. (2016). Forest structure, diversity and regeneration potential along altitudinal gradient in Dhanaulti of Garhwal Himalaya. *Forest systems*, *25*(2), e058-e058.

Sahoo, T., Acharya, L., and Panda, P. C. (2020). Plant diversity along disturbance gradients in tropical moist deciduous forests of eastern ghats of India. *Plant Archives (09725210)*, *20*(2).

Sahoo, U. K., and Lalfakawma, L. (2010). Population dynamics of Schima wallichii in an undisturbed vs a disturbed tropical forest stand of North-East India.

Sahu, S. C., Dhal, N. K., Lal, B., and Mohanty, R. C. (2012). Differences in tree species diversity and soil nutrient status in a tropical sacred forest ecosystem on Niyamgiri hill range, Eastern Ghats, India. *Journal of Mountain Science*, *9*(4), 492-500.

Saikia, P., Deka, J., Bharali, S., Kumar, A., Tripathi, O. P., Singha, L. B., ... and Khan, M. L. (2017). Plant diversity patterns and conservation status of eastern Himalayan forests in Arunachal Pradesh, Northeast India. *Forest Ecosystems*, *4*(1), 28.

Saimun, M. S. R., Karim, M. R., Sultana, F., and Arfin-Khan, M. A. (2021). Multiple drivers of tree and soil carbon stock in the tropical forest ecosystems of Bangladesh. *Trees, Forests and People*, *5*, 100108.

Sajad, S., Haq, S. M., Yaqoob, U., Calixto, E. S., and Hassan, M. (2021). Tree composition and standing biomass in forests of the northern part of Kashmir Himalaya. *Vegetos*, *34*(4), 857-866.

Sandra, P. R., Shankar, A., Garkoti, S. C., and Adarsh, C. K. (2025). Understanding the effects of forest types, vegetation structural diversity, and soil properties on above- and below-ground carbon stock of moist deciduous forest ecosystems in Western Ghats, India. *Catena*, *257*, 109198. https://doi.org/10.1016/j.catena.2025.109198

Sarkar, M., and Devi, A. (2014). Assessment of diversity, population structure and regeneration status of tree species in Hollongapar Gibbon Wildlife Sanctuary, Assam, Northeast India. *Tropical plant research*, *1*(2), 26-36.

Sathish, B. N., Viswanath, S., Kushalappa, C. G., Jagadish, M. R., and Ganeshaiah, K. N. (2013). Comparative assessment of floristic structure, diversity and regeneration status of tropical rain forests of Western Ghats of Karnataka, India. *Journal of Applied and Natural Science*, *5*(1), 157.

Sawmliana, M. (2003). The book of Mizoram plants. *Zakhuma P, Aizawl, Mizoram*.

Shah, S. A. A., Xu, M., Abrar, M. M., Mustafa, A., Fahad, S., Shah, T., ... and Shi, W. (2021). Long-term fertilization affects functional soil organic carbon protection mechanisms in a profile of Chinese loess plateau soil. *Chemosphere*, *267*, 128897.

Shaheen, H., Khan, S. M., Harper, D. M., Ullah, Z., and Qureshi, R. A. (2011). Species diversity, community structure, and distribution patterns in western Himalayan alpine pastures of Kashmir, Pakistan. *Mountain Research and Development*, *31*(2), 153-159.

Shaheen, H., Malik, N. M., and Dar, M. E. U. I. (2015). Species composition and community structure of subtropical forest stands in western Himalayan foothills of Kashmir. *Pakistan Journal of Botany*, *47*(6), 2151-2160.

Shaikh Parveen, R., and Bhosle Arjun, B. (2013). Heavy metal contamination in soils near Siddheshwar Dam Maharashtra, India. *Research Journal of Chemical Sciences. ISSN, 2231, 606X.*

Shankar, A., Kashyap, K., and Garkoti, S. C. (2025). Influence of vegetation and soil properties on carbon stocks in Shorea robusta forests under different disturbance regimes. *Journal of Environmental Management*, *380*, 124916.

Shannon's C.E. and Weiner, W.1963. *The mathematical theory of communication*. University of Illinois Press, Urbana.

Sharma, A., Patel, S. K., and Singh, G. S. (2023). Variation in species composition, structural diversity, and regeneration along disturbances in tropical dry forest of Northern India. *Journal of Asia-Pacific Biodiversity*, *16*(1), 83-95. https://doi.org/10.1016/j.japb.2022.11.004

Sharma, C. M., Baduni, N. P., Gairola, S., Ghildiyal, S. K., and Suyal, S. (2010). Tree diversity and carbon stocks of some major forest types of Garhwal Himalaya, India. *Forest Ecology and Management*, *260*(12), 2170-2179. https://doi.org/10.1016/j.foreco.2010.09.014

Sharma, S. B., Singh, N. S., and Lalruatfela, R. (2018). Tree diversity and carbon stocks of Hmuifang forest, Mizoram. *International Journal of Research in BioSciences*, *7*(1), 87-99.

Sharma, S., Arunachalam, K., and Arunachalam, A. (2017). Soil characteristics in the disturbed and undisturbed plots of a Sal (Shorea robusta) forest in the Shiwaliks of Indian Himalayan Region. *Indian Journal of Hill Farming*, *30*(2).

Silva Pedro, M., Rammer, W., and Seidl, R. (2015). Tree species diversity mitigates disturbance impacts on the forest carbon cycle. *Oecologia*, *177*(3), 619-630. https://doi.org/10.1007/s00442-014-3150-0

Simpson, E.H. (1949). Measurement of diversity. *Nature*, 163: 188.

Singh, J. S., Singh, S. P., Saxena, A. K., and Rawat, Y. S. (1984). The forest vegetation of Silent Valley, India.

Singh, N. P., Singh, K. P., and Singh, D. K. (2002). *Flora of mizoram* (Vol. 1). Botanical Survey of India, Ministry of Environment and Forests.

