IMPACT OF STONE MINING ON PLANT DIVERSITY AND SOIL NUTRIENT DYNAMICS IN TROPICAL FOREST ECOSYSTEMS IN TANHRIL AREA OF AIZAWL DISTRICT OF MIZORAM

THESIS SUBMITTED TO MIZORAM UNIVERSITY IN PARTIAL FULFILMENT FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY IN FORESTRY

By:

SHAIKHOM BIDYASAGAR SINGH

(Ph.D Regn No. MZU/ Ph.D/ 274 of 09.06.2009)

DEPARTMENT OF FORESTRY
SCHOOL OF EARTH SCIENCES & NATURAL RESOURCES MANAGEMENT, MIZORAM UNIVERSITY
AIZAWL – 796004

Year: 2013

DECLARATION

I, Mr. **Shaikhom Bidyasagar Singh** hereby declare that the subject matter of this thesis entitled "**Impact of Stone Mining on Plant Diversity and Soil Nutrient Dynamics in Tropical Forest Ecosystems in Tanhril area of Aizawl District of Mizoram**" is the record of work done by me, that the content of the thesis did not form basis for the award of any previous degree or to anybody else, and that I have not submitted the thesis in any other University/ Institute for any other degree.

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

Date: 01.10.2013 (Shaikhom Bidyasagar Singh)
Place: Aizawl

Mizoram University

Department of Forestry

School of Earth Sciences and Natural Resources Management, Aizawl- 796004

CERTIFICATE

This is to certify that the thesis entitled "**Impact of Stone Mining on Plant Diversity and Soil Nutrient Dynamics in Tropical Forest Ecosystems in Tanhril area of Aizawl District of Mizoram**" submitted by **Shri Shaikhom Bidyasagar Singh** for the award of degree of Doctor of Philosophy of the Mizoram University, Aizawl, embodies the record of original investigation carried out by him under my supervision. He has been duly registered and the thesis presented is worthy of being considered for the award of the Ph.D. Degree. The work has not been submitted for any degree of any other University.

(Prof. B.P. Mishra)
Department of Environmental Science
Joint Supervisor

(Dr. S.K.Tripathi)
Department of Forestry
Supervisor

(Prof. U.K. Sahoo)
Head
Department of Forestry
Mizoram University

Date: 01.10.2013
Place: Aizawl

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Place: Aizawl

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INTRODUCTION

1.1 Biological diversity: history and concept

Naturalists and scientists were documenting biological diversity in its various forms for the past two centuries (Barton, 1827; Darwin, 1859; Bews, 1927; Clausen *et al.*, 1941; Raunkiaer, 1934; Odum, 1950; Dalesman, 1968). Initially biological diversity or natural diversity of species was recorded where ever they were noticed, mostly at accessible locations. After that the naturalist started traveling inaccessible areas to explore new flora and fauna and published monographs for a specialized location, which was initiated from the Europe. Further, the documentation of the biological diversity has began along gradient, mostly along transects (Daubenmire, 1943). The concept of biological diversity was introduced by Lovejoy (1980) to express the number of species present in a community. Norse and McManus (1980) have emphasised about the genetic diversity and ecological diversity. Norse *et al.* (1986) further expanded the usage of the term biological diversity to include genetic (within species), species (species number) and ecological (community diversity).

The term biodiversity was coined for the first time by Walter G. Rosen in 1985 in the National Forum organized by the National Research Council under the title ‘Biodiversity’ (Wilson, 1988). Later, multi-dimensional aspect of biodiversity including species loss and conservation priorities was intensively discussed in the Earth Summit in 1992 at Rio De Janeiro, Brazil, since then the subject biodiversity attracted international attention and a great deal has been written on the subject.

The UN Convention on Biological Diversity defined the biodiversity as "the variability among the living organisms from all sources, including, inter-alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems" (UNEP, 1992). In strict sense, biodiversity is the variety of life on the Earth evolved as a result of speciation in millions of years of the evolution that can be described at many hierarchical levels, for example, from gene to ecosystems (i.e. DNA and genes - species population - community - ecosystem - landscape levels). Further, it is extended to the diversity of genes, species and ecosystem at three fundamental and hierarchically levels of biological organization (WCMC, 1992).

Biodiversity provides to humankind enormous direct economic benefits as many beneficial goods and an array of indirect essential services though natural ecosystems to play a significant role in modulating ecosystem function and stability (Singh *et al*., 1994; Singh *et al*., 2002). Fundamental ecosystem services such as regulation of climate, biogeochemical cycles, hydrological functions, soil protection, crop pollination, pest control, recreation and ecotourism rendered by biodiversity has been realised recently. The role of biodiversity on ecosystem processes has been a matter of great debate during recent years because of growing concern about the loss of biodiversity and their possible consequences to ecosystem functioning. There is growing concern over the current rate of species extinction and in determining how the loss of biodiversity might alter the ecological processes like productivity, decomposition and element cycling that are vital to the functioning of the ecosystems (Ehrlich and Wilson, 1991; Schulze and Mooney, 1994; Vitousek *et al.*, 1997; Chapin *et al*., 1997; Chapin *et al*., 2001). A number of researchers have emphasised that the biodiversity is the key to regulate many ecological processes (Naeem *et al.,* 1994;

Tilman *et al.,* 1996, 1997; Hooper and Vitousek, 1997; Mc Grady-Steed *et al.,* 1997; Wardle *et al.,* 1997). According to Richards (1996), plant component of a forest determines its structure and function. Plant species diversity assessment in forest ecosystem is one of the fundamental goals of ecological research and is essential for providing information on ecosystem function and stability (WCMC, 1992; Tilman, 2000; Townsend *et al.,* 2008).

1.2 Biodiversity hotspots

Norman Myer (1988) for the first time has given a concept of biodiversity hotspots as priority areas for *in situ* conservation of the World biodiversity. Idea of identification of biodiversity hotspots was mainly based on the number of endemic species present and the degree of threats to biodiversity at a place. On above basis, Myer *et al.* (2000) identified 25 global hotspots of biodiversity, the areas most important for preserving species, out of which two major hotspots occurred in India (e.g. Western Ghats and Indo-Burma - constitutes major part of North-Eastern India). The conservation International (2005) now recognizes a total of 34 biodiversity hotspots at global level reflecting a severe threat to endemic biodiversity (Roach, 2005). But, there is an ongoing global biodiversity crisis due to unprecedented loss of natural ecosystem (Achard *et al.,* 2002; Jenkins, 2003). These changes in components of the earth's biodiversity cause concern for ethical and aesthetic reasons but they also have a strong potential to alter ecosystem properties and the goods and services they provide to human beings (Hooper *et al.,* 2005). Therefore, the conservation of global biodiversity is an important concern (Gunawardene *et al.,* 2007).

1.3 Spatial and temporal patterns of biodiversity

Generally, diversity decreases with the increase in altitude and latitude. Species diversity is the product of species interaction through competition and niche diversification (Pianka, 1966; Bada, 1984), as both greatly manifested in the tropics due to high rainfall, humidity and temperature (Ojo and Ola-Adams, 1996). Variation in the climatic condition over the World has led to the uneven distribution of species (some areas reflecting high species richness and other low species richness). For example, warmer and wet areas are normally having high diversity of species than drier and cooler areas. Species richness, their dispersion, density and dominance in relation to the co-existing species are major determinants of community structure within any forest ecosystem. The unique species of a region is being utilized by the inhabitants for their daily need of medicine, food, fodder, fuel, timber, making agriculture tools and for various other purposes (Samant and Dharr, 1997; Samant *et al.*, 1998 a, b).

The plant community is a dynamic component which changes as a function of time; however, altitude, slope, latitude, aspect, rainfall and humidity play a key role in the formation of plant communities and their composition (Kharkwal *et al.*, 2005). Species diversity is a point of interest over the World because of the growing awareness of its importance on the one hand and the anticipated massive depletion on the other hand (Singh, 2002). The world vegetation cover under natural forests has been depleting at an alarming rate and a significant portion of such areas is being converted to man-made plantation forests, mainly dominated by timber yielding trees (Pandey and Shukla, 1999) to meet the growing need of the ever increasing human population. We now largely depend on managed forests for wild plant resources, as we do not have much natural forests left. The situation is worse in tropical habitats where much of the world's species diversity is concentrated (Nagendra and Gadgil, 1999; Sanchez-Azofeifa *et al*., 2003; Loarie *et al*., 2007). With accelerated increase in clearing of tropical forest areas and decline in their plant diversity across the world has necessitated to identify biodiversity hotspots locations and there *in situ* conservation by mapping the distribution of vegetation diversity across different habitats and landscapes and monitoring rates of their change over time.

The species are basically intertwined with each other through feeding relations and thus, composition of communities expresses their relationship to one another as well as to their physical environment than the dominance or any other community characteristics. Therefore, Whittaker (1975) emphasized that classification and interpretation of communities should be based on their floristic composition. Clement (1916) viewed community as a 'super organisms' with the successional development from pioneer stage to relatively stable climax stage. Tansley (1935) pointed that in a community certain populations are independent as they can establish themselves well in other communities while others are strongly dependent. Gleason (1926) claimed that community depends on its particular environment for its existence, which changes constantly with space and time.

Species composition, community dynamics and human welfare services of forest ecosystems become adversely affected by both natural and anthropogenic disturbances (Sousa, 1984). Whitemore and Burslem (1996) classified disturbance into large scale i.e. at community level (landslides, volcanoes, drought, lighting, forest fire and various human activities) and small-scale such as forest gaps created as a result of mortality of few trees. In fact majority of disturbances both natural and anthropogenic are amenable to scientific experimentation and immeasurable directly. Most of the past studies on forest ecosystems in relation to disturbance were focused on species-rich tropical rain forests (Ashton, 1993; Aravind *et al.*, 2001; Bhuyan *et al.,* 2001; Whitemore and Burslem, 1996) or temperate forests (Gilliam, 2002; Schumann *et al.*, 2003). The ecologists are now concerned with patterns of species diversity in various environmental gradients. Species diversity studies in relation to resource availability suggested a humped-back curve (Grime, 1973; Huston, 1980; Tilman, 1982). Prominent among these factors are disturbances which are thought to be key aspects, and the cause of local species variation within forests based on their intensity, scale and frequency (Hill and Curran, 2003; Laidlaw *et al*., 2007).

1.4 Measurements of plant species diversity

Species diversity exploration has been given due importance during the past few decades (Margalef, 1958; Pielou, 1975; Margurran, 1988). Proliferation of literature has reflected species diversity as the topic of interest over the past century, for instance, early studies on spatial and temporal patterns, species abundances and distribution (Clements, 1916; Gleason, 1917) to the formulation of mathematical concepts to the study various aspects of species diversity (Margalef, 1958; McIntosh, 1967; Pielou, 1975; Margurran, 1988; Orloei, 1975, 1991).

Over the years, various mathematical formulations and statistical methodologies of species diversity have emerged with specific applications to understand species diversity (Shannon and Weaver, 1963; Simpson, 1949; McIntosh, 1967; Pielou, 1975; Magurran, 1988). Extensive applications of these indices have been used for quantitative measurement of species diversity at the community and ecosystem levels by a number of workers (Wilson and Mohler, 1983; Smith, 1986; Tripathi *et al.,* 1987, 1989 a,b; Southwood and Henderson, 2000; Meff *et al.,* 2002;

Ponce-Hernandez, 2004; Baumgartner, 2005; Keylock, 2005; Latham, 2005; Legendre *et al*., 2005; Thukral *et al*., 2006). Numerous conceptual models of diversity have also been developed that offer mechanistic explanations for the pattern and maintenance of diversity (Connell, 1978; Huston, 1979; Menge and Sutherland, 1987; Crawley *et al*., 1999; Hector *et al*., 2001; Troumbis *et al*., 2002; Forgione *et al*., 2003; Xu *et al*., 2004; Fargione and Tilman, 2005; Mwangi *et al*., 2007). Species richness, species relative abundance and heterogeneity of their spatial and temporal distribution in a given area have been described as the subject of community ecology (He and Legendre, 2002). Increased species richness has been reported under mild disturbance condition (Connell, 1978; Grime, 1979; Huston, 1979; Nauch and Whittaker, 1979; Sausa, 1984; Petraitis *et al*., 1989) and is a simple and easily interpretable indicator of biological diversity within a community (Hurlbert, 1971; Peet, 1974; Whittaker, 1977).

A number of qualitative and quantitative indices of species diversity have been proposed by several workers (Simpson, 1949; Margalef, 1956; Shannon and Weaver, 1963; Pielou, 1975; Whittaker, 1972) which provide information on compositional change at different analytical levels and include species diversity in relation to size of area, relationship between local and regional species diversity and diversity along gradients across space or environmental factors (Busing and White, 1997; Gaston, 2000). Roy *et al.* 2004 have pointed out that biodiversity is a multi-dimensional concept which cannot be measured with a single index. Authors have also proposed a vector to document the multidimensional aspect of forest biodiversity that should take into account the variation in environmental factors, taxonomic variations among species, compositional diversity and functional diversity (Roy *et al.*, 2004).

The species have classified into various functional groups and these groups have been suggested as a way to simplify the examination of species effects on ecosystem properties and the likely effect of global change on species interactions (Korner, 1994). Within an ecosystem plants can be divided into groups with common features according to quality criteria such as life form, overall size, rooting depth, symbiotic association, fire resistance, spatial distribution of plants and plants organs (Lavorel *et.al*., 1997; Korner, 1994).

1.5 Geospatial biodiversity characterizations of Indian forests

Forest biodiversity is mainly studied by plot methods followed by different indices proposed by various authors (Simpson, 1949, Shannon and Weaver, 1963). Major problem of studying spatial biodiversity heterogeneity is the expert man power to sample data from large area at landscape level. In recent years, Indian satellite imagery adds a new dimension to assess spatial biodiversity with large area coverage (Kushwaha *et al*., 2000; Nagendra and Gadgil, 1999). This is simple and saving time technique than the field survey for landscape heterogeneity. Vegetation types maps generated from satellite imagery is used for two staged biodiversity inventory at landscape level (Roy and Tomar, 2000; IIRS, 2002; Behera *et al.*, 2006).

Geospatial approach developed by Indian Institute of Remote Sensing makes an effective use of satellite imagery data to generate homogeneous vegetation strata and landscape analysis to generate disturbance index by considering different parameters like fragmentation, patchiness (Romme, 1982) and proximity of vegetation (Forman and Godron, 1986), interspersion, juxtaposition (Lyon, 1983) and proximity to vegetation patches in relation to disturbances like roads, railways and settlements. This is compared with the field data collection and assessment using

Shannon-Weiner diversity index in different vegetation strata and evaluating community for its uniqueness like endemic and rare species and estimation of biodiversity value pertaining to medicine, food fodder, oil, dye, fuel, charcoal, tannin (Belal and Pringuel, 1996). Approach takes care of the terrain complexity calculated from the digital terrain model. Finally, the biological richness is calculated as a function of disturbance index, terrain complexity, biodiversity value, species richness and ecosystem uniqueness. The non-spatial field data are then converted to spatial data in the geographical information system and assigned values from 1 to 10. The output is scaled to different classes on the basis of richness (very high richness, high richness, medium richness and low richness) that reflect plant richness at different spatial scales (district, region or state). This approach saves considerable time and cost in comparison to ground based measurement methods. IIRS (2002) has enveloped a window-based software module BioCAP was developed to facilitate landscape analysis. Originally, this methodology was developed in 1988 and was validated extensively for the assessment of biological richness in Northeast India (2, 62, 179 km^2 area), Western Himalaya (3, 39, 575 km^2), Western Ghats (2, 60, 962 km^2) and Andaman and Nicobar Islands (8, 249 km^2) between the year 1999- 2001.

Recently, a national level landscape biodiversity characterization project was launched in India between the year 1998-2010 with an aim to create a national level database on the spatial distribution of biodiversity by characterizing and mapping flowering plant richness in forested landscape (Roy *et al.*, 2012a). This study has resulted in the creation of large baseline spatial database on vegetation types, porosity and patchiness, interspersion, juxtaposition, fragmentation, disturbance regimes, ecosystem uniqueness, terrain complexity and biological richness. The details of methodology, sampling techniques and biological richness have been published (Roy *et al.,* 2005; IIRS, 2003 a,b,c,d; NRSA, 2007 a,b; IIRS, 2011a,b,c,d).

1.6 Plant species diversity in tropical forests

Tropical forests are often referred to as one of the most species diverse terrestrial ecosystems, covering only 7% of the earth surface, and they account for about 70% of the world's species. During past few decades, majority of tropical forests are facing different degrees of disturbance due to increasing anthropogenic pressure with time and thus, require management interventions to maintain the overall biodiversity, productivity and sustainability. Whitton and Rajakaruna (2001) have suggested that 60,000 species of tropical plants will be at the risk of extinction in the next 50 years. The present rate of the species extinction is extremely high in comparison to the natural average rate, and this is happening largely through man-made alteration and destruction of environment rather than the process of evolution.

The massive destruction of tropical forests worldwide has led to limit our knowledge on taxonomy and the structural and functional dynamics of many tropical forests (Parthasarathy and Sethi, 1997). A species that is abundant at the local scale also tends to occur in more sites (Gaston *et al.,* 1997). This pattern is consistent across scales and taxa suggesting that similar processes might regulate local and regional abundances of species (Hanski, 1982; Bock and Ricklefs, 1983; Brown, 1984; Lacy and Bock, 1986; Bock, 1987; Gaston *et al.,* 1997; Jankowskil and Rabenold, 1997).

The tropical rain forests are non seasonal ecosystems consisting high species diversity (plants and animals) and complex structure, and thus are relatively stable (Richards, 1986). These forests are the major reservoir of plant diversity, particularly trees (Myer *et al.,* 2000), and are fundamental to total biodiversity of rainforest because they provide resource and habitat structure for other rainforest species (Cannon *et al.,* 1998). The diversity has been reported as a requisite for making sound decision about protecting and managing forests (Condit *et al.,* 1998).