Singh, N. S., Ovung, E. Y., and Tripathi, S. K. (2020). Changes in soil biochemical properties along different land uses of Mizoram, Northeast India.

Singh, P., and Negi, G. C. S. (2023). Microclimate variability under forest canopies along an altitudinal gradient in Western Himalaya. *Environ. Anal. Ecol. Stud*, *11*, 000765.

Singh, S. (2021). Low-to moderate-level forest disturbance effects on plant functional traits and associated soil microbial diversity in Western Himalaya. *Frontiers in Forests and Global Change*, *4*, 710658.

Singh, S. B., Mishra, B. P., and Tripathi, S. K. (2015). Recovery of plant diversity and soil nutrients during stand development in subtropical forests of Mizoram, Northeast India. *Biodiversitas Journal of Biological Diversity*, *16*(2). https://doi.org/10.13057/biodiv/d160216

Singh, S. L., and Sahoo, U. K. (2018). Assessment of biomass, carbon stock and carbon sequestration potential of two major land uses of Mizoram, India. *International Journal of Ecology and Environmental Sciences*, *44*(3), 293-306.

Sorensen, T. (1948). A method of establishing groups of equal amplitude in plant sociology based on similarity of species content and its application to analyses of the vegetation on Danish commons. *Biologiske skrifter*, *5*, 1-34.

Sovann, C., Tagesson, T., Vestin, P., Sakhoeun, S., Kim, S., Kok, S., and Olin, S. (2025). Land-cover change alters stand structure, species diversity, leaf functional traits, and soil conditions in Cambodian tropical forests. *Biogeosciences*, *22*(18), 4649-4677. https://doi.org/10.5194/bg-22-4649-2025

Spies, T. A. (1998). *Forest structure: A key to the ecosystem.* Northwest Science, 72(Special Issue), 34-39.

Sturtevant, B. R., and Fortin, M. J. (2021). Understanding and modeling forest disturbance interactions at the landscape level. *Frontiers in Ecology and Evolution*, *9*, 653647. https://doi.org/10.3389/fevo.2021.653647

Suchiang, B. R., Nonghuloo, I. M., Kharbhih, S., Singh, P. P., Tiwary, R., Adhikari, D., ... and Barik, S. K. (2020). Tree diversity and community composition in sacred forests are superior than the other community forests in a human-dominated landscape of Meghalaya. *Tropical Ecology*, *61*(1), 84-105.

Suddick, E. C., Whitney, P., Townsend, A. R., and Davidson, E. A. (2013). The role of nitrogen in climate change and the impacts of nitrogen–climate interactions in the United States: foreword to thematic issue. *Biogeochemistry*, *114*(1), 1-10.

Sun, L., and Guan, D. S. (2014). Carbon stock of the ecosystem of lower subtropical broadleaved evergreen forests of different ages in pearl river delta, China. *Journal of Tropical Forest Science*, 249-258.

Sunar, S., Lalramnghinglova, H., and Mishra, B. P. (2017). Consistent status of soil along disturbance gradient in the sub-tropical forest of Aizawl**,** Mizoram, India. *International Research Journal of Earth Sciences, 5*(4), 1–7.

Suthari, S. (2013). Biodiversity characterization and aboveground vegetation carbon pool assessment in northern Telangana at landscape level using geospatial technique. *Department of Botany, Kakatiya University, Warangal*.

Swamy, P. S., Sundarapandian, S. M., Chandrasekar, P., and Chandrasekaran, S. (2000). Plant species diversity and tree population structure of a humid tropical forest in Tamil Nadu, India. *Biodiversity & Conservation*, *9*(12), 1643-1669.

Swart, R. C., Pryke, J. S., and Roets, F. (2019). The intermediate disturbance hypothesis explains arthropod beta-diversity responses to roads that cut through natural forests. *Biological Conservation*, *236*, 243-251.

Tang, C. Q., Han, P. B., Li, S., Shen, L. Q., Huang, D. S., Li, Y. F., ... and Zhang, Z. Y. (2020). Species richness, forest types and regeneration of Schima in the subtropical forest ecosystem of Yunnan, southwestern China. *Forest Ecosystems*, *7*(1), 35.

Tenzin, J., and Hasenauer, H. (2016). Tree species composition and diversity in relation to anthropogenic disturbances in broad-leaved forests of Bhutan. *International Journal of Biodiversity Science, Ecosystem Services & Management*, *12*(4), 274-290.

Thakrey, M., Singh, L., Jhariya, M. K., Tomar, A., Singh, A. K., and Toppo, S. (2022). Impact of disturbance on biomass, carbon, and nitrogen storage in vegetation and on soil properties of tropical dry deciduous forest in Chhattisgarh, India. *Land Degradation & Development*, *33*(11), 1810-1820. https://doi.org/10.1002/ldr.4263

Thakrey, M., Singh, L., Singh, R., Toppo, S., and Singh, J. S. (2024). Effect of anthropogenic disturbance on biomass allocation to different above-and below-ground vegetation components of a dry tropical forest in India. *Proceedings of the Indian National Science Academy*, *90*(3), 776-785.

Thakur, A. K., Kumar, R., and Verma, R. K. (2020). Abundance, frequency and distribution pattern of tree species in recorded forest area of Western Himalaya. *Notulae Scientia Biologicae*, *12*(2), 341-355.

Thokchom, A., and Yadava, P. S. (2017). Biomass and carbon stock along an altitudinal gradient in the forest of Manipur, Northeast India.

Thom, D., and Seidl, R. (2016). Natural disturbance impacts on ecosystem services and biodiversity in temperate and boreal forests. *Biological Reviews*, *91*(3), 760-781.

Tiwari, A., Khanduri, V. P., Rawat, D., Singh, B., Riyal, M. K., Mishra, G., and Kumar, M. (2023). Vegetation composition, soil properties, and carbon stock of montane forests along a disturbance in the Garhwal Himalaya, India. *Frontiers in Forests and Global Change*, *6*, 1193792.

Tiwari, S. C., Tiwari, B. K., and Mishra, R. R. (1992). Variation in Some Physicochemical Characteristics of Pineapple Orchard Soils of North-Eastern India. *Journal of the Indian Society of Soil Science*, *40*(1), 204-208.

Toledo-Aceves, T., and Toledo-Garibaldi, M. (2025). Tree species diversity increases carbon stocks in tropical montane cloud forests across successional stages. *Forest Ecology and Management*, *578*, 122480.

Tynsong, H., Dkhar, M., and Tiwari, B. K. (2022). Tree diversity and vegetation structure of the tropical evergreen forests of the southern slopes of Meghalaya, North East India. *Asian Journal of Forestry*, *6*(1), 22-36.

Uniyal, P., Pokhriyal, P., Dasgupta, S., Bhatt, D., and Todaria, N. P. (2010). Plant diversity in two forest types along the disturbance gradient in Dewalgarh Watershed, Garhwal Himalaya. *Current Science*, 938-943.

Upadhaya, K., Barik, S. K., Pandey, H. N., and Tripathi, O. P. (2008). Response of woody species to anthropogenic disturbances in sacred forests of northeast India. *International Journal of Ecology and Environmental Sciences*, *34*(1), 00-00.

Velho, N., and Krishnadas, M. (2011). Post-logging recovery of animal-dispersed trees in a tropical forest site in north-east India. *Tropical Conservation Science*, *4*(4), 405-419.

Vieira, S., Trumbore, S., Camargo, P. B., Selhorst, D., Chambers, J. Q., Higuchi, N., and Martinelli, L. A. (2005). Slow growth rates of Amazonian trees: consequences for carbon cycling. *Proceedings of the National Academy of Sciences*, *102*(51), 18502-18507. https://doi.org/10.1073/pnas.0505966102

Waikhom, A. C., Nath, A. J., and Yadava, P. S. (2018). Aboveground biomass and carbon stock in the largest sacred grove of Manipur, Northeast India. *Journal of Forestry Research*, *29*(2), 425-428. https://doi.org/10.1007/s11676-017-0439-y

Walkley, A., and Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil science*, *37*(1), 29-38.

Wani, A. A., Joshi, P. K., and Singh, O. (2015). Estimating biomass and carbon mitigation of temperate coniferous forests using spectral modeling and field inventory data. *Ecological informatics*, *25*, 63-70. https://doi.org/10.1016/j.ecoinf.2014.12.003

Wannasingha, W., Gomontean, B., and Uttaruk, Y. (2023). Forest structures and carbon stocks of community forests with different forest management in Maha Sarakham Province, Thailand. *Biodiversitas Journal of Biological Diversity*, *24*(2). https://doi.org/10.13057/biodiv/d240216

Wapongnungsang, H. R., and Tripathi, S. K. (2017). Litter decomposition Vis-a-Vis carbon and nitrogen dynamics of Tephrosia candida components in different fallow periods following shifting cultivation in Mizoram. *Indian Journal of Ecology*, *44*(4), 791-796.

Watson, R. T., Noble, I. R., Bolin, B., Ravindranath, N., Dokken, D. J., and Verardo, D. J. (2000). IPCC: Land Use, Land-Use Change and Forestry.

Whitford, P. B. (1949). Distribution of woodland plants in relation to succession and clonal growth. *Ecology*, *30*(2), 199-208.

Woodall, C. W., Russell, M. B., Walters, B. F., D'Amato, A. W., Fraver, S., and Domke, G. M. (2015). Net carbon flux of dead wood in forests of the Eastern US. *Oecologia*, *177*(3), 861-874. https://doi.org/10.1007/s00442-014-3171-8

Xu, W., Xiao, Y., Zhang, J., Yang, W. U., Zhang, L. U., Hull, V., ... and Ouyang, Z. (2017). Strengthening protected areas for biodiversity and ecosystem services in China. *Proceedings of the National Academy of Sciences*, *114*(7), 1601-1606. https://doi.org/10.1073/pnas.1620503114

Yohannes, H., Soromessa, T., and Argaw, M. (2015). Carbon stock analysis along forest disturbance gradient in gedo forest: Implications of managing forest for climate change mitigation. *Journal of Ecosystem and Ecography*, *5*(3), 1-5. http://dx.doi.org/10.4172/2157-7625.1000170

Zanne, A. E., Lopez-Gonzalez, G., Coomes, D. A., Ilic, J., Jansen, S., Lewis, S. L., … and Chave, J. (2009). Data from: Towards a worldwide wood economics spectrum. *Dryad*.

Zhang, H., Li, Y., Xu, K., Yu, L., He, P., Zeng, S., ... and Sun, Y. (2024). Effects of Anthropogenic Disturbance on the Structure, Competition, and Succession of Abies ziyuanensis Communities. *Forests*, *15*(6), 1001. https://doi.org/10.3390/f15061001

Zimmer, M. (2002). Is decomposition of woodland leaf litter influenced by its species richness?. *Soil Biology and Biochemistry*, *34*(2), 277-284

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Impact of anthropogenic disturbance on diversity and distribution of tree species in a tropical semi-evergreen forest of Aizawl, Mizoram, India