Flora is an important part of the ecosystem that integrates the effects of the total environment. It is predominantly a result of physico-climatic conditions of a region. In other word, floristic composition represents a true image of a terrain and seasonal variation in temperature and precipitation, and provides basic information for understanding of regional development. It has a highly functional role in providing nutrients for an ecosystem, and provides suitable habitat, food and shelter for other biota. It also provides information regarding species composition and structure and its functional role in the landscape as a whole. Knowledge on floristic composition is valuable for many ecological studies such as succession and nature of plant communities which are supportive in reclamation of abandoned sites. The loss of biodiversity is perhaps the most crucial concern for human survival as it influences ecological services and livelihoods. However, global change factors like land use pattern and increasing atmospheric CO_2 concentration have been reported to drastically affect species composition and their relative abundance in natural ecosystems worldwide (Mendelson and Rosenberg, 1994; Chapin *et al*., 2000; Chapin *et al*., 2001). Natural variability is an intrinsic part of tropical forests, and therefore careful observations are required to have complete assessment of the ecosystems for base line information in future.

Disturbance is a discrete event that modifies landscape, ecosystem, community or population structures, which reduces plant biomass by causing its partial or complete destruction, and provide a diverse set of new conditions for seedling establishment and plant growth (Harper, 1977; Grime, 1979; White and Pickett, 1985). Study of disturbance regimes can explain differences in biological diversity among landscapes and regions and legacy of disturbance can determine the speed and direction of vegetation succession following disturbance (Spies and Turner, 1999). The natural regeneration is closely linked with degree of disturbance, and seedling recruitment largely depends upon the nature of species (Mishra *et al*., 2004).

Disturbance plays a central role in shaping the species composition in forests (Pickett and White, 1985). It directly influences the community structure and population dynamics by altering resource availability (Denslow *et al*., 1998) through influencing the relative competitive status of individuals (Sousa, 1984), which causes mortality of mature tree species and hampers establishment of new recruits (Canham and Marks, 1985). Disturbance associated with anthropogenic activities has overruled natural disturbance in many tropical landscapes and protective measures are needed to overcome human induced disturbance within a community. Despite a wide range of studies on the effect of disturbance on experimental (Armesto and Pickett, 1985; McCabe and Gotelli, 2000; Hooper *et al*., 2004), theoretical (Huston, 1979; Wilkinson, 1999) and observational (Abugov, 1982; Huston, 1994; Townsend *et al*., 1997; Slik *et al*., 2002; Hooper *et al*., 2004) conditions, there is lack of comprehensive understanding between vulnerability and sensitivity of ecosystems to change in disturbance regime (Death and Winterbourn, 1995; McCabe and Gotelli, 2000). Disturbances are responsible for making stand structure of plant communities through altering structural diversity of forest (Hubbel *et al.,* 1999).

Structural diversity of forest is consequently altered by the factor of disturbances which are responsible for making structure of plant communities (Hubbel *et al.,* 1999). The vegetation structure of tropical dry forests is not uniform but varied in different habitats. Change in structure of a forests has often been attributed to disturbance regimes (Kennard *et al.,* 2002) involving mostly a single factor that is limited in extent, e.g. selective logging (Cannon *et al.,* 1994; Nagaike *et al.,* 1999; Ramirez-Marcial *et al.,* 2001). In tropical forest, it has also been argued that species richness and diversity are invariably affected by frequent and fluctuating disturbances of low-intensity namely, grazing and browsing, and collection of firewood and fodder, suggesting the importance of combined effect of multiple factors (Sagar *et al*., 2003; Zhu *et al*., 2007).

Land use pattern has been ranked as one of the most important drivers for terrestrial biodiversity change in the 21st century (Sala *et al*., 2000; Chapin *et al*., 2001) with its more prominent role in tropical forests. Further forecasts for massive demands of natural resources in future as a result of increasing world human populations will magnificently increase the pressure on natural ecosystems. Environmental impacts due to mining manifest as water pollution, land degradation, loss of biodiversity, air pollution, and increase in health related problems, occupational noise pollution, vibrations, land subsidence and landslides. Land degradation is one of the significant impacts arising out of mining and quarrying activities and is mainly in the form of alteration of land structure due to excavation, stacking of top soil and loss of fertile soil due to dumping of mined overburden on top soil. Sandstone mining causes damage to property, depletion of forest land, adverse effects on the aquatic biodiversity and public health. The exploitation of natural resources by the local populations has resulted in depletion of the biodiversity of forest communities (Ramakrishnan, 2003). Forest degradation is usually accompanied by species extinction, loss of biodiversity and decrease in primary productivity. Consequently, there is a growing interest in quantifying habitat characteristics like forest structure, floristic composition and species richness in Indian forests (Nirmal Kumar *et al*., 2001, 2002; Yadav and Yadav, 2005).

One of the foundations for conservation of biological diversity in forest landscape is to understanding and managing the disturbance regimes of landscape under past natural or semi-natural conditions. Natural vegetation is dynamic with disturbance being essential for the maintenance of many species and processes (Connell, 1978; Pickett and White, 1985). Connell (1978) and Collin *et al*. (1995) proposed that overall species diversity would be high where disturbances are moderate. According to Pierce *et al*. (2007), the action of disturbance, creating heterogeneous environments and suppressing potential dominants, may also be important for maintenance of biodiversity. In many ecosystems, either increasing or decreasing disturbance changes overall community structure (Sousa, 1979; Collins, 2000; Shafroth *et al*., 2002). Disturbances in ecological systems promote characteristic patterns of environmental heterogeneity and regulate ecosystem processes, population dynamics, species interactions and species diversity (Davies, 2001).

Conservation biology aims to provide the principles and tools for preserving species that prevent extinction of species. A measure of biodiversity has already been lost if a species has been reduced to a few scattered populations, so that it is no longer an important constituent of the ecosystems to which it formerly belonged. The preservation of ecosystems and landscapes is a part of biodiversity conservation.

1.7 Edaphic factor and species diversity

The soil is the weathered surface of the earth's crust that is a complex made up of organic and mineral matters which support micro-organisms to live and plants to grow. Thus, the soil is composed of a parent material, the underlying geologic or mineral substrate, the air and water occupying the pores between the soil particles and an organic increment in which organisms and their products are intermingled with the finely divided particles of the modified parent materials. The nature and types of soil formed are largely governed by the nature of the parent material and its interaction with climate, topography, vegetation and organisms.

Topography affects soil characteristics and plays a critical role in determining the stand structure and floristic composition of forest by causing drainage, moisture and nutrients varying from top to bottom (Enoki and Abe, 2004). Temperature and rainfall are considered as primary factors in regulating over all structure and function while soil characteristics are considered as secondary (or modifying) factors. The absence of an extended cold season allows growth to continue throughout the year in tropical area as long as moisture conditions also remain favourable (Grubb, 1974). It is speculated that the high average annual temperature in tropical region may promote high rate of plant respiration followed by reduced net primary productivity (NPP).

The development of soil and production of vegetation are so intimately related, so that it is scarcely possible to study them without the knowledge of the other. The soil conditions determine the type of vegetation in an area and the nutrient status of the soil also varies considerably with the types of ecosystem and the dominating species present in the ecosystem which regulate the physico-chemical properties of soil (Singh *et al.*, 1995). The physical and chemical properties of the soil determine community composition and distribution of plant species (Ashton *et al.,* 1972; Tilman, 1984; Proctor *et al*., 1988; Scot *et al*., 1992).

The vegetation composition is closely linked with soil characteristics. The anthropogenic activities lead to alter vegetation composition and change in the soil nutrients. The disturbance determines forest dynamics and tree diversity at both local and regional scale (Hubbell *et al*., 1999; Sheil, 1999; Ramirez-Marcial *et al.,* 2001). Thus, disturbance is a key factor structuring communities and influencing variation in species diversity (Noss *et al.,* 1996; Elderd, 2003; Elderd and Doak, 2006; Pierce *et al.,* 2007). Its affects every level of biological organization and spans a broad range of spatial and temporal scales. Disturbance is normally human generated deviation from the normal successional development of equilibrium communities (Oliver and Larson, 1990). Disturbance disrupts the ecosystem, community or population structure, or the physical environment.

Studies along disturbance gradient provide information on functional resilience, biodiversity and landscape equilibrium (Romme, 1982; Turner *et al.,* 1993; Peterson *et al.,* 1998; Engelmark *et al.,* 1999; Walker *et al.,* 1999; White and Jentsch, 2001). Disturbance produces heterogeneous environment and drives variety of successional pathways. The biotic legacies that remain after disturbance vary in quality and quantity both, leading to a range of regeneration patterns like fine scale gap dynamics, patch dynamics or regeneration efficiency (Van der Maarel, 1996). It also locally removes inertia present in forest ecosystems, which are naturally dominated by long-lived, slow-acting organisms. Thus, successional pathways due to disturbance are continuously altering composition, velocity and trajectory, when exposed to varying environmental conditions like global warming or species invasion (White, 1979; White and Jentseh, 2001).

In tropical forest ecosystems, soil nutrients play an important role in the formation of plant communities, their species and structural diversity. Thus, soil restoration has fundamental significance for biodiversity conservation and sustainable land use (Karpachevsky, 1977). Additionally, diversity change may be related to initial nutrient condition of the community. In tropical forests, light reaches perpendicular to the ground, and decreases in a gradient from gap centre to edge to below-canopy locations (Chazdon, 1986; Denslow, 1987). Trees can either diminish or enlarge grass production by modifying the resource availability to ground flora (Vetas, 1992).

1.8 Role of species on ecosystem and concept of keystone species

All species in any ecosystem are not equal in terms of their quantitative influence on ecosystem functioning. The loss of species from the community can have some changes in energy flow and material cycling, and the extent of change varies from the species to species that may lead to maintenance of stable biotic composition of the community. In any ecosystem some species show negative or no redundancy with respect to their role in the ecosystem, and if such species perform some crucial activity, their loss from a forest ecosystem can create havoc for the normal functioning of the ecosystem (Fahey, 2001) and such species are known as keystone species. The concept of keystone species was formally introduced by Paine (1966) while stabilizing the importance of predation in maintenance of the prey species diversity in the rocky intertidal zone of specific coast in North America.

According to Paine (1969) the keystone species refers to as the species that preferentially consumed and held in checking another species that would otherwise dominate the system. Keystone species differ from dominant species, as their effects are much larger than would be predicted from their abundance (Power *et al*., 1996). Ambiguity in the use of the term 'keystone' and the lack of an operational definition has led to criticism of its continued application in research and policy contexts and made it hard to identify exactly which species should be designated as having a keystone role in a community (Simberloff, 1991; Mills *et al.,* 1993). However, despite all these problems, many ecologists still observe value in the concept of the ecological keystone species as a whole and believe that modifying rather than dismissing the idea may be a useful approach (deMaynadier and Hunter, 1994; Power *et al.,* 1996).

A number of definitions of keystone species had been attempted but the most acceptable definition has been given by Power *et al.* (1996) as 'a species whose effect is large and disproportionately large relative to its abundance'. Power *et al*., (1996) have suggested 'how great an effect is large' and 'how large a proportion is disproportionate' using the 'community importance index' developed by Mills *et al*. (1993). The keystone species concept has proved both promising and elusive in theoretical and applied ecology (Payton *et al*., 2002). Identifying keystone species is difficult (Power *et al*., 1996) and attempts to develop a set of species traits that a prior determine keystone interactions have thus far proved elusive (Menge *et al*., 1994). A Number of approaches have been exercised including natural history observation, historical reconstruction, comparative studies, manipulative field experiments and adaptive management (Walter, 1986). But each approach has distinct advantages and limitations. Finally, social, ethical and technical factors may limit the extent to which some species and communities of interest can be manipulated (Power *et al.,* 1996).

The loss of keystone species would result in widespread changes in the community structure and function and may often lead to species loss or elimination (Tripathi and Law, 2006). The identification of keystone species and study of their population dynamics in a forest ecosystem are important for biodiversity manipulation and management as well as for the sustainability of the forest. The population dynamics of keystone species is very useful in determining the pattern of succession of vegetation (Tripathi and Law, 2006)

Trees are the key species that drive the system in many tropical and temperate forest ecosystems. Only a few tree species or groups of species are keystone species, which play a crucial role in the maintenance of ecosystem stability through their key role in the functioning of these ecosystems. One of the possible ways of characterizing keystone species in the forest ecosystem has been suggested as the competitiveness of the species along the successional gradient in relation to existing vegetation (Tripathi and Law, 2006). The desired level of solar energy, water and nutrients are the most essential resources for the existence of organisms in a given community. In forest ecosystems, trees play a vital role of habitat modifier by manipulating nutrient status, water availability, and light gradient of the system (Peres, 2000). Trees also suppress light demanding species and help the shade tolerant species to successfully colonize the area and thus can be considered as a keystone species in forest ecosystem. Woody plant canopy has been widely reported to alter the microenvironment and soil characteristics (Weltzin and Coughenour, 1990) by reducing air temperatures, wind speed and irradiation that resulted into reduced soil water evaporation and increased relative humidity (Jose *et al.*, 2008; Rao *et al.*, 1998).

The nature of forest communities largely depends on the ecological characteristics at sites, species diversity and regeneration status of species. Micro environmental factors vary with seasonal changes which affect the growth stages i.e. seedling, sapling and young trees of the plant communities that maintain the population structure of any forest. Hence, it becomes an important issue to understand the tree diversity, population structure and regeneration status of forest communities for the maintenance of both natural and control forest. The natural regeneration of the forests largely depends on population structure characterized by the production and germination of seed, establishment of seedlings and saplings in the forest (Rao, 1988).

1.9 Plant species diversity and regeneration in Indian forests

In India, tropical forests account for about 86% of the total forest land (Singh and Singh, 1988), and are strongly influenced by anthropogenic activities (Champion and Seth, 1968; Singh *et al.*, 1991). Habitat destruction, over exploitation, environmental pollution and anthropogenic pressure are the major disturbances to forest ecosystems (UNEP, 2001). Invasion of exotic species especially weeds and their ecological effects on community structure and dynamics of native species have also been reported as a result of forest disturbance (Chandrasekaran and Swamy, 1995; 2002; Sagar *et al.*, 2003; Sagar and Singh, 2004, 2005). Habitat destruction is the leading cause of species extinction and biodiversity loss in natural ecosystems (Koh *et al.*, 2004; Pimm and Raven, 2000). Because of high anthropogenic pressure in the past few decades, the dry deciduous forest cover in most parts of the central India is depleting and resulting into dry deciduous scrub, dry savanna and dry grasslands which are progressively species poor. This situation calls for in-depth study of these forests with respect to species diversity, community structure and regeneration.

Canopy opening readily supports the growth of invasive weeds and other herbaceous plants which usually interfere with regeneration and impede recovery of trees and shrubs (Epp, 1987; Hawthorne, 1993; 1994; Madoffe *et al*., 2006). Invasive weeds cause threat to biodiversity by displacing native species and disrupting community structure (Parker *et al*., 1999; Richardson *et al*., 2000; Sala *et al*., 2000; Stein *et al*., 2000). Soil water availability is also considered as key factor for the regeneration, survival and growth of seedling communities (Lieberman and Lieberman, 1984; Ceccon *et al*., 2002). Light condition influencing regeneration pathways (Haugasen *et al*., 2003) and ultimately affecting the composition and structure of forest. It has been reported that light limitation alone may prevent seedling survival regardless of other resource levels (Tilman, 1982).

Seedling recruitment is one of the most important stages of the dynamic assembly of ecosystem which needs to be critically examined to understand current state and to predict future of the ecosystem (Matthes and Larson, 2006). Recruitment of tree seedlings has been widely reported to play a major role in determining forest composition and finale configuration of the community which is controlled by several environmental barriers to survival that are species specific and variable over space and time (Grubb, 1977; Cornett *et al*., 2000; Castro *et al.*, 2004). Natural regeneration is of great importance in the maintenance of the numerical stability of species in a community and also in the maintenance of a stable age structure of the species of plants in the community (Fatubarin, 1987). Successful regeneration of tree species might be considered to be a function of its ability to initiate new seedlings and sapling to grow (Good and Good, 1972).

Recruitment reflects not only seed production belt, but also the compound filtering effects of seed dispersal and seedling establishment (Uriate *et al.,* 2005). The population structure characterized by the presence of sufficient number of seedlings, sapling and young trees depicts satisfactory regeneration behaviour, while inadequate number of seedling and saplings of tree species in a forest indicates poor regeneration (Saxena and Singh, 1984).

The establishment of a young forest stand by means of natural regeneration involves a series of biological processes occurring over several years, all of which are affected by environmental conditions to a varied degree (Tripathi and Khan, 2007; Yadav and Gupta, 2009). The interaction between seed germination requirement and its environment is thought to be critical in determining species distributions (Forbis *et al.*, 2004). For majority of species, small scale disturbance creates a favourable regeneration niche (Whitmore, 1989). Moreover, the intensity, magnitude and frequency of disturbance also determine the structure and composition of plant communities in the forest ecosystem (Armesto and Pickett 1985; Khan *et al.,* 1987; Duchok *et al.,* 2005). Micro-site characteristics of the forest floor and micro-environmental condition under the forest canopy influence seed regeneration of tree species (Tripathi and Khan, 1990). Variation in temperature, water stress and light requirement strongly influences the germination of seeds and these factors often show significant interaction in their effects on germination (Bokhari *et al*., 1975; Kobe *et al.,* 1995; Turner, 2001; Herrera, 2002; Khera and Singh, 2005). Within forest stand, variation in vegetation composition, community structure and foliage distribution creates spatial variation in light transmittance in the understorey, tree seedlings and saplings (Montgomery and Chazdon, 2001). However, the presence of sufficient number of seedlings, saplings and young trees is greatly influenced by interaction of biotic and abiotic factors (Boring *et al*., 1981; Aksamit and Irving, 1984).