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ABSTRACT

The study aimed to evaluate the diversity and distribution of tree species along a disturbance gradient in Hmuifang forest of Aizawl district, Mizoram. For detailed investigation 0.5 ha area of 3 forest stands each representing undisturbed stand (>50% canopy cover and <10% Disturbance Index), moderately disturbed stand (20-50% canopy cover and 10-50% Disturbance Index), and highly disturbed forest stand (<20% canopy cover and >50% Disturbance Index) was sampled. Altogether, a total of 115 tree species belonging to 81 genera and 47 families were recorded. Of this, undisturbed stand was represented by 89 species belonging to 66 genera and 41 families, moderately disturbed stand with 63 species belonging to 51 genera and 36 families, and highly disturbed stand with 31 species belonging to 24 genera and 20 families. According to the Importance Value Index, *Lindera pulcherrima* was the dominant tree species in the undisturbed forest stand, while in the moderately disturbed stand *Drypetes indica* was dominant, and in the highly disturbed stand, *Schima wallichii* was abundant. The Shannon Wiener diversity index (H') was computed highest (4.06) in the undisturbed stand, followed by moderately disturbed stand (3.79) and highly disturbed stand (3.05). On the contrary, the Simpson's index of dominance (D) was found to be 0.0219, 0.0284 and 0.054 in the undisturbed, moderately disturbed and highly disturbed forest stands respectively. The Pielou's evenness index (J') was computed as 0.91, 0.898 and 0.888 for the undisturbed, moderately disturbed and highly disturbed forest stands respectively. The highest similarity was recorded between undisturbed and moderately disturbed stands (0.64) followed by moderately disturbed and highly disturbed stand (0.42). The least similarity was recorded between undisturbed and highly disturbed stand (0.37). The study conducted in the three different forest stands reveals that the community composition changes with disturbance showing a strong negative correlation with disturbance.

Key words: *Disturbance gradient, Canopy cover, Tree diversity, Tree distribution, Richness*

Introduction

Forests are fundamental parts of terrestrial ecosystems which offer a variety of essential services and tasks that humanity and biodiversity demand. Tropical forest ecosystems feature out in terms of the delivery and accessibility of the majority of these vital services, as well as serving as a key platform for worldwide carbon storage and sequestration, which offers solutions for climate change remediation (Bentsi-Enchill *et al.*, 2022). Forests and woodland encompass over 3.95 billion hectares of the terrestrial masses, with tropical forests accounting for over half of the total forest and containing the

INDIAN JOURNAL OF SCIENCE AND TECHNOLOGY

ORIGINAL ARTICLE

Effects of Anthropogenic Disturbance on Soil Characteristics in a Forest of Aizawl District, Mizoram

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Abstract

Objectives: Terrestrial ecosystems depend on forests for various services and functions, which are vital to biodiversity. The study examines anthropogenic impacts on soil quality caused due to anthropogenic disturbance. **Methods:** Three research sites (undisturbed, moderately disturbed, and highly disturbed forest stands) were selected, based on the degree of disturbance considering the canopy cover. Soil samples were collected from two depths i.e., 0-10 cm (topsoil) and 10-20 cm (subsoil) depths on the seasonal basis (pre-monsoon, monsoon, and post-monsoon seasons) and analysed for various characteristics namely, bulk density, pH, organic carbon content, moisture content, and nutrient availability (potassium, phosphorus, and nitrogen). **Findings:** With a range of 17.44 $\pm$ 0.52% to 44.13 $\pm$ 0.48%, the results showed an inverse relationship between the degree of disturbance and soil moisture. Soil bulk density values ranging from 0.71 $\pm$ 0.11 g/cm^3 to 1.36 $\pm$ 0.01 g/cm^3 and soil compaction increased with disturbance. The less disturbed site had a greater acidic level, with pH range of 4.59 $\pm$ 0.06 to 5.88 $\pm$ 0.03. Higher concentrations in topsoil showed a substantial variation in the organic carbon content (0.92 $\pm$ 0.03%-3.66 $\pm$ 0.19%). In contrast to disturbed stands, undisturbed stands have significantly better nutrient availability. The results demonstrate how anthropogenic disturbance impairs soil health. **Novelty:** Unlike many studies which focus on general forest degradation, the present study shows how anthropogenic activities like jhum cultivation and unsustainable logging have affected the soil health of Mizoram's forests along various degree of disturbance. It also highlights how seasonal variation affects soil health. The study shows the importance of implementing sustainable forest management practices to prevent soil degradation.

Keywords: Anthropogenic disturbance; Forest; Soil nutrient; Seasonal variation; Soil depth

BIO-DATA

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XII	Science	B.K. Bajoria School	CBSE	2013	I	78.80
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MSc	Environmental Science	North Eastern Hill University (NEHU)	NEHU	2018	I	77.33

ACHEIVEMENTS

1. Qualified Joint CSIR-UGC National Eligibility Test (NET) for Assistant Professor held on 16-06-2019 with UGC Ref. No.:3221/(CSIR-UGC NET June 2019) in Life Sciences.
2. Qualified Joint CSIR-UGC National Eligibility Test (NET) for Junior Research Fellowship (JRF) and Eligibility for Lectureship (LS)/Assistant Professor held on 15-12-2019 with CSIR-HRDG Ref. No.:15/12/2019 (ii) EU-V.

SEMINAR/CONFERENCE PARTICIPATED AND PAPER PRESENTED

1. Delivered an oral presentation on the topic "Estimation of Carbon Stock in the forest of North-Eastern Hill University, Shillong, Meghalaya", in Two Days National Seminar on "Land use and Bioresource Management for Sustainable Livelihood" jointly organized by the Department of Environmental Science, Mizoram University, Mizoram Science, Technology and Innovation Council (MISTIC) and National Bank for Agriculture and Rural Development (NABARD) on 27-28th March, 2023.
2. Delivered an oral presentation on the topic "Effects of anthropogenic disturbance on diversity and distribution of tree species in a forest of Aizawl district, Mizoram", in the International Conference on "Climate Change and Natural Resource Management for Sustainable Development (ICNS -2024)" hosted by the School of Earth Sciences & Natural Resources Management, Mizoram University from 13-15th March, 2024.
3. Delivered an oral presentation on the topic "Impact of Anthropogenic Disturbance on Carbon Stock in a Forest of Aizawl District, Mizoram", in the International Conference on Transdisciplinary Approaches in Contemporary Scientific Research (ICTACSR 2025) held at Cachar College, Silchar, Assam, India from 6-8th November, 2025.

PUBLICATIONS

1. **Elizabeth Nemhoihkim**, Enmuanliana, L K Thang Ngaihte and B.P. Mishra (2024). Impact of anthropogenic disturbance on diversity and distribution of tree species in a tropical semi-evergreen forest of Aizawl, Mizoram, India. *Ecology, Environment and Conservation 30 (August Suppl. Issue)*, S478-S486.
2. **Elizabeth Nemhoihkim**, Enmuanliana, L K Thang Ngaihte, Lucky Smita Basumatary and B.P. Mishra (2025). Effects of Anthropogenic Disturbance on Soil Characteristics in a Forest of Aizawl District, Mizoram. *Indian Journal of Science and Technology*, *18*(21), 1696-1702.
3. L K Thang Ngaihte, **Elizabeth Nemhoihkim**, O.P. Tripathi & B.P. Mishra (2024). Impact of Altitude on Soil Quality in Current Jhum Fields of

Churachandpur, Manipur. *Ecology, Environment and Conservation 30 (August Suppl. Issue), 30 (August Suppl. Issue)*, S200-S213.

4. L K Thang Ngaihte, **Elizabeth Nemhoihkim**, O.P. Tripathi & B.P. Mishra (2024). Seasonal Variations in Soil Properties Across Altitudinal Gradient of Current Jhum Fields in Champhai District, Mizoram. *Indian Journal of Natural Sciences*, Vol. *15*(87)/DEC/2024, 83025-83035.

DECLARATION

I declare that the information provided above are true to the best of my knowledge and believe.

Date:

Place:

(Elizabeth Nemhoihkim)

PARTICULARS OF THE CANDIDATE

NAME OF THE CANDIDATE	:	ELIZABETH NEMHOIHKIM
DEGREE	:	DOCTOR OF PHILOSOPHY
DEPARTMENT	:	ENVIRONMENTAL SCIENCE
TITLE OF THESIS	:	EFFECTS OF ANTHROPOGENIC DISTURBANCE ON TREE COMMUNITY CHARACTERISTICS AND CARBON STOCK IN THE FORESTS OF AIZAWL DISTRICT, MIZORAM
DATE OF ADMISSION	:	31/08/2021
APPROVAL OF RESEARCH PROPOSAL		
1. DRC	:	31.03.2022
2. BOS	:	25.05.2022
3. SCHOOL BOARD	:	10.06.2022
MZU REGISTRATION NO.	:	2200072 of 2021
Ph.D. REGISTRATION NO. & DATE:		MZU/Ph.D./1884 of 31.08.2021
EXTENSION (IF ANY)	:	NIL

(Prof. A. S. Devi)
(Head)
Department of Environmental Science

ABSTRACT

EFFECTS OF ANTHROPOGENIC DISTURBANCE ON TREE COMMUNITY CHARACTERISTICS AND CARBON STOCK IN THE FORESTS OF AIZAWL DISTRICT, MIZORAM

AN ABSTRACT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

ELIZABETH NEMHOIHKIM

MZU REGISTRATION NO.:2200072

Ph.D. REGISTRATION NO.: MZU/Ph.D./1884 of 31.08.2021

DEPARTMENT OF ENVIRONMENTAL SCIENCE

SCHOOL OF EARTH SCIENCES AND NATURAL RESOURCES MANAGEMENT

DECEMBER, 2025

EFFECTS OF ANTHROPOGENIC DISTURBANCE ON TREE COMMUNITY CHARACTERISTICS AND CARBON STOCK IN THE FORESTS OF AIZAWL DISTRICT, MIZORAM

BY

ELIZABETH NEMHOIHKIM

Department of Environmental Science

PROF. B.P. MISHRA

(Supervisor)

Submitted

In partial fulfillment of the requirement of the Degree of Doctor of Philosophy in Environmental Science of Mizoram University, Aizawl.

ABSTRACT

Forests sustain about 80% of the total terrestrial biodiversity and are among the very dynamic ecosystems on earth. They also act as a storehouse for carbon and helps in mitigating climate change (FAO, 2020; Watson et al., 2000). According to Franklin et al. (2002), the structure and composition of a forest depend on biotic factors (living components) and the abiotic factors (climate, type of soil, topography). Over the last few decades, forest change due to anthropogenic activities has become a great concern (Bellasse and Luyssaert, 2014; Haq et al., 2022).

The forests in Mizoram are rich in biodiversity as they are a part of the Indo-Burma Biodiversity Hotspot. Though most of the forest areas which are inaccessible are rich still rich in biodiversity, those that are closer to human settlements are undergoing high level of pressure due to various activities like collection of fuelwood and non-timber forest products, grazing, and shifting cultivation by the locals. These activities have caused alteration in species diversity, forest composition, and ecosystem functions like water cycle and nutrient cycle disruption (Kumar et al., 2024). When forests are disturbed, they shift their role from carbon sinks to carbon sources by releasing stored carbon into the atmosphere (Pan et al., 2013). Therefore, it is very important to understand the effect of anthropogenic disturbance on tree community characteristics and carbon stock in the forest (Luyssaert et al., 2008).

The study provides crucial baseline information on the forest structure, tree diversity and carbon storage under varying disturbance intensities that will help in building a deeper comprehension on how human activities affect forest ecosystems. The objectives of the present research work envisage the following:

1. To study tree community characteristics in the selected forest stands along disturbance gradient.
2. To determine the biomass and carbon stock in the vegetation and soil.
3. To assess the effects of disturbance on diversity-distribution of trees and carbon stock of the forests in Aizawl district of Mizoram.

The study was carried out in Hmuifang and its adjoining areas in the Aizawl district and the site was selected based on several criteria, viz., the area must

represent broader ecological and disturbance patterns that are common to Mizoram's forests, it should contain forest stands along a clear level of anthropogenic disturbance from untouched to severely degraded stands, and the practical possibility and accessibility for frequent field visits.