Several workers have determined regeneration status of tree species considering age and diameter of tree population (Marks, 1974; Bormann and Likens, 1979; Veblen *et al*., 1979; Bhuyan *et al*., 2003). Some significant studies on regeneration status and population structure have been carried out by Pritts and Hancock (1983), Saxena *et al.,* (1984), Khan *et al*., (1987), Ashton and Hall (1992), Cao *et al.,* (1996), Uma Shankar (2001) Mishra *et al*., (2003) and Laloo *et al*., (2006). Tree population structure and its implication for regeneration status have been studied in different forest communities situated in Garhwal (Baduni and Sharma, 2001; Bhandari, 2003; Pokhriyal *et al*., 2010), Himachal Pradesh (Sood and Bhatia, 1991), Western Himalayas (Pande *et al*., 2002), Western Ghats (Parthasarathy, 2001) and North eastern region (Yadava *et al*., 1991; Maram and Khan, 1998; Bhuyan *et al.*, 2002, 2003; Mishra *et al*., 2005).

The population structure of tree species largely determines regeneration status and the presence of sufficient number of seedlings, saplings and young trees in a given population indicates high regeneration efficiency (Khan *et al.*, 1987; Mishra *et al*., 2005). A sustained regeneration in the presence of older plants is required for the growth of plant community (Taylor and Zisheng, 1988). Information on forest composition, effects of biotic and abiotic pressure, type of species surviving and the extent of biomass removal can help in rejuvenation of depleting forest through refinement of silvicultural practices, which must be compatible with community involvement (Sundriyal *et al.*, 1994; Murali and Setty, 2001).

The regeneration efficiency of tree determines the future composition of forests (Ayyapan and Parthasarthy, 1999; Henle *et al*., 2004), and therefore, an understanding of the processes that affect regeneration of forest species is of crucial importance (Slik *et al*., 2003). A large number of canopy species are dependent upon the gaps for their regeneration and an understanding of gap dynamics offers an insight into the patterns and processes within the forest ecosystem (Hartshorn, 1980).

The present study has been aimed to determine the effects of sandstone quarrying, a prevalent practice in tropical hilly areas of Mizoram, on plant community characteristics, phytosociological attributes and soil characteristics; and to understand the pattern of recovery of these properties in semi- evergreen tropical forest ecosystem in Tanhril area of Aizawl district of Mizoram.

1.10 Objectives

1. To determine the species composition, relative abundance of species and the level of plant species diversity in natural and degraded forest ecosystems.
2. To study the regeneration potential of key species in natural and degraded forest ecosystems.
3. To measure carbon and nutrient (nitrogen, phosphorus, potassium) dynamics in natural and degraded forest ecosystems.

Chapter- 2

REVIEW OF LITERATURE

The biodiversity assessment and conservation were among important issues in the later phase of the past century mainly after the Earth Summit at Rio de Janeiro in 1992, and continued to be one of the challenging areas of research in the 21st century for ecologists/environmentalists, community, planners and administrators. Many countries including India are party to the Convention on Biological Diversity, each nation has the solemn and sincere responsibility to record the species of plants and animals occurring in their respective countries and evolve suitable management strategies for their conservation. Biodiversity has often been described as the Living Heritage of Man and used as a collection of gene, species and habitat of an area. Therefore, the studies of biodiversity describe the levels of heterogeneity in the composition of the natural ecosystems at various spatial and temporal scales. The diversity of a biological system depends on the number of species present and pattern of distribution of individual species among the ecosystems and various processes occurring at the levels of genes to ecosystems (Hunter, 1990, Kvalseth, 1991).

Biodiversity has been widely suggested to be studied at three levels of organization i.e., genetic diversity, species diversity and ecosystem diversity (Wikipedia, 2010). Measurement of species diversity is one of the most important aspects of community characterization (Thukral *et al.*, 2006). Over the years, various mathematical formulations and statistical methodology of species diversity have merged, each having its specific applications (Shannon and Weaver, 1963; Simpson, 1949; McIntosh, 1967; Pielou, 1975; Magurran, 1988). Extensive studies on the indices commonly used for quantitative measurement of species diversity have been carried out by many workers at the community and ecosystem levels (Wilson and Mohler, 1983; Smith, 1986; Southwood and Henderson, 2000; Meff, 2002; Ponce-Hernandez, 2004; Baumgartner, 2005; Keylock, 2005; Latham, 2005; Legendre *et al*., 2005; Thukral *et al*., 2006). Numerous conceptual models of diversity have been developed that offer mechanistic explanations for the pattern and maintenance of diversity (Connell, 1978; Huston, 1979; Menge and Sutherland, 1987; Crawley *et al*., 1999; Hector *et al*., 2001; Troumbis *et al*., 2002; Forgione *et al*., 2003; Xu *et al*., 2004; Fargione and Tilman, 2005; Mwangi *et al*., 2007).

Human induced disturbances have been widely reported to cause the biodiversity at an unprecedented rate over the world (Pimm *et al*., 1995). This has led to many changes in the ecosystem characteristics like altered species richness, relative abundances and heterogeneity of their distribution at various spatial and temporal scales (He and Legendre, 2002). Species richness is a simple and easily interpretable indicator of biological diversity (Hurlbert, 1971; Peet, 1974; Whittaker, 1977), which has been reported to increase after mild disturbance (Connell, 1978; Grime, 1979; Huston, 1979; Nauch and Whittaker, 1979; Sausa, 1984; Petraitis *et al*., 1989). A number of qualitative and quantitative indices of species diversity have been proposed by several workers (Simpson, 1949; Margalef, 1956; Shannon and Weaver, 1963; Pielou, 1975; Whittaker, 1972) which provide information on compositional change at different analytical level and include species diversity in relation to size of area, relationship between local and regional species diversity and diversity along gradients across space or environmental factors (Busing and White, 1997; Gaston, 2000). Recently, Roy *et al.* (2004) have proposed a vector to account multi-dimensional aspect of biodiversity that should take into account the variation in environmental factors, taxonomic variations among species, compositional diversity and functional diversity.

The phytosociological study is the pre-requisite to understand the dynamics of structural and functional attributes of the ecosystem. These together determine the nature plant community of a place by providing an environment for the species to grow and develop (Busing and White, 1997; Gaston, 2000; Chapin et al 2000). Vegetation structure of plant communities depends on floristic composition and number of species (Gleason, 1926). The floristic composition and species diversity of vegetation reflect the gene pool and adaptation potential of plant community (Odum, 1971). Hanson (1958) reviewed the principles in the formation and classification of communities. Many workers conducted studied on description, classification and ordination of different plant communities around the world (Mueller–Dombois and Ellenberg, 1974; Whittaker, 1965, 1972; Fralish *et al*., 1993). Vander Maarel (1984) has reported that community serves as the context for interpreting population phenomena and concluded that plant communities provide conditions for various flora and fauna population to co-exit.

Several workers have made significant contribution towards biodiversity in the tropics and sub-tropic (Gentry, 1988a, b; Leiberman *et al.*, 1996; Vazquezg and Givnish, 1998; Hubbel, 2001; Chave and Leigh, 2002; Condit *et al.*, 2002; Hall *et al*., 2004; Heindrich and Hurka, 2004; Valencia *et al*., 2004; Paoli *et al*., 2006; Kobayashi, 2007). A number of studies have sought to consider the effects of disturbance on species distribution (Grime, 1979; Tilman, 1987; Wilkinson, 1999; McCabe and Gotelli, 2000; Slik *et al.,* 2002; Snyder and Boss, 2002; Stevens and

Carson, 2002; McLaraen and McDonald, 2003; Ackerly, 2004; Baer *et al.,* 2004). Pierce *et al.* (2007) have studied the influence of disturbance on the functions and frequency of the species comprising alpine sedge dominated region in eastern European Alps, Lombardy, Italy. Many other studies suggested that environmental factors are closely linked with species diversity in forests ecosystem (Whittaker, 1956; Gentry, 1988b; Tuomisto *et al*., 1995, 2003; Clark *et al*., 1999; Webb and Peart, 2000; Harms *et al*., 2001; Takyu *et al.*, 2002; Phillips *et al*., 2003; Hall *et al*., 2004; Legendre *et al.*, 2005). Kubota *et al.* (2004) studied the effects of topographic heterogeneity on tree species richness and stand dynamics in a sub-tropical forest in Okinawa Island, Southern Japan.

Tree species diversity in the tropics varies dramatically from place to place (Pitman *et al*., 2002). Much attention has been given to tropical forests due to their high species richness (Whitmore, 1984), high standing crop biomass (Bruenig, 1983) and greater productivity (Jordan, 1983). Tall trees could be better competitors for light and less resource limited than shorter understory trees and shrubs (Kelly, 1996). Thomas and Bazzaz (1999) have observed that tall canopy trees in a Malaysian rain forest have higher photosynthetic capacity relative to understory species. Dominant trees in temperate forests also tend to have similar traits (Kobe, 1996, Koike, 2001), indicating that similar processes might regulate tree distributions in tropical and temperate forests.

Recently, extensive geospatial approaches has been developed by Indian Institute of Remote Sensing Dehradun for effective use of satellite imagery data (Romme, 1982; Lyon, 1983; Forman and Godron, 1986; Belal and Springuel, 1996; IIRS, 2002).

Further, the approach has been extended to landscape biodiversity characterization at national level through a project carried out between 1998- 2010 to create a country level database on the spatial distribution of biodiversity of flowering plant in forested landscape (Roy *et al.*, 2012a, Roy *et al.*, 2012b). This study has resulted in an extensive baseline spatial data on vegetation types, porosity and patchiness, interspersion, juxtaposition, fragmentation, disturbance regimes, ecosystem uniqueness, terrain complexity and biological richness. The detailed methodology, sampling techniques and biological richness have been published (Roy *et al.*, 2005; IIRS 2003a,b,c,d; NRSA 2007a,b; IIRS 2011a,b,c,d). Roy and Srivastava (2012) have used geospatial approach to identify potential hotspots of land use and land cover change for biodiversity conservation.

India constitutes about 2.4% of total geographical area of the world and holds 8% of the global biodiversity (Kumar and Asija, 2000). India is a vast country with a rich diversity with a total of 1, 36, 000 species (47, 000 species of plants and fungi and 89, 000 species of animals) of biotic resources (Khoshoo, 1995, 1996; MoEF, 1999) this could be attributed to large variations in the physical environment, latitude, longitude, geology, climate and altitude. The plant wealth of the country roughly constitutes 12% of the world plant diversity (Jain, 1987; Tiwari, 1993). About 17,000 species of flowering plants have been described in India (Khoshoo, 1995). As many as 3000 to 4000 plants have been reported as endangered (Chaturvedi, 1994). Western Ghats, Andaman and Nicobar Islands, Himalaya and North East India are still very rich in biodiversity, and therefore have tremendous scope for biodiversity conservation in the Indian context (Singh *et al*., 1994).

In India, several workers have studied floristic diversity in tropical forests of the Western Ghats (Ganesh *et al.,* 1996; Parthasarathy and Karthikeyan, 1997; Ayyappan and Parthasarathy, 1999; Parthasarathy, 2001; Ramesh, 2001; Davidar *et al.,* 2005, 2007b; Gunawardene *et al.*, 2007; Anitha *et al*., 2008), Eastern Ghats (Rao and Hajra, 1986; Kadavul and Parthasarthy, 1999; Shankar, 2001; Devi and Behera, 2003; Sagar *et al.,* 2003; Arunachalam *et al*., 2004; Behra and Misra, 2006) and Central Himalaya (Ralhan *et al*., 1982; Saxena and Singh, 1982; Singh and Singh, 1987; Tripathi *et al.,* 1987; Khera *et al*., 2001; Kharkwal *et al*., 2005; Ram *et al*., 2005; Gupta and Narayan, 2006). Ramanujam and Kadamban (2001) studied plant biodiversity of two tropical dry evergreen forests in the Pondicherry region of South India. Tripathi *et al*. (2004b) reported species diversity of Saddle peak forests in Andaman Island.

From the ecological view point, the maintenance of biological diversity is an assessment of the relative importance in terms of diversity of different areas, habitats or ecosystem. The north-eastern India is very significant in terms of high biodiversity with high level of endemism (Khan *et al*., 1997). Out of a total of 3331 plant species, 1236 (37.1%) are endemic to Meghalaya and 133(4%) are confined to the sacred forests. The Assam provinces are the richest in biological species among the eastern Himalayan region (Daniels, 1993). In North-eastern India, several studies have been carried out to quantify plant diversity and to understand the ecology of forest communities of different areas (Khan *et al.,* 1987; Jamir, 2000; Parthasarathy, 2001; Bhuyan *et al.,* 2003; Tripathi *et al.*, 2004a; Paul *et al*., 2005; Mishra *et al*., 2003, 2004, 2005; Kumar *et al*., 2006; Laloo *et al.,* 2006; Upadhaya *et al.,* 2008; Mishra, 2010; Tynsong and Tiwari, 2010; Tynsong and Tiwari, 2011). The plant inventory and community characteristics of tropical semi-evergreen forest of Mizoram have been studied by some workers (Lalramnghinglova, 2003; Lalnunmawia, 2003; Lalramenga, 2006a, b; Lalnuntluanga, 2007; Lalchhuanawma, 2008; Lalfakawma *et al.,* 2009; Rai and Lalramnghinglova, 2010).

The existence of a forest community depends on the successful regeneration of the species composing the forest stand in time and space. The recruitment of tree seedlings plays a major role in determining the later forests composition and the finale configuration of the community is controlled by safe sites and barriers to survival that are species specific and variable over space and time (Grubb, 1977; Cornett *et al*., 2000; Castro *et al*., 2004). Understanding the processes of tree population recruitment and their limitation is the scientific basis to assure the forest natural regeneration and to improve techniques of restoration and afforestation (Maronon *et al*., 2004). Several workers have predicted the regeneration status of tree species based on the age and diameter structure of population (Grubb, 1977; Priffs and Hancock, 1983; Breckle, 1997; Delisssio *et al*., 2002; Pariona *et al*., 2003; Pollman and Veblen, 2004; Appolinario *et al*., 2005; Wangda and Ohsawa, 2006).

The interaction between seed germination requirement and its environment is thought to be critical in determing species distribution (Forbis *et al*., 2004). Numerous studies have reported that germination and survival of tree seedlings are influenced by various factors including moisture (DeSteven, 1994; Battaglia *et al*., 2000; Connell and Green, 2000; Gilbert *et al*., 2001; Miura *et al*., 2001; Delissio and Primack, 2003; Uriate *et al.*, 2004a,b), light (Kobe, 1999; Battaglia *et al*., 2000; Poorter and Arets, 2003; Linn *et al*., 2004; Landis and Peart, 2005; Uriarte *et al*., 2005; Ninemets, 2006; Yamada *et al*., 2006) and soil characteristics (Baillie *et al*., 1987; Herrera, 2002; Philips *et al*., 2003 and Palmiotto *et al*., 2004). Batlzer and Thomas (2007) compared whole plant light compensation point for growth and survivorship of saplings of

Bornean tree species which differ in shade tolerance and evaluated the importance of various physiological and morphological traits in predicting whole plant light compensation point. They argued that minimum light level for growth do not diverge from those for survivorship and do not support the view that low-light survivorship solely determines shade tolerance. The role of disturbance in forest stand dynamics has been studied extensively as it is importance for regeneration, co-existence and diversity of tree species (Armesto and Pickett, 1985; Foster, 1988; Veblen, 1992; Runkle *et al*., 1995; Kusipalo *et al*., 1996; Molino and Sabatier, 2001; Sousa *et al*., 2003; Forbis *et al*., 2004; Gutierrez *et al*., 2004; Pollmann and Veblen, 2004; Brown and Wu, 2005 and Smith *et al*., 2005).

There have been considerable works on the effects of microhabitat variability on seedling establishment and growth of forest tree species (Wilson, 1983; Kadmon and Shmida, 1990; Clark *et al*., 1999; Kollmann, 2000; Blundell and Peart, 2001; Harms *et al*., 2001; Montgomery and Chazdon, 2001; Dalling and Hubbell, 2002; Potts *et al*., 2002; Pearson *et al*., 2003; Phillips *et al*., 2003; Matthes and Larson, 2006). Wright *et al*. (2005) carried out detailed study on spatial and temporal variation in seedfall and seedling recruitment in a seasonal tropical forest of Panama, and reported that mechanisms driving seedling dynamic may vary over time, both spatial and temporal variation should be assessed simultaneously. Yamada *et al*. (2007) analysed habitat specific performance and demography of a tropical rain forest with strong habitat preference at Lambir hills, Malaysia and found that strong habitat preference of rain forests tree species does not necessarily imply strong difference in tree performance, demography or population growth across habitats. Many workers have reported the effects of intra and inter-specific competition in seedling regeneration (Barton, 1993; Fowler, 1995; Freckleton and Watkinson, 2001; Canham *et al*., 2004; Uriarte *et al*., 2004b; Barberis and Tanner, 2005; Ladd and Facelli, 2005; Stoll and Newbery, 2005). Massey *et al*. (2006) studied effects of neighbourhood composition on the growth and herbivory of tropical rainforest tree seedlings and suggested that diversity of seed banks can be an important determinant of regeneration success and forest dynamics.

In India, many workers have reported the population structure, regeneration status of tree species from different forest of Central Himalaya (Ralhan *et al*., 1982; Saxena and Singh 1982, 1984; Singh *et al*., 1986; Rikhari *et al*., 1991; Rajwar *et al*., 1999; IIyas and Khan, 2005), Sal forest of Eastern Himalaya (Shankar, 2001), Plantation forest of Uttara Kannada district and Western Ghats (Murthy *et al*., 2002; Shrikant *et al.*, 2013), forest vegetation of North-Eastern Uttar Pradesh (Pandey and Shukla, 2001; Pathak and Shukla, 2004). Davidar *et al*. (2007a) studied that effects of adult tree density on regeneration success of woody plants in natural tropical dry evergreen forest of Pondicherry, and concluded that restoration success depends on the population size of adults.

In north-eastern India, several workers have studied the population behaviour and regeneration pattern of woody plants in sub-tropical forests of Meghalaya (Barik *et al*., 1996; Jamir, 2000; Tripathi *et al*., 2004a; Mishra *et al*., 2003; Laloo *et al*., 2006; Tripathi *et al*., 2010; Mishra and Jeeva, 2012), Arunachal Pradesh (Bhuyan *et al*., 2002 and Duchok *et al*., 2005), Assam (Borah and Garkoti, 2011) and Manipur (Khumbongmayum *et al*., 2005). Tripathi and Khan (2007) also worked on regeneration dynamics of natural forests and important aspects related to processes and phases of natural regeneration. The available literature depicts that there is paucity of data and information on the subject with regards to the state of Mizoram. Lalfakawma (2007) has studied regeneration of plants with limited objectives.

The species composition of a forest determines chemical composition of soil and soil fertility (VanDerKrift and Berendse, 2001). The past workers have argued that dominant plant species act as an important biotic factor in controlling ecosystem fertility (Berendse, 1990; Wedin and Tilman, 1990). The effects of disturbance on elemental cycling and nutrient loss in forest ecosystems have been a matter of long standing concern among the forest scientists. Elements losses following disturbance have been used to characterize the degree of homeostasis in forest biogeochemical cycle and is considered as a useful measure of ecosystem stability.

Mining activities change the soil physical, chemical and biological properties, and play the major role in determining soil fertility, as degradation of soil adversely affects nutrient inputs (Alfred *et al*., 2008). The soil nutrient build up during the initial stages of ecosystem succession is also a gradual process that would favour the growth of plant species that are shade intolerant or low in nutrient efficiency (Arunachalam *et al*., 2000). Heterotrophic populations (bacteria, fungi) may thrive better and have an important role to play in soil nutrient cycling (Arunachalam *et al*., 1997). In humid tropics, standing crop biomass has been reported as the major storehouse of nutrients instead of the soil (Greenland and Herrera, 1975).

The physical and chemical properties of the soil are highly influenced by several factors. The physical properties of the surface soil are affected by climatic conditions, slope, elevation, aspects, nature of parent material, exposure and human activities. Similarly, the chemical properties are affected by erosion, leaching and removal of nutrient elements and accelerated oxidation of organic matter. Heterogeneity in texture, structure and composition of the soil matrix introduces the differences occurring in its physical and chemical properties. The physico-chemical characteristics of soil have been studied by several workers worldwide (Thompson *et* *al*., 1954; Rodin and Bazilevich, 1967; Brunig, 1970; Kawahara and Tsutsumi, 1972; Sorensen, 1972; Duvigneaud and Delayers de-Smet, 1970; Funakawa, 1997; Finer *et al*., 2003; Tanaka *et al*., 2004; Gundale *et al*., 2005; Zhang *et al*., 2010; Arifin *et al*., 2012).

In India, significant researches on physico-chemical characteristics of soil have been carried out in natural forest ecosystem by several workers (Pandey, 1980; Negi *et al*., 1983; Chaturvedi and Singh, 1987; Rawat and Singh, 1988; Singhal *et al*., 1989; Arunchalam *et al*., 1994; Tripathi and Singh, 1994; Semwal and Bhatt, 1994; Maithani *et al*., 1998; Pathak and Gupta, 2004; Roy *et al*., 2005; Sharma *et al*., 2006; Bajrachyarya *et al*., 2007; Tripathi *et al*., 2008; Semwal *et al*., 2009). Mishra (2011) has studied the soil nutrients status from monoculture to polyculture considering broad-leaved, mixed pine and pine forests of Meghalaya, north-east India. He has reported increase in soil fertility from monoculture to polyculture. It seems that the studies on chemical composition and dynamics of soils of different types of forests in Mizoram are still in juvenile stage. Some preliminary studies on nutrient status in soil of semi-evergreen forests of Mizoram have been carried out by Lalchhuanawma (2008) and Tawnenga (1996).

CHAPTER- 3

MATERIAL AND METHODS

3.1 Description of study area

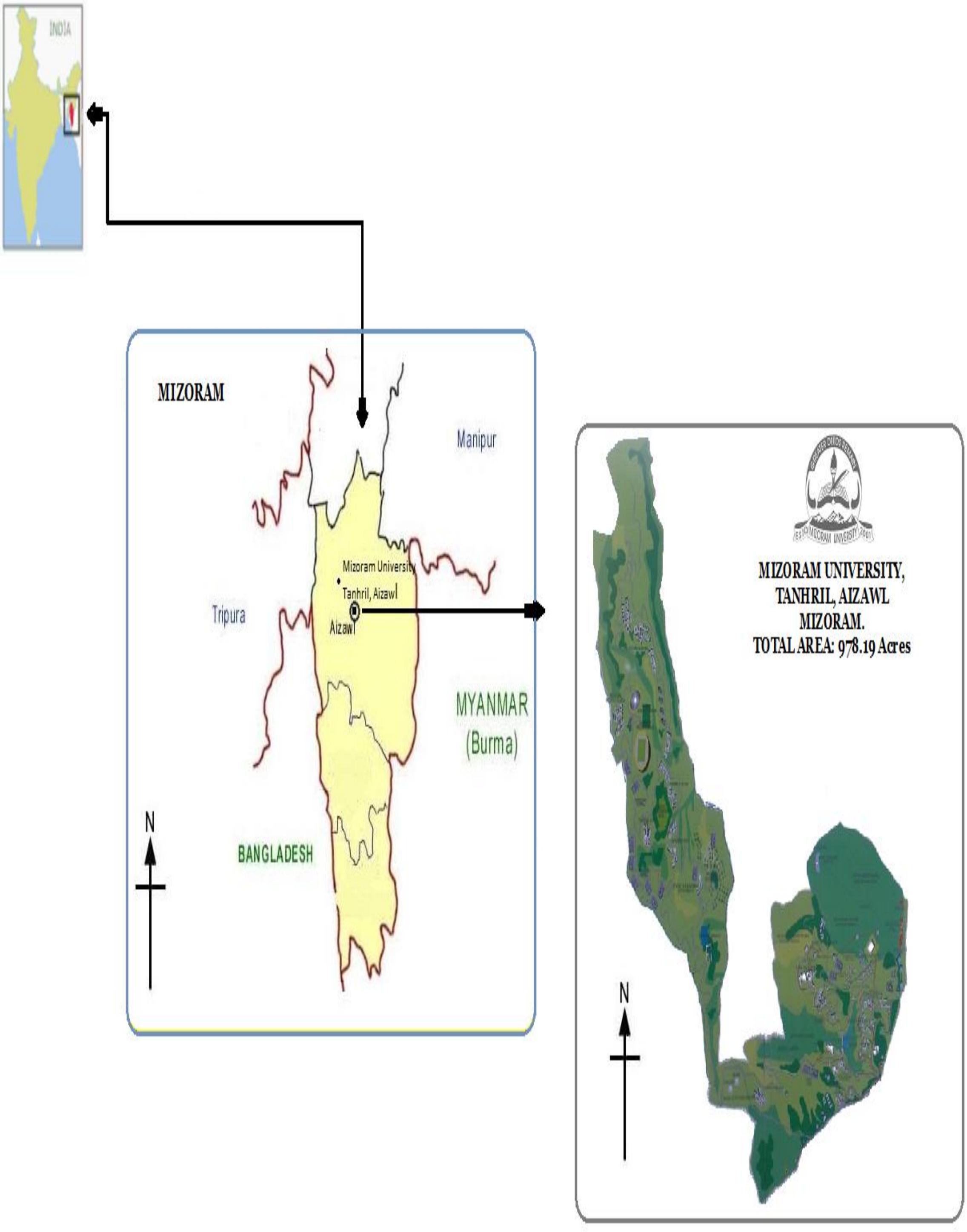
The state of Mizoram (21^{o}58'- 24^{o}35' N latitude and 92^{o}15'- 93^{o}29' E longitude) is bordered by Myanmar to the east and south, Bangladesh to the west, and by the Indian states namely, Assam, Manipur and Tripura to the north. Mizoram means land of highlanders, and it has undulating topography with several troughs and peaks that ranges from 800 m to 2000 m asl (near the Myanmar border). The capital of state is Aizawl (21°56'- 24°31' N latitude and 92°16'- 93°26' E longitude) with a mean elevation of 1132 m asl. The map showing the study area has been presented as (Map.3.1).

The study was conducted in the forest patches within and outside the Mizoram University campus situated in Tanhril area (23^{o}45'25" N- 23^{o}43'37" N latitude and 92^{o}38'39''E- 92^{o}40'23"E longitude) of Aizawl district, Mizoram. The University campus is located in the western part of Aizawl district which is 15 km away from the Aizawl city.

For present investigation, three distinct study sites were selected along disturbance gradient representing undisturbed (UD), moderately disturbed (MD) and highly disturbed (HD) stands. The natural forest stand where no stone mining activity was done in the past referred to as undisturbed stand (Plate. 3.1 A and B). The moderately disturbed forest stand is a secondary forest developed naturally after the abandonment of stone mining activity (mining operation about 7 years back in 2002 3.2 A and B). The highly disturbed forest stand is an open mining area where there is less vegetation (Plate. 3.3 A and B). The forest vegetation falls under three tropical semi-evergreen forests (Champion and Seth, 1968). Vegetation characteristics of the study sites are shown in Table. 3.1.

Table: 3.1. Canopy cover, light interception and disturbance index in the undisturbed, moderately disturbed and highly disturbed forest stands.

	Stands		
Parameter	**Undisturbed**	**Moderately disturbed**	**Highly disturbed**
Canopy cover (%)	>80	20 - 80	<20
Light interception (%)	>80	20 - 80	<20
Disturbance Index (%)	Zero	23.5	58



Map. 3.1 Map of Mizoram showing the study area.

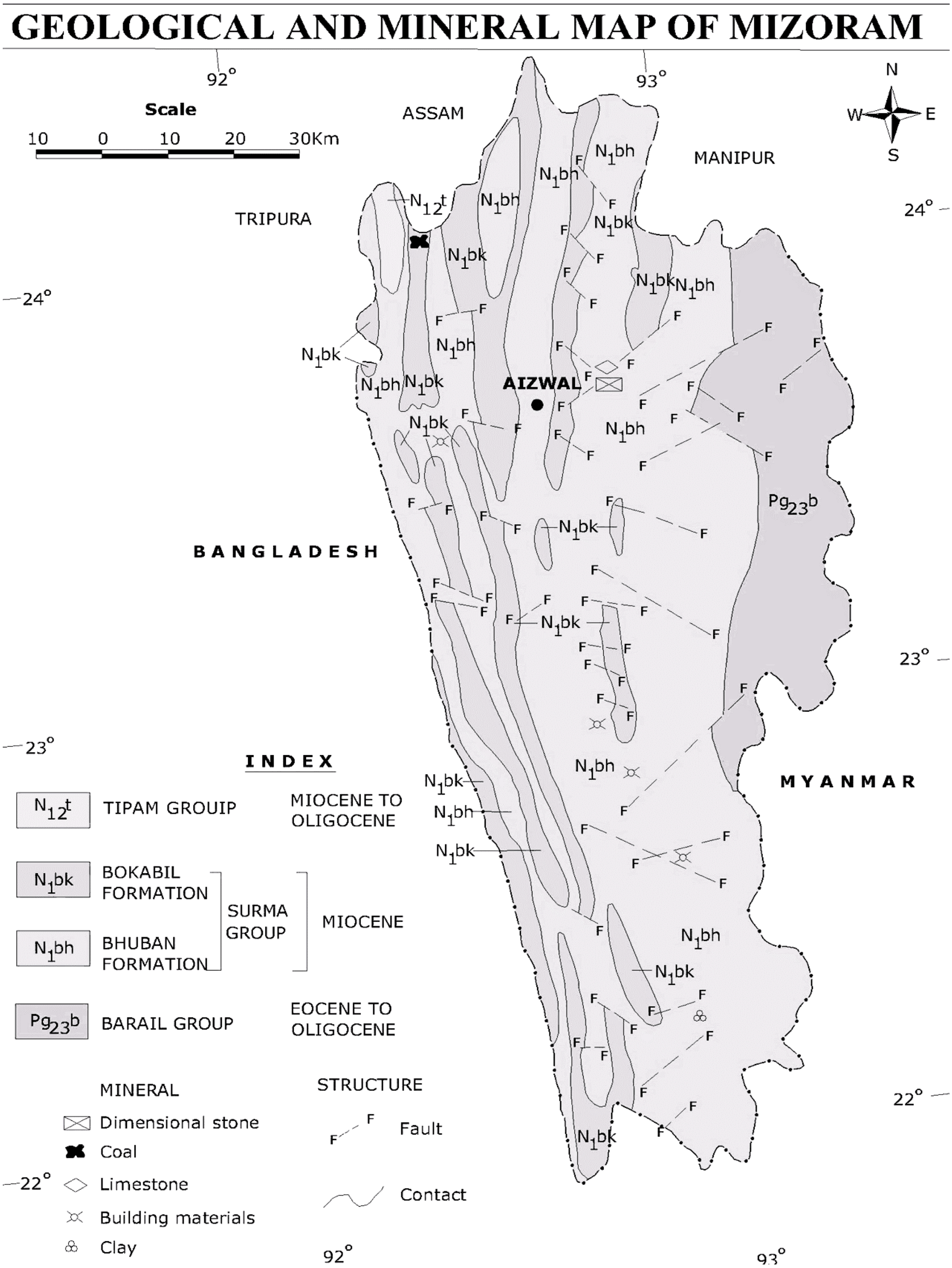
Plate. 3.1. Overview (A) and close veiw (B) of undisturbed forest stand.

Plate. 3.2. Overview (A) and close veiw (B) of moderately disturbed forest stand

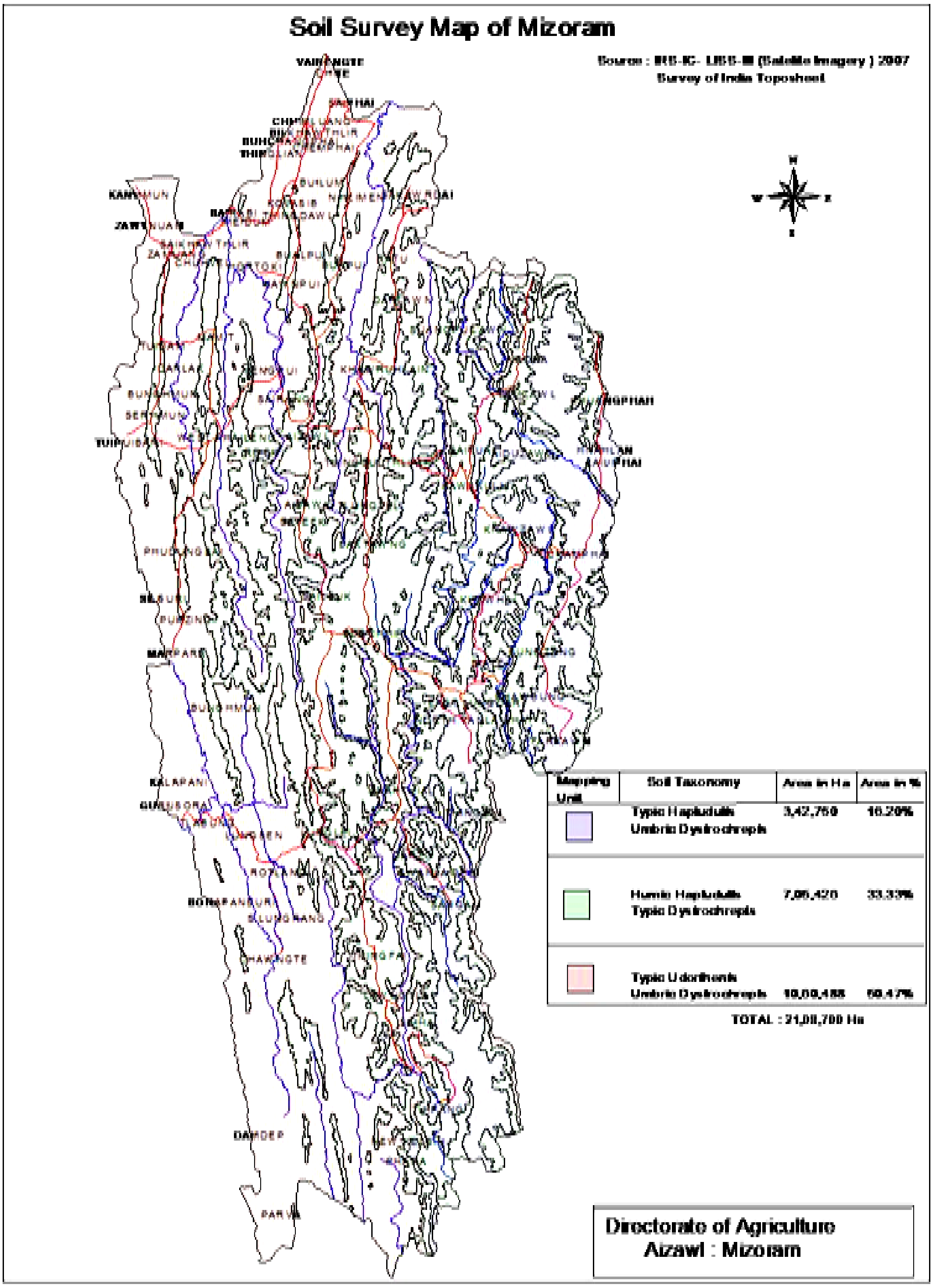
Plate. 3.3. Overview (A) and close veiw (B) of highly disturbed forest stand.