The present study was carried out for 2 successive years, i.e., from the post-monsoon season of 2022 to the monsoon season of 2024, covering all the three seasons i.e., pre-monsoon, monsoon and post-monsoon. To quantify the degree of disturbance caused by anthropogenic activities, disturbance index (DI), canopy cover and light interception were analysed (Pandey and Shukla, 1999). Depending on the disturbance level, the area of research was categorised into 3 stands viz., undisturbed (UD), moderately disturbed (MD) and highly disturbed (HD) forest stands, were selected in and around Hmuifang, Aizawl district, Mizoram. A total of 3 ha (1 ha for each stand) was surveyed during the study.

For the present study, the method as outlined by Misra (1968) was followed for vegetation analysis. The quadrat size of 10m x 10m for trees, 5m x 5m for shrubs, and 1m x 1m for herbs were laid randomly. In case of trees, all individuals having more than 30 cm girth at breast height (1.37 m) above ground were measured. Identification of species were done using the books, "The book of Mizoram Plants" (Sawmliana, 2003) and "Flora of Mizoram Vol. 1" (Singh et al., 2002). The species identified were then cross-checked with the herbarium records of the Department of Environmental Science, Mizoram University. Since the primary focus of the study was on trees, quantitative analysis was done for such species only. However, the list of shrub and herb species along with their presence or absence in the UD, MD and the HD stands were recorded.

The quantitative analysis viz., abundance, density and frequency, were calculated for trees using the methods proposed by Curtis and McIntosh (1950). The Importance Value Index (IVI) was calculated following the method proposed by Phillips (1959). The Whitford index, Shannon-Wiener diversity index, Pielou evenness index, Simpson dominance index, Margalef diversity index, and Sorensen similarity were also calculated for comparative assessment among the selected forest stands (Whitford, 1949; Shannon and Weiner, 1963; Pie Lou, 1969; Simpson, 1949; Margalef, 1958); Sorensen, 1948). The soil samples were collected from two depths, i.e., topsoil (0 – 10 cm) and subsoil (10 – 20 cm). The soil samples were collected from the sites by inserting a 10 cm scaled soil corer with 5.2 cm inner diameter. The soil pH, soil temperature, soil moisture content (SMC), ant the bulk density (BD) were analysed using the methods described by Allen et al. (1974) and Anderson and Ingram (1993). The soil organic carbon (SOC) was calculated following the Walkey and Black's titration method (1934). The total nitrogen (TN) was analysed using the Kjeldahl Digestion method developed by Walkey and Black (1934). The available phosphorus ($P_{avail.}$) was determined using spectrophotometer method of Bray and Kurtz (1945). The available potassium ($K_{avail.}$) was determined using the flame photometer method of Jackson (1973). For the estimation of biomass of trees, a non-destructive approach was followed where the aboveground biomass (AGB_{trees}) was calculated using the allometric equation developed for trees in northeast part of India (Nath et al., 2019), and the belowground biomass (BGB_{trees}) was calculated following Cairns et al. (1997). The specific wood gravity of trees was derived from the global wood density database developed by Zanne et al. (2009). A destructive approach was taken for estimation of biomass of the understorey vegetation (shrubs and herbs). The method proposed by Pearson et al. (2005) was used for calculating the amount of biomass in understorey vegetation and litter. The carbon stock was considered as 50% of the total biomass following Brown et al. (1989).

In the UD stand the DI was 0%, the canopy was dense at 74% and the light interception was at 85%. This revealed that the forest stand was stable and well-preserved. The MD stand was slightly disturbed, with DI of 26.80%, canopy cover of 49% and light interception of 64%, showing some signs of anthropogenic disturbance while still maintaining so part of its natural structure. In the HD stand the DI was 71.89%, the canopy cover was 9% and light interception was 32%, indicating that the stand was severely disrupted due to anthropogenic disturbance which caused alteration in its structure.

The microclimate changed across the disturbance gradient, mainly because the canopy either covers or exposes the ground. Relative humidity was seen to be ranging between 69.1±0.35% (pre-monsoon season in HD stand) and 98.6±0.46% (monsoon season in UD stand) while the air temperature was seen to be ranging between 17.5±0.53°C (post-monsoon season in UD stand) and 28.2±0.84°C (pre-monsoon season in HD stand). Canopy opening allowed more sunlight and wind to reach the ground, making the air warmer and drier.

Anthropogenic disturbances played a big role in floral diversity. The UD stand documented 137 species, 11 genera, and 72 families of plants, but maximum plant species was observed in MD stand with 170 species, 141 genera, and 86 families. The HD stand comprised of 142 species, 125 genera, and 76 families, where most of the species are herbaceous. The MD stand had the most diversity, thereby supporting the Intermediate Disturbance Hypothesis (IDH) which states that mild disturbance allows more diversity.

The tree diversity tends to decrease with increase in disturbance. A total of 128 tree species were documented in all the forest stands. The UD stand had the highest diversity, with 99 species, 75 genera and 45 families, pointing towards a healthy ecosystem with tree species that are firm and typical of mature forests. As the forest experienced moderate disturbance, the tree diversity also decreased with 78 species, 58 genera and 37 families. The HD stand experienced maximum disturbance, thereby only included 35 species, 26 genera and 22 families. The sudden decrease in tree diversity shows a shift from well structured, diverse, and mature community to a simpler vegetation type which is dominated by fast growing, shade-intolerant and disturbance tolerant species.

The tree density and basal area decreased with increase in disturbance. The UD stand documented tree density of 1275 individuals ha^{-1}, the MD stand had 955 individuals ha^{-1}, and the HD stand had only 314 individuals ha^{-1}. This decline in density showed the impact of logging, shifting cultivation, and repeated extraction of forest products. The basal area was highest in UD stand at 40.196 m^2 ha^{-1}. The MD and HD stands recorded a basal area of 25.997 m^2 ha^{-1} and 5.787 m^2 ha^{-1} respectively, indicating that large mature trees were the first to be cut down in disturbed areas.