3.1.1 Topography

The topography of Mizoram is unique. There are N-S trending mostly anticlinal strike ridges with steep slopes and narrow intervening synclinal valleys and a series of parallel hummocks or topographic highs. The rock system is in formation stage, generally weak, unstable, weathered and prone to seismic and weather influence producing landslides. The soft, black to grey rock is used locally for building materials and low trafficked road construction work. Typical soils are sandy loam and clay loam has been heavily leached due to the high slopes leaving it porous and lacking in minerals or humus. The geology and mineral map, soil survey map of Mizoram are given as Map. 3.2 and 3.3.



Map. 3.2 Map showing the geology of the state of Mizoram



Map. 3.3 Map showing the soil survey of the state of Mizoram

3.1.2 Climate

The climate of the area is typically monsoonic with three distinct seasons, i.e. warm-wet rainy season (June to October), cool-dry winter season (November to February), and hot dry summer season (March to May). During rains the climate in the lower hills is humid and enervating. It is quite cool and pleasant on the high hills, even during the hot season. Heavy storms come from the north-west and they sweep over the hills in the entire state. Mizoram, as a whole, gets an average rainfall of about 3,000 mm with Aizawl town having 2350 mm. Temperature in the state varies from 11^{o}C to 21^{o}C in winter and 20^{o}C to 30^{o}C in summer (Laltlanchhuanga, 2006). There is sparse rain during the winter months.

3.1.3 Study area characteristics

The meteorological data from 2009 to 2011 was procured from Border Roads Task Force (BRTF), Puspak, Aizawl. The study site characteristics may be presented as follows.

3.1.3.1 Temperature

The average ambient air temperature were range from 17.32 ^{0}C to 27.27 ^{0}C. The maximum and minimum monthly temperature values were 29.66 ^{0}C (April) and 20.88 ^{0}C (April) during 2009; 31.04 ^{0}C (March) and 20.54 ^{0}C (July) during 2010; 28.67 ^{0}C (April) and 20.97 ^{0}C (September) during 2011 (Fig. 3.1.1).

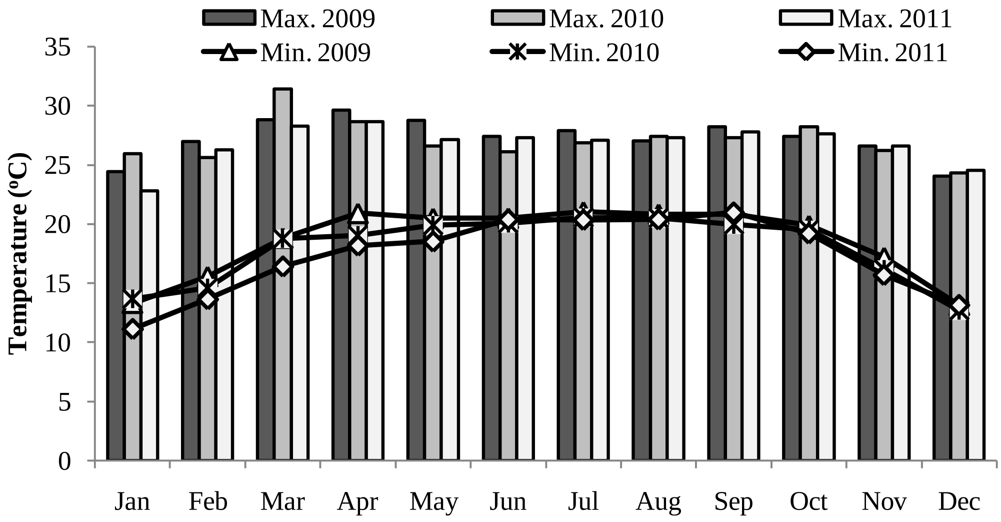


Fig. 3.1.1: Monthly average air temperature (maximum and minimum ^{0}C) of Aizawl from 2009 to 2011.

3.1.3.2 Relative humidity

The relative humidity was range from 75.07%, 77.96% and 78.19% respectively. The maximum and minimum monthly humidity values were 92.06 % (August) and 51.61 % (March) during 2009; 93.87 % (August) and 54.06 % (March) during 2010; 93.19 % (August) and 60.09 % (March) during 2011 (Fig. 3.1.2).

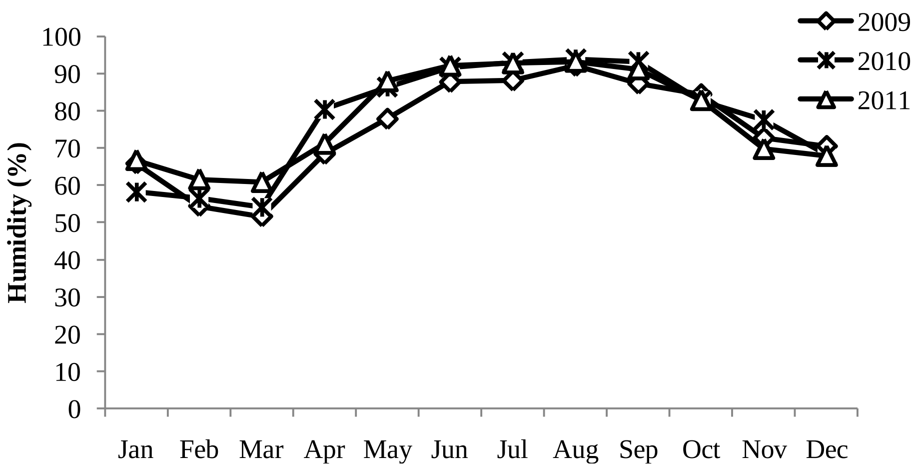


Fig. 3.1.2: Monthly average humidity (%) of Aizawl from 2009 to 2011.

3.1.3.3 Rainfall

During 2009- 2011, Aizawl received total annual rainfall of 2092 mm. The maximum and minimum monthly rainfall values were 361.7 mm (September) and 14.6 mm (March) during 2009; 477.7 mm (September) and 15.8 mm (February) during 2010; 442.5 mm (August) and 0.7 mm (February) during 2011 (Fig. 3.1.3).

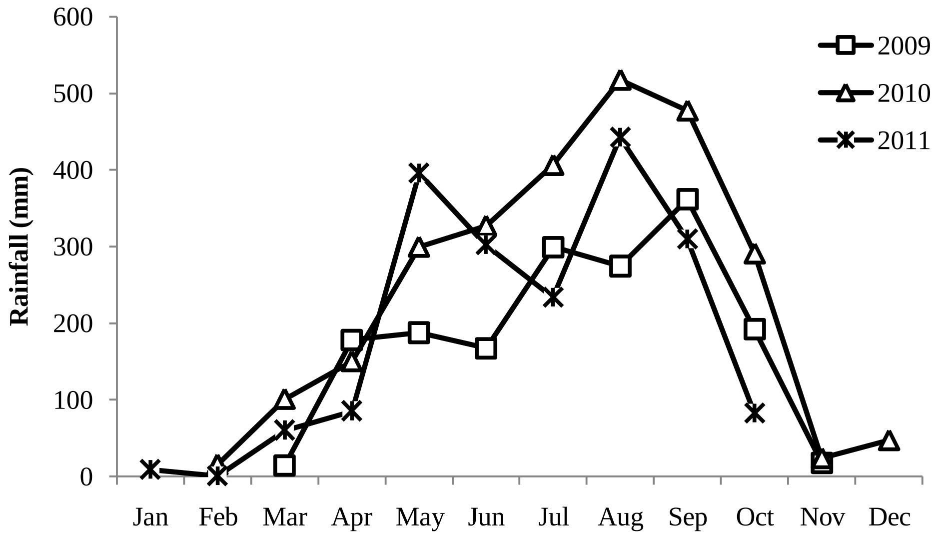


Fig. 3.1.3: Monthly average rainfall (mm) of Aizawl from 2009 to 2011.

3.2 Methods

3.2.1 Field Sampling and Identification of Plant Species

The field study was carried out during 2009 to 2011, for vegetation and soil analysis. The phytosociological study was conducted during the peak vegetative growth, which occurred in September. The quadrat method was adopted for field data on vegetation. The size of quadrat was 10 x 10m for trees, 5 x 5m for shrubs/ saplings and 1 x 1m for herbs/ seedlings. The plant species were identified with the help of herbarium of the concerned University Department, herbarium of the BSI, Eastern circle, Shillong, and counter checked with the help of flora (Kanjilal *et al.*, 1934-40; Haridasan and Rao, 1985). The soil samples were collected from two depths i.e., top-soil (0-10cm depth) and sub-soil (10-20cm depth) for analysis of various physico-chemical characteristics.

3.2.2 Analysis of vegetation

The field data on vegetation was analyzed for frequency, density and abundance as proposed by Curtis and Mclntosh (1950). The basal area is regarded as the index of the dominant of species and nature of the community. The circumference/girth at breast height (1.37m) was taken for determination of tree basal area. The Importance value index (IVI) was calculated as per Philips (1959). The ratio of abundance to frequency (A/F) for different species was determined for eliciting the distribution patterns (Whitford 1949). Dominance-diversity curve for trees was plotted by a co-ordinate point method by placing IVI on y- axis and its position in the sequence of species from highest to lowest IVIs on x- axis (Whittaker 1975). Species composition and relative abundances were calculated following the methods as outlined by Misra (1968) and Mueller-Dombois and Ellenberg (1974). The population structure of trees in different girth classes was also calculated. Following formulae were used for calculating various parameters.

Frequency:

Frequency refers to the number of sampling units in which a particular species occurs. Thus, frequency of each species was calculated as follow:

$$\text{Frequency (\%)} = \frac{\text{Number of sampling units in which the species occurred}}{\text{Total number of sampling unit studied}} \times 100$$

Density:

Density is used to describe the characteristic of plant communities. Basically, it is number of individuals per unit area, and it gives an idea of degree of competition. It was calculated as follow:

$$\text{Density (Indv. ha}^{-1}\text{)} = \frac{\text{Total number of individual of a species in all sampling}}{\text{Total number of sampling unit studied}} \times 100$$

Abundance:

Abundance is the number of individuals of a species per sampling unit of occurrence. It was calculated as follow:

$$\text{Abundance} = \frac{\text{Total number of individuals of a species in all sampling units}}{\text{Number of sampling units in which the species occurred}}$$

Importance value index:

The IVI is used to determine the overall importance of a species within community. This is the sum of the relative frequency, relative density and relative dominance values of a species (Philips, 1959).

IVI of a species = Relative frequency + Relative density + Relative dominance

Distribution pattern:

The distribution pattern of species was calculated by dividing the abundance of a species by frequency (F) of the species as the method suggested by Curtis and Cottam (1956) and calculated as follow.

$$\text{Distribution pattern} = \frac{\text{Abundance of a species (A)}}{\text{Frequency of a species (F)}}$$

The distribution of plants is said to be regular, random and contagious when the value of A/F ratio is <0.025, between 0.025-0.05 and >0.05, respectively.

Shannon diversity index:

Shannon-Weiner diversity index proposed by Shannon and Weaver (1963) was calculated by the following formula.

$$H' = -\sum_{i=1}^{s} p_i \ln p_i$$

Where, H’ = Shannon-Weiner index of diversity,

p_i = the proportion of important value of the i^{th} species.

Simpson dominance index:

The Simpson index of dominance (1949) was calculated as follows.

$$D = \frac{\sum_{i=1}^{s} qi\,(qi-1)}{Q\,(Q-1)}$$

Where, qi = Total number of individual of a particular species

Q = Total number of individual of all species

D = Simpson dominance index

Simpson index of diversity:

The Simpson index of diversity was calculated as follows.

= 1- D

Where, D = Simpson dominance index

Margalef's index of species richness:

The Margalef's index of species richness (1972) was calculated as follows.

$$D = \frac{S-1}{\ln N}$$

Where, D = Margalef's index

S = Number of species

N= Number of the individuals.

Evenness index:

The evenness index (Pielou's index, 1957) was calculated as follows.

$$E = \frac{H'}{H'max}$$

Where, H' = Shannon's index value

H'max = InS, S = Total number of species

Similarity index (Sorenson's index):

The similarity index (Sorenson's, 1948) was calculated as follows.

$$\text{Sorenson's index of similarity(S)} = \frac{2C}{A+B}$$

Where, C = Species common in both the stands.

A= Species present in stand A.

B= Species present in stand B.

Disturbance index:

Canopy cover was taken into consideration for determing disturbance index.

3.2.3 Natural regeneration

The regeneration status of woody species was determined through ration of seedlings to saplings and saplings to trees. Four dominance and medicinally important woody species namely, *Callicarpa arboria* Roxb., *Castanopsis tribuloides* DC., *Schima wallichii* (DC) Korthals and *Sterculia villosa* Roxb. Ex. Smith. were selected for regeneration study. These species were present in all three study sites. The seedling was observed at month interval for mortality, and factors causing seedling mortality. The population in different stages i.e., seedlings (one m height or gbh below 5cm), saplings (gbh 5 to <30cm) and trees (gbh 30cm and above) was taken into account for determination of regeneration efficiency of a species.

$$\text{Conversion of seedlings into saplings (\%)} = \frac{\text{Number of saplings}}{\text{Number of saplings} + \text{seedlings}} \times 100$$

$$\text{Conversion of saplings into trees (\%)} = \frac{\text{Number of trees}}{\text{Number of trees} + \text{saplings}} \times 100$$

3.2.4 Soil Analysis

The soil samples were collected in triplicate from selected study sites during February 2010 to January 2011 at monthly intervals, and the result was expressed seasonally i.e., early rain (April), late wet (September), early dry (December) and late dry (February). The soil samples were collected with the help of soil corer for top-soil (0-10cm depth) and sub-soil (10- 20cm depth). The samples were brought to the laboratory for analysis and air dried and then powdered with the help of mortar and pestle. The powdered samples were passed through 2 mm sieve, and used for the analysis of soil physic-chemical properties namely, soil moisture content, soil pH, soil organic carbon, total nitrogen, available phosphorus, and exchangeable potassium by the methods outlined by Allen *et al*., (1976) and Anderson and Ingram (1993).

Soil Moisture Content:

The soil moisture content was calculated as the difference between fresh and dry soil samples after drying in oven for 24 hours at 105^0C temperature.

Soil pH:

The pH was measured by a pH meter using glass electrode in the supernatant suspension of 1:2.5 ratio of soil water.

Organic carbon:

Organic carbon concentration in soil was determined by rapid titration method as the procedure outlined by Walkley and Black's (1934). Known amount of soil (1.0 g) was added with known volume (10 ml) of 1 N solution of $K_2Cr_2O_7$ and concentrate H_2SO_4. After half an hour of digestion the remaining amount of $K_2Cr_2O_7$ was determined by titration with ferrous ammonium sulphate solution, using Diphenylamine as an indicator. Organic carbon concentration in the soil was calculated as formula given below:

$$\text{Organic carbon (\%)} = 0.003 \times \frac{10\ \text{(blank reading-titration reading)}}{\text{Blank reading} \times \text{Weight of the soil (g)}} \times 100$$

Total nitrogen:

Total nitrogen in the soil was analysed by kjeldahl digestion and distillation procedure (Jackson, 1958). The known amount of soil was digested with strong sulphuric acid to convert the organic nitrogenous compounds into ammonium which was then distilled with NaOH to liberate NH_4^+ which then was trapped in boric acid solution and back titrated with standard H_2SO_4 solution. During the digestion potassium sulphate was added to raise the boiling point of the mixture during digestion and copper sulphate and selenium powder mixture were added as catalyst (Misra, 1968).

Available phosphorous:

Olsen method was used to determine available phosphorous content in the soil. The sample was extracted with sodium bicarbonate solution at pH 8.5. Available phosphorus in the extract was determined calorimetrically by ammonium molybdate and stannous chloride blue colour method (Jackson, 1958; Misra, 1968).

Exchangeable potassium:

Exchangeable potassium in the soil was determined with flame photometer by extracting the soil with 1 M ammonium acetate solution and comparing the strength of unknown solution with that of known solution (Jackson, 1958; Misra, 1968).

CHAPTER- 4

RESULTS

The findings of the present investigation are described below:

4.1 Vegetation characteristics

4.1.1 Forests stand compositions

A total of 189 plant species belonging to 143 genera and 69 families of angiosperms were recorded from undisturbed, moderately disturbed and highly disturbed forest stands. Of this, 120 species representing 102 genera and 53 families, 134 species belonging to 106 genera and 50 families and 105 species belonging to 87 genera and 46 families were reported from undisturbed, moderately disturbed and highly disturbed stand, respectively. There was a shift in position of plant habits. Number of tree species was decreased from undisturbed to highly disturbed stand. On contrary, number of shrubs and herbs was increased from undisturbed to highly disturbed stand (Table 4.1 to 4.3).

The undisturbed stand was comprised of 50 tree species (belonging to 43 genera and 29 families) followed by 49 tree species (from 41 genera and 22 families) in moderately disturbed and 24 tree species (from 21 genera and 17 families) in highly disturbed stand (Table 4.1). Corresponding values for shrub species were: 26 species (from 23 genera and 16 families) in undisturbed stand, 38 species (from 27 genera and 21 families) in moderately disturbed and 43 species (from 36 genera and 26 families) in the highly disturbed stand (Table 4.2). The herbaceous vegetation comprised of 34 species (from 29 genera and 24 families of angiosperms), 48 herb species (from 45 genera and 29 families) and 55 herb species (52 genera and 30 families) in the undisturbed, moderately disturbed and highly disturbed stands, respectively (Table 4.3).