The diversity indices show how disturbance reshaped the forest community. The Shannon-Wiener index (H´) in the UD stand had the highest value (4.15) which is followed by MD stand (4.00) and HD stand (3.23). Margalef's species richness index (Dmg) ranged from 13.71 in UD stand to 11.22 in MD stand and 5.91 in HD stand. These show a gradual loss of both richness and balance among the species.

Pielou's evenness index (J) was recorded at 0.91, 0.90, and 0.88 in the UD, the MD and the HD stand respectively, showing some signs of dominance in the HD stand. In the Simpson's dominance index (D), the value slowly increased from 0.02 in UD stand to 0.03 in MD stand and highest in HD stand at 0.05, indicating a shift in community structure from a more even to a more dominant composition. The Sorensen similarity index (S_E) revealed the similarity in species in different forest stands. The UD and MD stands was the most similar (0.62), with 55 common species, indicating that the level of disturbance was not too high to change the forest structure completely. The MD and HD stand had lower similarity (0.44) with 25 common species. The UD and HD stands had the least similarity (0.39), with only 26 common species. These indicate how disturbance can affect the species composition.

The size-class pattern showed how distinct the three stands were. There were trees of all girth sizes on the UD stand from younger trees (30-60cm) to medium sized (60-90cm) and older trees (>150cm) girth sizes, which is typical of a mature and stable forest stand. Maximum trees fall in the 30-60cm girth class category in the HD forest stand with just a single tree between 120-150cm and none in the higher girth class, indicating that the forest is unstable.

The IVI showed shift in dominance of species. In the UD stand, *Engelhardia spicata* was the most dominant species with IVI score of 18.89, but it was replaced by *Drimycarpus racemosus* with an IVI score of 15.67 in the MD stand, which was further replaced by *Schima wallichii* with an IVI score of 44.71 in the HD stand. There was a clear pattern of succession, going from the climax or late successional species becoming the most dominant or common in the UD stand, to early successional species or pioneer species being the most dominant in the HD stand. The MD stand still maintained species diversity, though shift in the community structure due to disturbance has been observed. The dominance-diversity curve depicts that the UD curve and the MD curve showed the log normal distribution assuming stable and complex community. However, the HD stand showed short-hooked curve depicting an unstable community.

The family dominance-distribution curve showed a clear shift in family dominance of trees along the disturbance gradient. Lauraceae was the most dominant family in both the UD and the MD stands, indicating its strong ecological presence even under mild disturbance. However, Lauraceae was replaced by Fagaceae as the most dominant species in the HD stand, indicating a shift towards species groups which can withstand disturbance as well as changed habitat conditions.

Out of the 128 species, most of them were put in the Least Concern (LC) category by IUCN. *Alseodaphnopis petiolaris* and *Memecylon grande* were classified as Vulnerable (VU), while *Dipterocarpus retusus* and *Palaquium polyanthum* were categorised as Endangered (EN), indicating their vulnerability. The species *Saurauia punduana* was listed as Critically Endangered (CR), and was present only in the UD stand, indicating its risk of extinction.

The soil temperature was seen to range from 15.22±0.44°C (post-monsoon season at 10-20 cm depth in UD stand) to 22.53±0.55°C (pre-monsoon season at 0-10 cm depth in HD stand). The soil warmed up faster in disturbed areas because of the open canopy which allowed light to hit the ground more directly. Soil moisture ranged between 17.44±0.52% (pre-monsoon season at 10-20 cm depth in HD stand) and 44.13±0.48% (monsoon season at 0-10 cm depth in UD stand). This shows that the more disturbed the forest was, the less moisture it could hold. The loss of soil moisture was because there was less vegetation and the soil structure was weaker in the disturbed area, which made it difficult for the soil to hold water.

The bulk density of soil was seen to increase with increase in disturbance, with values ranging between 0.81±0.11 g cm^{-3} (pre-monsoon season at 0-10cm depth in UD stand) and 1.38±0.01 g cm^{-3} (monsoon season at 10-20cm depth in HD stand), indicating that the soil in disturbed site is more compact and the soil is more exposed to trampling and erosion. Soil pH was moderately to slightly acidic across all forest stands, with values ranging between 5.27±0.04 (pre-monsoon season at 0-10cm depth in UD stand) and 6.20±0.05 (post-monsoon season at 10-20cm depth in MD stand. The UD stand had lower pH because of more litter organic acid buildup. The disturbed stands have slightly higher pH because the vegetation has been burnt and organic input has been lost.

Total Nitrogen was seen to decrease with increase in disturbance. The values ranged from 0.05±0.01% (monsoon season at 10-20cm depth in HD stand) to

0.34±0.02% (post-monsoon season at 0-10cm in UD stand). This big drop may be caused by the loss of organic matter, the soil's poorer ability to fix nitrogen, and more leeching as the vegetation gets thinner. The available Phosphorus was also seen to decrease along the disturbance gradient, with values ranging between 6.84±0.67 kg ha^{-1} (monsoon season at 10-20cm depth in HD stand) and 31.90±1.21 kg ha^{-1} (post-monsoon season at 0-10cm depth in UD stand). This reduction shows how erosion, slower litter breakdown and less microbial activity slowly strip nutrients from the disturbed soil.

The amount of available Potassium was seen to decrease with increase in disturbance, with values ranging between 39.33±1.75 kg ha^{-1} (monsoon season at 10-20cm depth in HD stand) and 207.41±0.80 kg ha^{-1} (post-monsoon season at 0-10cm depth in UD stand). The amount of SOC had values ranging from 0.92±0.03% (monsoon season at 10-20cm depth in HD stand) to 3.66±0.19% (post-monsoon season at 0-10cm depth in UD stand). These huge drop in potassium and organic carbon indicate how disturbance reduce the soil fertility, making it less able to support healthy forest growth and store carbon effectively.

There was a strong negative correlation between disturbance level and soil moisture content ($r=-0.762$, $p<0.01$), total Nitrogen ($r=-849$, $p<0.01$), available Phosphorus ($r=-0.880$, $p<0.01$), available Potassium ($r=-0.876$, $p<0.01$), and soil organic carbon ($r=-0.839$, $p<0.01$). Conversely, there was a positive correlation between disturbance levels and bulk density ($r=0.644$, $p<0.01$), and soil temperature ($r=0.462$, $p<0.01$). Also, there was positive correlations among nutrient parameters, indicating their interdependence in maintaining soil fertility and ecosystem functioning.

The aboveground biomass of trees was 238.64 t ha^{-1} in the UD stand, followed by 145.27 t ha^{-1} in the MD stand, and only 29.93 t ha^{-1} in the HD stand. The same pattern was seen in the belowground biomass, where biomass dropped from 126.33 t ha^{-1} in the UD stand to 79.94 t ha^{-1} in the MD stand and 17.55 t ha^{-1} in the HD stand. The total amount of tree biomass dropped from 364.98 t ha^{-1} in the UD stand to 225.21 t ha^{-1} in the MD stand and finally to 47.48 t ha^{-1} in the HD stand. It can clearly be seen that there is a drop of about 87% from UD to HD stand, indicating how disturbance takes away the forests' ability to store carbon and protect against climate change. The carbon stock pattern was like the biomass data where trees stored 182.49 t ha^{-1} in the UD stand, followed by 112.60 t ha^{-1} in the MD stand, and then dropped dramatically to23.74 t ha^{-1} in the HD stand.

The UD stand clearly demonstrated that the 60-90cm girth sized trees stored the most amount of biomass at 111.08 t ha^{-1} and carbon stock at 55.38 t ha^{-1}. In MD and HD stand the 30-60cm girth sized trees stored maximum biomass at 87.63 t ha^{-1} and 31.08 t ha^{-1} respectively, and carbon stock at 43.82 t ha^{-1} and 15.54 t ha^{-1} respectively. This change indicates that the bigger trees which store high amount of carbon are usually the first to be affected by anthropogenic activities.

The species *Ostodes paniculata* was the highest contributor of biomass and carbon stock in the UD forest stand at 30 t ha^{-1} of biomass and 15 t ha^{-1} of carbon, followed by *Quercus floribunda*, *Engelhardia spicata*, *Quercus floribunda* and *Lindera pulcherrima*. These five major species collectively contributed 33.47% of the total carbon in the UD stand. In the MD stand, *Drimycarpus racemosus* stored the maximum biomass at 18.37 t ha^{-1} and carbon at 9.19 t ha^{-1}, followed by *Quercus xylocarpus, Rapanea capitellata, Schima wallichii,* and *Engelhardia spicata.* These five major species collectively contributed 28.16% of the total carbon. In the HD stand, *Schima wallichii* was the highest contributor of biomass at 11.22 t ha^{-1} and carbon at 5.61 t ha^{-1}, followed by *Quercus xylocarpus*, *Wendlandia grandis, Carallia brachiate,* and *Macaranga denticulata*. The five major species collectively contributed 51.24% of the total carbon. This change from late-successional species with high wood density in the UD stand to fast growing pioneer species with lower wood density in the HD stand shows why the amount of carbon stored declined with increase in disturbance.

The biomass in shrubs varied along the disturbance gradient, ranging from 0.072 t ha^{-1} in UD stand to 0.724 t ha^{-1} in MD stand. Similarly, the amount of carbon stored in shrubs ranged from 0.034 t ha^{-1} in UD stand to 0.344 t ha^{-1} in MD stand, indicating that moderately disturbed forests usually have thicker shrub layer.

The biomass in herbaceous vegetation was seen to range between 0.03 t ha^{-1} in UD stand to 0.229 t ha^{-1} in HD stand, and carbon stock ranged from 0.014 t ha^{-1} UD stand to 0.109 t ha^{-1} in HD stand. Herbs were reported to grow best in disturbed area. This is because the lighter, more open canopy in disturbed areas lets more light to pass through and have fewer competitors overhead.

Litter made up an important part of the understorey biomass, ranging between 0.143 t ha^{-1} in HD stand and 2.437 t ha^{-1} in UD stand, and carbon stock was seen to be ranging from 0.070 t ha^{-1} in HD stand to 1.157 t ha^{-1} in UD stand. The closed canopy in the undisturbed regions have high litterfall throughout the year, making a thick layer of biomass in the forest floor, while open canopy can produce warmer microclimates that fasten decomposition process, thereby minimizing litter accumulation.

The Carbon-to-Nitrogen (C:N) ratio was seen to be directly proportional to disturbance, ranging between 10.77 (post-monsoon season at 0-10cm depth in UD stand) and 18.40 (monsoon season at 10-20cm in HD stand). The C:N ratio was the highest in the HD stand, followed by the MD stand and lowest in the UD stand. Also, the value in the subsoil was consistently higher than the topsoil across all stands. The increase in the C:N ratio along the disturbance gradient indicates a decline in soil fertility. The UD stand is more fertile as it consistently receives fresh litter and promotes active nutrient cycling while the HD stand was less fertile due to lower litter input, reduced nitrogen supply, and slow decomposition rate.

In the UD forest stand, most of the carbon was stored in the trees, while in HD stand the soil held more amount of carbon. This was not because the soil absorbed more carbon, but because of loss of vegetation. This indicates how vulnerable the forests carbon pools are when anthropogenic pressure increases. It also highlights the importance of conserving and protecting these forests to store carbon thereby minimizing climate change.

Anthropogenic activities have severe impact on the forest ecosystem by reducing the tree diversity, altering the community structure, and decreasing carbon storage, especially in the highly disturbed stand. With increase of degree of disturbance, there is a sharp change in microclimates, species composition, and the overall function of the ecosystem. The findings of the study highlight the importance of protecting and managing the forest stands that are undisturbed and to restore the damaged forest stands. There is an ample scope of integrated management approach involving governments, local communities, NGOs, and researchers together to conserve and manage the forests in a way that protects the diversity, stores carbon, provides ecological services, and supports local livelihoods.