4.1.2 Community characteristics

There was sharp decline in tree density from undisturbed stand (970±3.2 indv. ha^{-1}) to the moderately disturbed stand (742±3.4 indv. ha^{-1}) and finally to the highly disturbed stand (410±3.2 indv. ha^{-1}). A similar trend was observed for total tree basal area which was highest in the undisturbed stand (20.83 m^2ha^{-1}) followed by moderately disturbed stand (9.85 m^2ha^{-1}) and highly disturbed stand (5.38 m^2ha^{-1}). In contrast, the total density of shrub and herbaceous species was highest in highly disturbed stand followed by moderately disturbed stand and undisturbed stand. Shannon-Weiner diversity index for tree species was maximum (3.3) in the undisturbed stand and minimum in the highly disturbed stand (2.6). On the contrary, Shannon-Wiener index for shrubs and herbs was recorded minimum in the undisturbed stand. A reverse trend in the results was observed in case of the Simpson index of dominance. The species richness (Margalef's Index) of tree species was maximum in moderately disturbed stand followed by undisturbed stand and highly disturbed stand but in case of shrub and herbaceous species it was maximum in highly disturbed stand followed by moderately disturbed and highly disturbed stands. The Evenness Index (Pielous Index) for tree, shrub and herbaceous species did not show much variation in results with respect to the degree of disturbance (Table 4.1 to 4.3).

Table 4.1. Tree community structure in the undisturbed, moderately disturbed and highly disturbed forest stands.

Parameter	Forest Stands		
	UD	MD	HD
No. of Family	29	22	17
No. of Genera	43	41	21
No. of Species	50	49	24
Tree density (Indv.ha^{-1})	970±3.2	742±3.4	410±3.2
Tree basal area (m^{2}h^{-1})	20.83	9.85	5.38
Shannon-Weiner index	3.3	2.9	2.6
Simpson dominance index	0.07	0.12	0.1
Simpson index of diversity	0.9	0.8	0.8
Simpson reciprocal index	13.3	8.2	9.1
Species Richness (Margalef's index)	7.5	7.7	4
Evenness index (Pielou)	0.84	0.74	0.81

Table 4.2. Shrub community structure in the undisturbed, moderately disturbed and highly disturbed forest stands.

Parameter	Forest Stands		
	UD	MD	HD
No. of Family	16	21	26
No. of Genera	23	27	36
No. of Species	26	38	43
Shrub density (Indv.ha^{-1})	1257	1680	2217
Shannon-Weiner index	2.9	3.3	3.4
Simpson dominance index	0.08	0.04	0.05
Simpson index of diversity	0.9	0.9	0.9
Species Richness (Margalef's index)	4.63	6.5	7.04
Evenness index (Pielou)	0.89	0.9	0.9

Table 4.3. Herbaceous community structure in the undisturbed, moderately disturbed and highly disturbed forest stands.

Parameter	Stands		
	UD	MD	HD
No. of Family	24	29	30
No. of Genera	29	45	52
No. of Species	34	48	55
Herb density (Indv.100m^2)	380	602	724
Shannon-Weiner index	3.2	3.5	3.2
Simpson dominance index	0.05	0.04	0.07
Simpson index of diversity	0.9	0.9	0.9
Species Richness (Margalef's index)	5.9	7.7	8.6
Evenness index (Pielou)	0.9	0.9	0.7

4.1.3 Phytosociological attributes of tree species

Schima wallichii, the dominant species contributed very high density in the undisturbed (225 indv. ha^{-1}) and moderately disturbed (222 indv. ha^{-1}) compared to the highly disturbed stand (105 indv. ha^{-1}). The co-dominant species were *Castanopsis tribuloides*, *Callicarpa arboria* and *Sterculia villosa* in the undisturbed stand; *Castanopsis tribuloides*, *Callicarpa arboria* and *Wendlandia tinctoria* in the moderately disturbed stand; *Sterculia villosa*, *Callicarpa arboria* and *Wendlandia peniculata* in the highly disturbed stand. Majority of tree species in all three stands exhibited contagious/clumped type of non-random distribution pattern. Whereas, *Schima wallichii*, the dominant species showed random distribution in all three stands. None of the species had regular distribution. Among other species, *Callicarpa arboria* and *Emblica officinalis* were randomly distributed in the undisturbed stand.

Castanopsis tribuloides was randomly disturbed in the moderately disturbed stand (Table 4.4 to 4.6).

The findings reveal that *Schima wallichii*, the dominant species (IVI 63.76) possessed maximum tree density (225 indv. ha^{-1} and basal area 5.04 m^2ha^{-1}) in the undisturbed stand. The co-dominant species were *Castanopsis tribuloides* (IVI 19.99) and *Callicarpa arboria* (IVI 19.44) and they possessed a similar trend in results as observed in case of dominant species. However, abundance was maximum for *Sterculia villosa* followed by *Schima wallichii* and *Terax cheruletum* (Table 4.4).

In the moderately disturbed stand, *Schima wallichii* was dominant species (IVI 83.31) and it was followed by co-dominant species namely, *Castanopsis tribuloides* (IVI 39.81) and *Callicarpa arboria* (IVI 17.54). These species followed a similar trend in results of tree density and basal area, as recorded in the undisturbed stand. *Schima wallichii* the dominant species possessed highest abundance followed by *Wendlandia tinctoria* and *Wendlandia peniculata* (Table 4.5).

In the highly disturbed stand, *Schima wallichii* was recorded as a dominant species (IVI 75.87), and it was followed by co-dominant species namely, *Sterculia villosa* (IVI 39.04) and *Callicarpa arboria* (IVI 24.89). A similar trend in results was observed as reported in the undisturbed stand and moderately disturbed stand in terms of tree density and basal area. The abundance was maximum in case of *Schima wallichii* followed by *Albizzia lebbeck* and *Sterculia villosa*, respectively (Table 4.6).

The findings on phytosociological attributes reveal that *Schima wallichii* was dominant species in all three stands. However, co-dominant species *Castanopsis tribuloides* was replaced by *Sterculia villosa* in the highly disturbed stand. It was also observed that dominant and co-dominant species normally contributed much towards

IVI with increased degree of distribution. Moreover, *Schima wallichii* the dominant species had highest IVI value in the moderately disturbed stand.

Table 4.4. Phytosociological attributes of tree species in the undisturbed forest stand.

Species	Frequency (%)	Density (Ind. ha^{-1})	Abundance	Tree basal area(m^2h^{-1})	IVI	A/F ratio Distribution pattern
Acacia farnesiana Willd	1.42	5	3	0.09	1.17	2.11
Albizzia lebbeck Benth.	5.72	8	1.25	0.08	2.37	0.21
Albizzia procera Benth.	8.57	10	1.17	0.18	3.73	0.13
Antidesma diandrum Roxb.	12.85	18	1.45	0.36	6.39	0.11
Aporusa roxburghii Baill	1.42	3	2	0.06	0.88	1.4
Artocarpus heterophyllus Lam	2.85	4	1.5	0.1	1.53	0.52
Bauhinia purpurea L.	2.85	3	1	0.07	1.21	0.35
Bielschmedia assamica Meissn.	1.42	7	5	0.1	1.53	3.52
Bombax ceiba L.	4.28	7	1.67	0.12	2.24	0.39
Bridelia cuneata Gehrm	8.57	15	1.84	0.32	4.99	0.21
Bridelia stipularis Bl.	8.57	20	2.34	0.5	6.3	0.27
Bursera sarrata Colebr.	1.42	2	2	0.04	0.78	1.4
Callicarpa arboria Roxb.	31.42	58	1.86	1.42	19.44	0.05
Callicarpa macrophylla Vahl.	2.85	4	1.5	0.06	1.32	0.52
Glochidion velutinum Wt.	2.85	5	1.5	0.1	1.53	0.52
Castanopsis Hystrix A.DC.	15.71	31	2	0.8	10.41	0.12
Castanopsis tribuloides DC.	28.57	62	2.15	1.59	19.99	0.07
Combretum desystachyum Kurz.	7.14	18	2.4	0.35	4.92	0.33
Crotalaria linifolia L.	5.72	13	2.25	0.21	3.5	0.39
Debregeasia valutina Gaud.	10	11	1.14	0.36	4.96	0.11
Dipterocarpus turbinatus Gaerter *f.*	4.28	7	1.66	0.13	2.26	0.38
Emblica officinalis Gaertn.	25.72	32	1.27	0.35	10.45	0.04
Engelhardtia spicata Lindl.	1.43	2	1	0.06	0.72	0.69
Erythrina stricta Roxb.	10	15	1.42	0.33	5.17	0.14
Eugenia macrocarpa Roxb.	8.58	20	2.33	0.46	6.05	0.27
Ficus virens Ait.	5.72	6	1	0.14	2.45	0.17
Grewia macrophylla G.Don	1.43	2	1	0.02	0.54	0.69
Lagerstroemia parviflora Roxb.	2.86	2	1	0.05	1.17	0.34
Lepionurus oblongifolius Mast	4.28	8	2	0.13	2.42	0.46
Litsea chinensis Lour.	2.85	6	2	0.11	1.75	0.7
Litsea citrata Bl.	7.15	15	2.2	0.33	4.73	0.3
Meliosma Pinnata Roxb.	7.16	18	2.4	0.37	5.04	0.33
Micromelum integrerrimum (Roxb. Ex DC.)	7.14	11	1.6	0.24	3.8	0.22
Murraya koenigii (L.)Spreng.	7.15	15	2	0.08	3.35	0.27

Oroxylum indicum (L.) Kurz.	4.28	9	2	0.12	2.33	0.46
Phoebe cooperiana UN. Kanjilal	8.58	14	1.66	0.35	4.98	0.19
Psidium guajava Linn.	2.86	4	1.5	0.08	1.48	0.52
Quercus semisarrata Roxb.	7.15	14	2	0.34	4.63	0.27
Quercus spicata Benth.	12.85	32	2.45	0.58	8.72	0.19
Rhus succedanea Linn.	17.15	21	1.25	0.34	7.44	0.07
Schefflera wallichiana (Wt & Art)	11.43	18	1.62	0.29	5.76	0.14
Schima wallichii (DC.) Korthals.	77.15	225	2.93	5.04	63.76	0.03
Sterculia villosa Roxb.ex Smith.	18.58	57	3.07	1.52	17.07	0.16
Tapiria hirsuta Hook.	8.58	17	2	0.55	6.18	0.23
Terax cheruletum Wall	4.29	12	2.67	0.27	3.35	0.62
Terminalia arjuna Roxb.ex DC.	2.85	3	1	0.08	1.27	0.35
Toona ciliata M.Roem	10	15	1.43	0.34	5.24	0.14
Turpinia nepalensis Wight & Arn.	2.86	7	2.5	0.1	1.83	0.87
Wendlandia peniculata DC.	10	26	2.58	0.54	7.34	0.25
Wendlandia tinctoria (Roxb.) DC.	15.72	33	2.09	0.58	9.53	0.13
		970		**20.83**	**300**	

Table 4.5. Phytosociological attributes of tree species in the moderately disturbed forest stand.

Species	Frequency (%)	Density (Ind. ha^{-1})	Abundance	Tree basal area (m^{2}h^{-1})	IVI	A/F ratio Distribution pattern
Acacia auriculiformis	2.85	3	1	0.02	1.36	0.35
Albizia chinensis Osb. Merr.	2.85	4	1.5	0.06	2.04	0.52
Albizzia lebbeck Benth.	7.14	13	1.8	0.13	4.95	0.25
Albizzia procera Benth.	10	12	1.28	0.19	6.39	0.12
Antidesma diandrum Roxb.	1.42	2	1	0.03	0.96	0.7
Bridelia stipularis Bl.	2.85	6	1	0.06	2.56	0.35
Callicarpa arboria Roxb.	4.28	42	1.33	0.58	17.54	0.31
Glochidion velutinum Wt.	22.85	15	1.81	0.15	6.14	0.07
Cassia leavigata Willd	10	5	1.42	0.07	1.73	0.14
Castanopsis Hystrix A.DC.	1.43	8	3	0.08	3.2	2.09
Castanopsis tribuloides DC.	4.29	102	2	1.4	39.81	0.46
Clausena excavata Burn.f.	44.29	5	2.32	0.1	2.95	0.05
Crotalaria linifolia L.	4.28	4	1.34	0.07	2.45	0.31
Delonix regia (Boj)Rafin.	4.28	1	1	0.02	0.86	0.23
Derris robusta Roxb.exDC.	1.43	2	1	0.01	0.93	0.69
Emblica officinalis Gaertn.	1.43	30	2	0.28	11.87	1.39
Eucalyptus globules Labill.	18.57	1	1.62	0.02	0.75	0.08

Eugenia macrocarpa Roxb.	1.43	5	1	0.07	2.18	0.69
Ficus elastica Roxb.ex Hornem	2.86	6	2	0.06	2.83	0.69
Grevillea robusta A.Cunn.	5.72	2	1	0.02	0.75	0.17
Lagerstroemia parviflora Roxb.	1.43	2	1	0.04	0.91	0.69
Litsea chinensis Lour.	1.43	14	1	0.19	5.83	0.69
Litsea citrata Bl.	7.15	8	2	0.07	3.63	0.27
Macaranga denticulata Roxb.	7.15	2	1	0.03	1.06	0.13
Machilus bombycina King ex Hook.f.	1.43	4	2	0.05	1.57	1.39
Mangifera indica Linn.	2.86	4	1	0.06	2.29	0.34
Melia azadarach Linn.	4.28	5	1	0.04	2.07	0.23
Meliosma Pinnata Roxb.	4.28	5	1	0.07	2.09	0.23
Michelia champaca Linn.	2.85	3	1.5	0.03	1.36	0.52
Michelia panduana Hook.Thamn.	2.85	5	1	0.06	1.95	0.35
Micromelum integrerrimum (Roxb. Ex DC.)	2.85	5	1.5	0.05	1.78	0.52
Murraya koenigii (L.)Spreng.	2.86	17	1.5	0.28	7.11	0.52
Phoebe cooperiana UN. Kanjilal	7.15	8	2.4	0.07	4.09	0.33
Plumeria acutifolia Poir.	8.57	2	1	0.03	1.42	0.11
Psidium guajava Linn.	2.86	5	1	0.08	3.08	0.34
Pterospermum acerifolium Willd.	5.72	9	1	0.08	3.38	0.17
Quercus semisarrata Roxb.	5.72	10	1.5	0.09	3.84	0.26
Quercus spicata Benth.	5.72	2	1.75	0.09	0.86	0.3
Rhus succedanea Linn.	1.43	22	1	0.19	8.11	0.69
Sarchochlamys pulcherrima Gaud.	11.43	2	2	0.02	1.29	0.17
Saurwia nepalensis D.C.	2.85	12	1	0.18	5.07	0.35
Schefflera wallichiana (Wt & Art)	5.72	2	2.25	0.03	1.5	0.37
Schima wallichii (DC.) Korthals.	75.72	222	2.95	3.28	83.31	0.03
Sterculia villosa Roxb.ex Smith.	12.86	24	1.88	0.34	10.15	0.14
Syzygium cumini Linn.	1.43	2	1	0.01	0.61	0.69
Tapiria hirsuta Hook.	8.57	2	1.34	0.03	0.86	0.15
Toona ciliata M.Roem	1.42	12	1	0.22	6.02	0.7
Wendlandia peniculata DC.	11.42	28	2.37	0.34	10.02	0.2
Wendlandia tinctoria (Roxb.) DC.	14.28	36	2.5	0.38	12.49	0.17
		742		**9.85**	**300**	

Table 4.6. Phytosociological attributes tree species in the highly disturbed forest stand.

Species	Frequency (%)	Density (Ind. ha^{-1})	Abundance	Tree basal area (m^2h^{-1})	IVI	A/F ratio Distribution pattern
Albizia chinensis Osb. Merr.	8.57	15	1.66	0.15	10.19	0.19
Albizzia lebbeck Benth.	2.85	6	2.5	0.13	4.78	0.87
Albizzia procera Benth.	8.57	12	1.33	0.15	9.38	0.15
Bombax ceiba L	2.85	4	1.5	0.06	3.48	0.52
Callicarpa arboria Roxb.	17.14	32	1.91	0.49	24.89	0.11
Glochidion velutinum Wt.	1.43	1	1	0.04	1.77	0.69
Castanopsis tribuloides DC.	14.28	24	1.7	0.3	18.05	0.11
Colona floribunda (Kurz)Craib.	5.72	7	1.25	0.1	6.23	0.21
Derris robusta Roxb.exDC.	2.86	6	2	0.09	4.44	0.69
Dipterocarpus turbinatus Gaerter *f.*	1.43	1	1	0.05	1.77	0.69
Emblica officinalis Gaertn.	12.86	20	1.55	0.16	13.78	0.12
Erythrina stricta Roxb.	2.86	4	1.5	0.04	2.96	0.52
Ficus virens Ait.	4.29	5	1.34	0.08	4.83	0.31
Grewia macrophylla G.Don	1.43	5	4	0.07	3.22	2.79
Lagerstroemia parviflora Roxb.	4.28	5	1	0.06	4.19	0.23
Lepionurus oblongifolius Mast	4.28	8	1.67	0.07	5.09	0.39
Quercus semisarrata Roxb.	4.28	7	1.67	0.07	5.04	0.39
Rhus succedanea Linn.	14.28	21	1.5	0.17	14.67	0.1
Schima wallichii (DC.) Korthals.	45.72	105	2.32	1.59	75.87	0.05
Sterculia villosa Roxb.ex Smith.	25.72	58	2.23	0.74	39.04	0.08
Tapiria hirsuta Hook.	5.72	9	1.5	0.12	6.7	0.26
Toona ciliata M.Roem	8.58	12	1.34	0.19	10.33	0.15
Wendlandia peniculata DC.	12.85	26	2	0.27	17	0.15
Wendlandia tinctoria (Roxb.) DC.	10	17	1.71	0.19	12.3	0.17
		410		**5.38**	**300**	

4.1.4 Phytosociological attribute of shrub species

On the basis of density, *Chromolaena odorata* was the dominant species with maximum density (446 indv.ha^{-1}) in the highly disturbed stand followed by undisturbed (285 indv.ha^{-1}) and moderately disturbed stands (252 indv.ha^{-1}). The co-dominant species were: *Mussaenda gandra*, *Rubus rugosus* and *Solanum xanthocarpum* in the undisturbed stand; *Urena lobata, Solanum xanthocarpum* and *Solanum torvum* in the moderately disturbed stand; *Melastoma melabatricum, Solanum xanthocarpum* and *Mussaenda gandra* in the highly disturbed stand (Table 4.7 to 4.9).

In undisturbed stand, importance value index (IVI) of *Chromolaena odorata* was maximum (IVI 37.3). The co-dominant species were: *Rubus rugosus* (IVI 21.8) and *Mussaenda gandra* (IVI 18.2). However, *Argyreia speciosa* exhibited maximum abundance followed by *Chromolaena odorata* and *Mussaenda gandra* (Table 4.7).

In the moderately disturbed stand, *Chromolaena odorata* was dominant species (IVI 26.58) followed by co-dominant species namely, *Urena lobata* and *Solanum xanthocarpum*. *Ipomoea purpurea* and *Ipomoea vitifolia* had highest abundance followed by *Vities diverigata* and *Melastoma melabatricum* (Table 4.8).

In the highly disturbed stand, *Chromolaena odorata* was recorded as a dominant species (IVI 33.84) followed by co-dominant species namely *Melastoma melabatricum* and *Solanum xanthocarpum*. The abundance was maximum in case of *Clerodendrum colebrookianum* and *Hedychium spicatum*, it was followed by *Costus speciosus* and *Chromolaena odorata,* respectively (Table 4.9).

The findings of phytosociological attributes reveal that *Chromolaena odorata* was dominant species in all three stands. All shrub species exhibited contagious distribution pattern.

Table 4.7. Phytosociological attributes of shrub species in the undisturbed forest stand

Species	**Frequency (%)**	**Density (Indv.ha^{-1})**	**Abundance**	**IVI**	**A/F ratio distribution pattern**
Apios carnea Bl.	2.85	6	0.5	2.27	0.17
Argyreia speciosa Sw.	4.28	52	3	6.81	0.7
Barleria cristata Linn.	7.14	35	1.2	7.28	0.16
Camelia caudata Wall.	2.85	22	2	3.64	0.7
Cassia hirsuta Linn.	2.85	17	1.5	3.19	0.52
Chromolaena odorata Linn.	22.85	285	3.12	37.27	0.13
Cratoxylum sumatranum Bl.	4.28	34	2	5.46	0.46
Crotolaria albida Hyne.	2.85	18	1.5	3.18	0.52
Derris trifoliata Lour	5.71	40	1.75	6.81	0.3
Desmodium gyroids DC.	5.71	40	1.75	6.81	0.3
Hedychium spicatum Buch.-Ham	2.85	22	2	3.63	0.7
Ipomoea cymosa Roxb.	5.71	28	1.25	5.91	0.21
Lantana camera Linn.	4.29	17	1	4.09	0.23
Melastoma melabatricum Linn.	5.72	46	2	7.28	0.35
Melastoma nepalensis Lodd.	4.29	40	2.33	5.9	0.54
Mussaenda gandra Vahl.	15.72	103	1.63	18.19	0.1
Phyllanthus clarkei Hoof.	4.29	40	2.33	5.9	0.54
Phyllanthus roeperiana Wall.	1.43	18	3	2.28	2.1
Physalis minima Linn.	5.72	40	1.75	6.82	0.3
Pyrsiasia wallichii Schoott.	4.29	35	2	5.46	0.46
Rubus insignis Hoof.	1.43	5	1	1.37	0.7
Rubus rugosus Smith	17.15	137	2	21.82	0.11
Solanum torvum Swartz	4.29	40	2.33	5.91	0.54
Solanum xanthocarpum	7.15	51	1.8	8.64	0.25
Tithonia diversifolia Hemsl.	5.72	46	2	7.27	0.35
Urena lobata L.	5.72	40	1.75	6.81	0.3
		1257		**200**	

Table 4.8. Phytosociological attributes of shrub species in the moderately disturbed forest stand

Species	**Frequency (%)**	**Density (Indv.ha^{-1})**	**Abundance**	**IVI**	**A/F ratio distribution pattern**
Acacia oxyphylla Grah. Ex Benth.	5.71	35	1.5	4.48	0.26
Apios carnea Bl.	1.42	5	1	0.96	0.7
Barleria cristata Linn.	4.28	22	1.33	3.18	0.31
Bauhinia malabarica Roxb.	5.71	40	1.75	4.83	0.3
Cajanus cajan Linn.	1.42	12	2	1.29	1.4

Camelia caudata Wall.	8.57	68	2	7.77	0.23
Cassia hirsuta Linn.	5.72	23	1	3.79	0.17
Cassia occidentalis L.	5.71	35	1.5	4.48	0.26
Chromolaena odorata Linn.	27.14	252	2.31	26.58	0.08
Debregeasia longifolia	11.42	68	1.5	8.97	0.13
Desmodium gyroids DC.	11.43	75	1.62	9.29	0.1
Desmodium triquetrum DC.	1.43	5	1	0.98	0.7
Dioscorea sikkimensis	5.71	57	2.5	5.88	0.43
Flemingia stricta Roxb.	10	63	1.57	8	0.15
Ipomoea cymosa Roxb.	2.85	23	2	2.59	0.7
Ipomoea purpurea Linn.	1.43	17	3	1.68	2.1
Ipomoea vitifolia	4.28	52	3	4.89	0.7
Lantana camera Linn.	4.28	40	2.33	4.29	0.54
Lycopodium spp.	4.29	28	1.66	3.51	0.38
Melastoma melabatricum Linn.	4.29	45	2.66	4.55	0.62
Melastoma nepalensis Lodd.	8.58	51	1.5	6.71	0.17
Mussaenda gandra Vahl.	11.43	75	1.62	9.27	0.14
Phyllanthus clarkei Hoof.	2.86	22	2	2.58	0.7
Priotropis cytisoides WA.	7.15	40	1.4	5.42	0.19
Pyrsiasia wallichii Schoott.	4.29	23	1.33	3.18	0.31
Rhus succedanea Linn.	10	58	1.42	7.66	0.14
Rubus rugosus Smith	4.28	18	1	2.84	0.23
Sarchochlamys pulcherrima Gaud.	1.43	5	1	0.94	0.7
Solanum anguivi Lamk.	2.85	18	1.5	2.23	0.52
Solanum torvum Swartz	12.86	80	1.55	10.24	0.12
Solanum xanthocarpum	12.86	92	1.77	10.92	0.13
Tithonia diversifolia Hemsl.	2.86	17	1.5	2.25	0.52
Urena lobata L.	11.43	102	2.25	11	0.19
Vities barbata Wall.	4.29	22	1.33	3.19	0.31
Vities diverigata Wall.	2.86	29	2.5	2.95	0.87
Vities japonica Thumb.	1.43	5	1	0.96	0.7
Vities mollis Wall.	1.43	7	1	0.97	0.7
Vities repens W.A.	4.28	51	3	4.7	0.7
		1680		**200**	

Table 4.9. Phytosociological attributes of shrub species in the highly disturbed forest stand

Species	**Frequency (%)**	**Density (Indv.ha^{-1})**	**Abundance**	**IVI**	**A/F ratio distribution pattern**
Acacia oxyphylla Grah. Ex Benth.	4.28	52	3	4.61	0.7
Apios carnea Bl.	1.43	34	6	2.3	4.19
Argyreia speciosa Sw.	4.28	45	2.66	4.34	0.62

Barleria cristata Linn.	8.57	74	2.16	7.93	0.25
Bauhinia malabarica Roxb.	2.85	28	2.5	2.82	0.87
Berberis camcina Hoof.	1.42	17	3	1.55	2.11
Byttneria pilosa Roxb.	4.28	57	3.33	4.87	0.77
Camelia caudata Wall.	1.42	22	4	1.79	2.81
Cassia hirsuta Linn.	5.71	46	2	5.15	0.35
Cassia occidentalis L.	4.28	40	2.33	4.09	0.54
Chromolaena odorata Linn.	25.71	446	4.33	33.84	0.16
Clerodendrum colebrookianum Walp.	1.42	29	5	2.05	3.52
Costus speciosus (Koening) Sm.	5.71	92	4	7.17	0.7
Desmodium gyroids DC.	2.85	35	3	3.07	1.05
Dioscorea sikkimensis	2.85	45	4	3.59	1.4
Elaeocarpus floribundus Bl.	2.86	29	2.5	2.82	0.87
Fagraea khasiana Bl.	2.86	35	3	3.08	1.04
Flemingia stricta Roxb.	1.43	23	4	1.79	2.79
Hedychium spicatum Buch.-Ham	1.43	28	5	2.06	3.49
Lantana camera Linn.	4.29	46	2.66	4.36	0.62
Melastoma melabatricum Linn.	10	103	2.57	9.98	0.25
Melastoma nepalensis Lodd.	4.29	46	2.66	4.35	0.62
Mikania cordata (Burm)B.L.Robinson	2.86	17	1.5	2.3	0.52
Mussaenda gandra Vahl.	8.58	80	2.33	8.19	0.27
Phyllanthus clarkei Hoof.	1.43	18	3	1.54	2.09
Physalis minima Linn.	2.86	34	3	3.07	1.04
Priotropis cytisoides WA.	2.86	40	3.5	3.34	1.22
Pteris longipes Andes	4.29	51	3	4.6	0.69
Pyrsiasia wallichii Schoott.	1.43	22	4	1.8	2.79
Rhus insignis Hk.f.	2.86	23	2	2.56	0.69
Rubus rugosus Smith	4.28	63	3.66	5.14	0.85
Sambucus hookerii Rebd.	2.86	28	2.5	2.82	0.87
Smilex macrophylla	4.29	46	2.66	4.36	0.62
Solanum anguivi Lamk.	2.86	29	2.5	2.7	0.87
Solanum torvum Swartz	8.58	46	1.33	6.66	0.15
Solanum xanthocarpum	10	91	2.28	9.46	0.22
Stemona griffithii Hoof.	2.86	40	3.5	3.34	1.22
Tithonia diversifolia Hemsl.	4.29	51	3	4.6	0.69
Urena lobata L.	2.86	40	3.5	3.35	1.22
Vities diverigata Wall.	4.29	40	2.33	4.09	0.54
Vities japonica Thumb.	1.43	23	4	1.79	2.79
Vities repens W.A.	4.29	35	2	3.83	0.46
Vities sikkimensis	2.86	28	2.5	2.85	0.87
		2217		**200**	

4.1.5 Phytosociological attribute of herb Species

The findings reveal that *Costus speciosus* was the dominant species (IVI 25.15) possessed maximum density (50 indv.100m^{-2}) in the undisturbed stand. The co-dominant species were: *Achyranthes aspera* (IVI 22.32) and *Cynoglossum wallichii* (IVI 15.22). However, *Scoparia dulcis* was most abundant species followed by *Spilanthes acemella* and *Micratha oppositifolia* (Table 4.10).

In the moderately disturbed stand, *Mimosa pudica* was dominant species (IVI 20.81) followed by co-dominant species namely, *Spilanthes acemella* (IVI 16.34) and *Ageratum conyzoides* (IVI 13.53). However, *Spilanthes acemella* recorded highest abundance followed by *Pteris longipes* and *Mimosa pudica* (Table 4.11).

In the highly disturbed stand, *Mimosa pudica* was the dominant species (IVI 32.85) followed by co-dominant species namely *Ageratum conyzoides* (IVI 25.59) and *Spilanthes acemella* (IVI 16.45). The abundance was maximum in case of *Plantago erosa,* which was followed by *Cymbogogon citrates* and *Ageratum conyzoides,* respectively (Table 4.12).

The findings of phytosociological attributes reveal that *Costus speciosus* was dominant species in the undisturbed stand which was replaced by *Mimosa pudica* in the moderately disturbed and highly disturbed stands. Herbaceous species were contagiously distributed in all stands. There was no regular and random distribution pattern in case of herbaceous species.

Table 4.10. Phytosociological attributes of herbaceous species in the undisturbed forest stand.

Species	**Frequency (%)**	**Density (Indv.100m^{-2})**	**Abundance**	**IVI**	**A/F ratio distribution pattern**
Abelmoschus moschatus Medik.	1.42	2	2	1.41	1.4
Achyranthes aspera Linn.	15.71	44	1.93	22.32	0.08
Achyranthes bidentata Blume.	4.28	6	1.33	3.5	0.31
Ageratum conyzoides Linn.	7.14	11	1.6	6.34	0.22
Cassia nodosa Roxb.	2.85	5	2	2.83	0.7
Costus speciosus (Koening) Sm.	25.71	50	1.94	25.15	0.07
Cynoglossum wallichii G.Don	22.85	30	1.9	15.22	0.12
Cyrtococcum spp.	5.71	10	1.75	5.29	0.3
Dendrobium fluconeria	5.71	7	1.25	4.54	0.21
Dendrocalamus giganteus Munro	4.28	8	2	4.25	0.46
Desmodium laxiflorum D.C	2.85	3	1	2.08	0.35
Didymocarpus pulchera Clarke	5.72	8	1.5	4.92	0.26
Dumaria villosa D.C.	4.28	4	1	3.13	0.23
Elaeocarpus sikkimmensis	4.28	4	1	3.13	0.23
Floscopa seandens Lour.	2.85	5	2	2.84	0.7
Gynura crepidioides Benth.	2.85	4	1.5	2.47	0.52
Impatien chinensis Linn.	4.28	6	1.33	3.51	0.31
Latuca rostrata Thumb.	7.14	13	1.8	6.72	0.25
Leucas mollissima	5.72	10	1.75	5.29	0.3
Lindernia multiflora Roxb.	2.86	4	1.5	2.47	0.52
Lowsonia intermis Linn.	2.86	6	2	2.84	0.69
Micratha oppositifolia Wall.	4.28	10	2.33	4.64	0.54
Mimosa pudica Linn.	10	23	2.28	10.69	0.22
Murdannia simplex	1.43	2	1	1.05	0.69
Myriactis wallichii Linn.	2.85	6	2	2.84	0.7
Phyllanthus glaucus Wall	2.86	5	1.5	2.47	0.52
Phyllanthus urinaria Linn.	10	19	1.85	9.56	0.18
Pteris longipes Andes	4.28	6	1.33	3.51	0.31
Scoparia dulcis Linn.	2.86	9	3	3.58	1.04
Solanum nigrum Linn.	8.58	13	1.5	7.38	0.17
Spilanthes acemella Murr	11.43	23	2	11.35	0.17
Spiraea callosa Thunb.	7.14	12	1.6	6.35	0.22
Streptocaulon scanden Bl.	1.43	2	1	1.04	0.69
Webera pumila Hook.	5.72	10	1.75	5.29	0.3
		380		**200**	

Table 4.11. Phytosociological attributes of herbaceous species in the moderately disturbed forest stand.

Species	Frequency (%)	Density (Indv.100m^2)	Abundance	IVI	A/F ratio distribution pattern
Abelmoschus moschatus Medik.	2.85	5	2	1.97	0.7
Abutilon striatum L.	4.28	7	1.66	2.73	0.38
Achyranthes bidentata Blume.	12.85	25	1.88	8.66	0.14
Achyranthus Aspera Linn.	7.14	16	2.2	5.18	0.3
Ageratum conyzoides Linn.	17.14	44	2.58	13.53	0.15
Aleuritis fordii Hemsl.	2.85	7	2.5	2.21	0.87
Bidens pilosa Linn.	4.28	7	1.66	2.73	0.38
Botrechium conuginassus Linn.	5.71	12	2	3.95	0.35
Cassia nodosa Roxb.	4.28	6	1.33	2.49	0.31
Centilla asiatica Linn.	5.71	13	2.25	4.19	0.39
Costus speciosus (Koening) Sm.	10	19	1.85	6.68	0.18
Cynoglossum wallichii G.Don	17.14	39	2.25	12.58	0.13
Cyperus spp.	1.42	4	3	1.22	2.11
Dendrobium fluconeria	2.85	2	1	1.5	0.35
Desmodium laxiflorum D.C	2.85	3	1	1.5	0.35
Dichrocephala latifolia DC.	2.85	4	1.5	1.74	0.52
Dumaria villosa D.C.	5.72	8	1.5	3.48	0.26
Elaeocarpus sikkimmensis	2.86	5	1.5	1.74	0.52
Eleusine indica Linn.	4.28	9	2	2.96	0.46
Gynura crepidioides Benth.	8.58	13	1.5	5.22	0.17
Impatien chinensis Linn.	2.86	8	2.5	2.22	0.87
Laggera flava Benth.	1.43	2	1	0.76	0.69
Latuca indica Linn.	2.86	3	1	1.51	0.34
Latuca rostrata Thumb.	8.58	20	2.33	6.42	0.27
Leucas mollissima	8.58	24	2.83	7.13	0.32
Lindernia multiflora Roxb.	1.43	3	2	0.99	1.39
Lobelia colorata Wall.	2.85	6	2	1.98	0.7
Logoscia mollis Linn.	2.85	2	1	1.51	0.35
Lycopodium cirnum Linn.	2.86	2	1	1.51	0.34
Micratha oppositifolia Wall.	4.28	7	1.66	2.74	0.38
Mimosa pudica Linn.	22.86	75	3.31	20.81	0.14
Morus nigra Linn.	4.29	8	2	2.97	0.46
Murdannia simplex	4.29	4	1	2.26	0.23
Myriactis wallichii Linn.	5.72	8	1.25	3.25	0.21
Phyllanthus glaucus Wall	5.72	8	1.5	3.49	0.26
Phyllanthus urinaria Linn.	5.72	11	2	3.96	0.34
Physalis minima Linn.	8.58	17	2	5.94	0.23
Polygonum larigerum R.Bor.	4.29	9	2	2.97	0.46
Pteris longipes Andes	2.86	10	3.5	2.69	1.22
Scirpus macronatus Linn.	2.86	7	2.5	2.22	0.87

Scoparia dulcis Linn.	5.72	10	1.75	3.73	0.3
Sida rhombifolia Linn.	4.28	5	1.33	2.49	0.31
Solanum nigrum Linn.	5.72	9	1.5	3.49	0.26
Spilanthes acemella Murr	15.72	65	4.09	16.34	0.26
Spiraea callosa Thunb.	5.72	10	1.75	3.72	0.3
Streptocaulon scanden Bl.	1.42	1	1	0.75	0.7
Themeda villosa	2.85	10	3.5	2.68	1.22
Webera pumila Hook.	4.29	10	2.33	3.21	0.54
		602		**200**	

Table 4.12. Phytosociological attributes of herbaceous species in the highly disturbed forest stand.

Species	Frequency (%)	Density (Indv.100m^2)	Abundance	IVI	A/F ratio distribution pattern
Abelmoschus manihot Medik.	4.28	8	2	2.79	0.46
Abutilon striatum L.	1.43	2	2	0.93	1.39
Achyranthes bidentata Blume.	5.72	12	2.25	3.93	0.39
Achyranthus Aspera Linn.	7.14	11	1.6	4.26	0.22
Ageratum conyzoides Linn.	27.14	111	4.1	25.59	0.15
Ageratum haustonianum	4.29	22	5	4.58	1.16
Aleuritis fordii Hemsl.	1.43	1	1	0.74	0.69
Bidens pilosa Linn.	2.85	9	3	2.25	1.05
Botrechium conuginassus Linn.	1.43	5	3	1.13	2.09
Cassia nodosa Roxb.	1.43	3	2	0.94	1.39
Centilla asiatica Linn.	11.42	38	3.37	9.62	0.29
Costus speciosus (Koening) Sm.	10	15	1.57	5.93	0.15
Crotalaria acutta Bl.	1.43	2	2	0.94	1.39
Cyanotis cristata D.Don.	1.43	6	4	1.32	2.79
Cymbogogon citratus Stapf.	7.15	33	4.6	7.22	0.64
Cynoglossum wallichii G.Don	2.86	5	1.5	1.67	0.52
Cyperus spp.	5.72	11	2	3.73	0.34
Cyrtococcum spp.	2.86	6	2	1.86	0.69
Dendrobium fluconeria	2.85	2	1	1.47	0.35
Dendrocalamus giganteus Munro	1.43	3	2	0.94	1.39
Desmodium laxiflorum D.C	1.43	3	2	0.94	1.39
Echinocarpus spp.	1.42	5	3	1.12	2.11
Elaeocarpus sikkimmensis	1.43	3	2	0.94	1.39
Eleusine indica Linn.	2.86	5	1.5	1.67	0.52
Erigeron alpinus Linn.	1.43	5	3	1.12	2.09
Floscopa seandens Lour.	1.43	1	1	0.74	0.69
Gynura crepidioides Benth.	2.85	2	1	1.47	0.35

Impatien chinensis Linn.	5.72	12	2	3.73	0.34
Laggera flava Benth.	1.43	2	1	0.74	0.69
Latuca indica Linn.	1.43	2	1	0.74	0.69
Leucas mollissima	2.85	8	3	2.25	1.05
Lilium wallichianum Schultes f.	2.86	8	3	2.25	1.04
Lindernia multiflora Roxb.	1.43	3	2	0.94	1.39
Lobelia colorata Wall.	1.42	5	3	1.12	2.11
Lowsonia intermis Linn.	1.43	1	1	0.74	0.69
Lycopodium cirnum Linn.	2.86	7	2.5	2.07	0.87
Lygodium scandens Giff.	1.43	5	4	1.32	2.79
Mimosa pudica Linn.	38.57	133	3.44	32.85	0.08
Morus nigra Linn.	1.43	3	2	0.94	1.39
Murdannia simplex	1.43	3	2	0.94	1.39
Myriactis wallichii Less.	2.85	5	1.5	1.66	0.52
Phyllanthus glaucus Wall	7.14	16	2.2	4.85	0.3
Phyllanthus urinaria Linn.	14.28	26	1.8	8.92	0.12
Physalis minima Linn.	11.42	23	2	7.45	0.17
Plantago erosa Wall.	7.15	30	4.2	6.84	0.58
Polygonum larigerum R.Bor.	1.43	1	1	0.74	0.69
Salidog spp.	1.43	2	1	0.74	0.69
Scirpus macronatus Linn.	1.43	2	1	0.74	0.69
Scoparia dulcis Linn.	2.85	5	2	1.86	0.7
Solanum nigrum Linn.	10	19	1.85	6.32	0.18
Spilanthes acemella Murr	18.58	68	3.69	16.45	0.19
Spiraea callosa Thunb.	1.43	2	1	0.74	0.69
Streptocaulon scanden Bl.	1.43	2	1	0.74	0.69
Themeda villosa	1.43	1	1	0.74	0.69
Webera pumila Hook.	1.43	1	1	0.74	0.69
		724		**200**	

4.1.6 Girth class distribution of tree species and basal area

Findings of the girth class distribution of trees showed that there is a decreasing trend in the number of individuals from lower to higher girth classes, irrespective of stands, except in case of the undisturbed stand where number of individuals was higher in case of girth classes 50-70cm and 30-50cm. The moderately disturbed stand showed maximum number of adult trees (girth classes 30-50cm), however, mature trees (girth classes 50-70cm) were maximum in the undisturbed stand. There was a sharp decline in the number of individuals in the higher girth classes with increase in degree of disturbance. The girth class was also reduced from undisturbed to highly disturbed stand (Fig. 4.1). The lower girth class (30-50cm) markedly contributed much towards basal area. There was sharp reduction in basal area from lower to higher girth classes, except girth class > 90cm. Like the tree density, basal area was highest in the girth classes 30-50cm under the moderately disturbed stand. Intermediate girth classes possessed lower basal area in all the stands (Fig. 4.2).

Tree density and basal area for common dominant species at all sites were plotted on two axis of a graph (Fig 4.3). On the basis of tree density and basal area of common dominant species, *Schima wallichii* contributed maximum in all three stands followed by *Castanopsis tribuloides* and *Callicarpa arborea* respectively (Fig. 4.3).

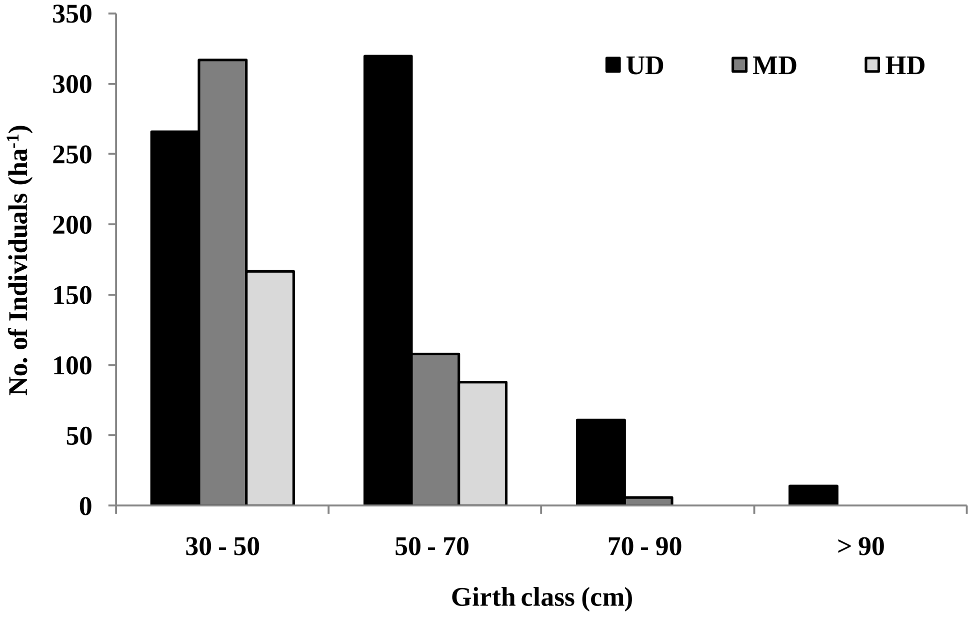


Fig: 4.1. Distribution of tree species in different girth classes in the undisturbed (**UD**), moderately disturbed (**MD**) and highly disturbed (**HD**) forest stands.

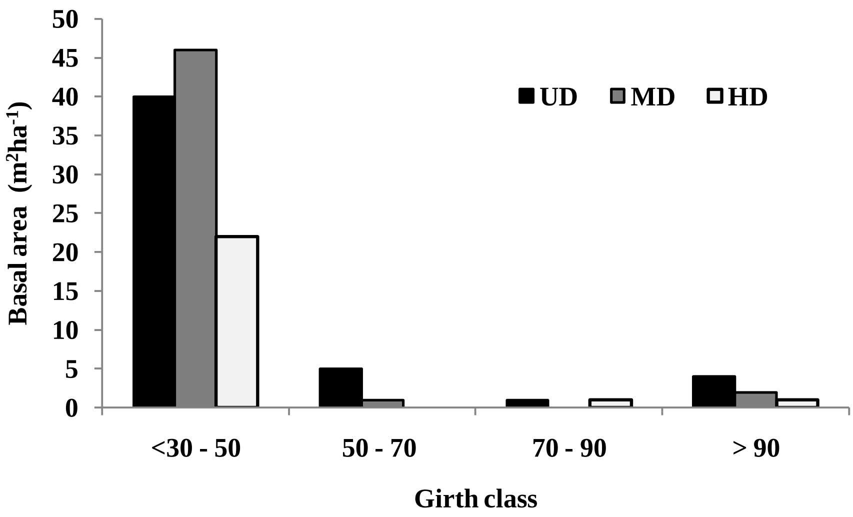
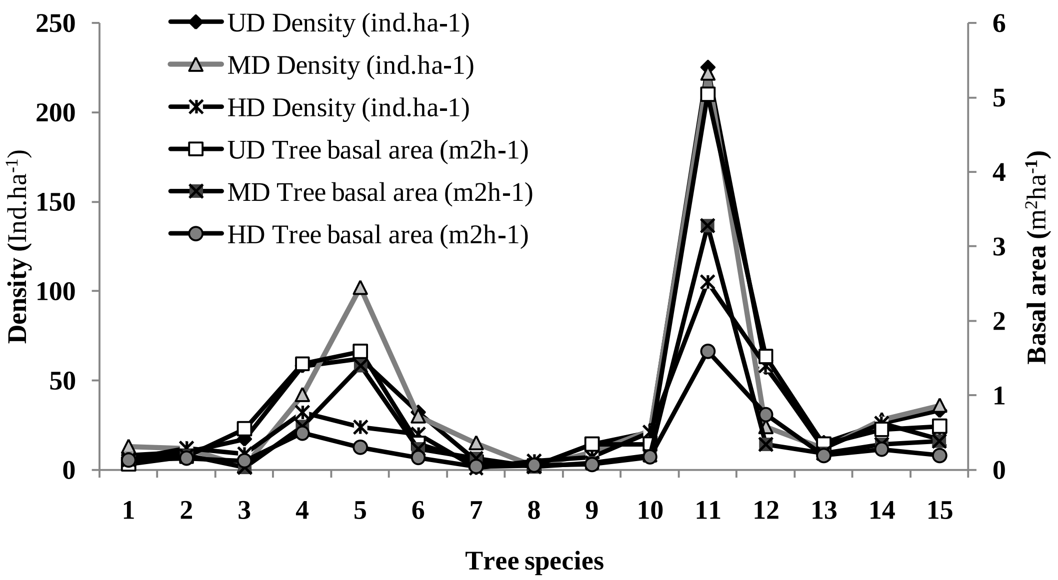


Fig: 4.2. Distribution of tree basal area in different girth classes in the undisturbed (**UD**), moderately disturbed (**MD**) and highly disturbed (**HD**) forest stands.



1- *Albizzia lebbeck*, **2-** *Albizzia procera*, **3-** *Aporusa roxburghii*, **4-** *Callicarpa arborea*, **5-** *Castanopsis tribuloides*, **6-** *Emblica officinalis*, **7-** *Glochidion velutinum*, **8-** *Largerstroemia parviflora*, **9-** *Quercus semisarrata*, **10-** *Rhus succedanea*, **11-** *Schima wallichii*, **12-** *Sterculia villosa*, **13-** *Toona ciliate*, **14-** *Wendlandia peniculata*, **15-** *Wendlandia tinctoria*

Fig: 4.3. Relationship between density and basal area of tree species common in the undisturbed (**UD**), moderately disturbed (**MD**) and highly disturbed (**HD**) forest stands.

4.1.7 Dominance - diversity pattern

Dominance-diversity pattern was established to determine stability of the community and the interpretation of community organisation in terms of resource share and niche space. The log-normal dominance-diversity curve (based on IVI) was found for the tree species in the undisturbed and moderately disturbed stands, however, it was short hooked in case of highly disturbed stand (Fig. 4.4).

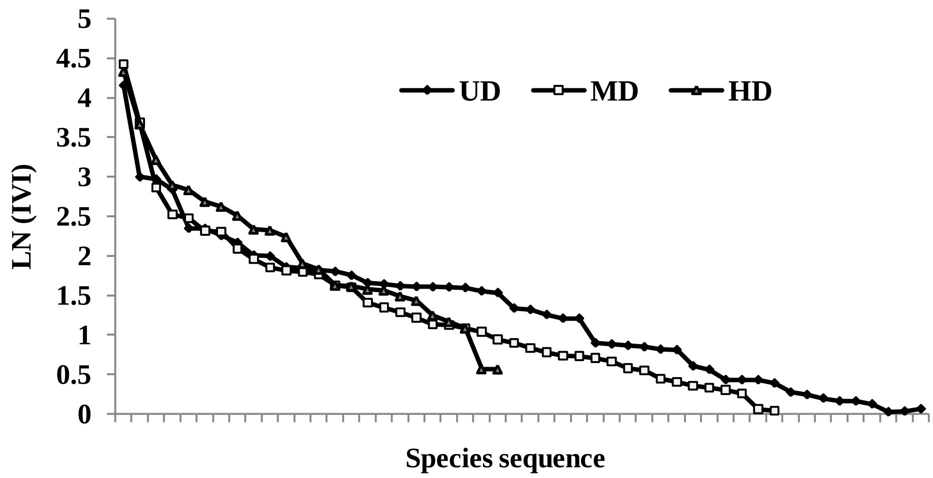


Fig: 4.4. Dominance- diversity curves of tree species along disturbance gradient.

4.1.8 Sorenson's index of similarity

The Sorenson's Index of similarity for tree species was maximum (0.58) between undisturbed and moderately disturbed stands. On contrary, value was minimum (0.46) between moderately disturbed and highly disturbed stands.

Moderately disturbed stand was more similar to the highly disturbed stand in case of shrubs (similarity index 0.64) and herbs (similarity index 0.77). On the contrary, undisturbed stand was least similar with moderately disturbed stand in case of shrubs (similarity index 0.56) and with highly disturbed stand in case of herbs (similarity index 0.62) (Table 4.13).

The tree species common in all tree stands were: *Albizzia lebbeck, Albizzia procera, Callicarpa arboria, Emblica officinalis, Schima wallichii, Sterculia villosa, Toona ciliate, Wendlandia peniculata* and *Wendlandia tinctoria*. Similarly, common shrubs in all stands were: *Apios carnea, Barleria cristata, Camelia caudate, Cassia hirsute, Chromolaena odorata, Desmodium gyroids, Lantana camera, Melastoma melabatricum, Melastoma nepalensis, Mussaenda gandra, Solanum torvum, Solanum xanthocarpum, Tithonia diversifolia* and *Urena lobata*. However, herbaceous species common to all stands were: *Achyranthus Aspera, Achyranthes bidentata, Gynura crepidioides, Impatien chinensis, Mimosa pudica, Phyllanthus urinaria, Scoparia dulcis, Solanum nigrum, Spilanthes acemella, Streptocaulon scanden* and *Webera pumila*.

Table: 4.13. Sorenson's index of similarity

Plant habits	**Forest Stands**		
	UD : MD	**MD : HD**	**UD : HD**
Tree species	0.58	0.46	0.56
Shrubs	0.56	0.64	0.57
Herbs	0.70	0.77	0.62

4.1.9 Diversity and dominance of families

A total number of 69 were families recorded from three stands. Of this, 53 families were reported from undisturbed stand, 50 families from moderately disturbed stand and 46 families from highly disturbed stand including common one. In the undisturbed stand, Asteracease was the dominant family with 13 species and it was followed by Papilionaceae (7 species), Euphorbiaceae (6 species), Caesalpinaceae, Commelionaceae, Mimosaceae, Solanaceae (5 species each), Vitaceae (4 species). Further, five families namely, Anacardiaceae, Malvaceae, Poaceae, Rubiaceae, Verbenaceae (with 3 species each followed by 16 families namely Amaranthaceae, Cyperaceae, Elaeocarpaceae, Fabaceae, Graminae, Liliaceae, Lythraceae, Melastomaceae, Polydiaceae, Polygonaceae, Rosaceae, Scrophulareaceae,Sterculiaceae, Theaceae, Tiliaceae, Zingiberaceae (representing 2 species each) and remaining 24 families were represented by mono species.

Similarily, in the moderately disturbed stand, Asteraceae was dominant family with 12 species and it was followed by Caesalpiniaceae (9 species), Euphorbiaceae (8 species), Fabaceae (7 species), Mimosaceae, Papilionaceae, (6 species each), Solanaceae, Vitaceae (5 species each), Rubiaceae, Myrtaceae, Malvaceae, Lauraceae (4 species each), Anacardiaceae, Commelionaceae, Convolvulaceae (3 species each), Acanthaceae, Amaranthaceae, Cyperaceae, Lycopodiaceae, Magnoliaceae, Melastomaceae, Meliaceae, Polygonaceae, Robaceae, Rutaceae, Scrophulareaceae, Sterculiaceae, Theaceae, Urticaceae, Verbenaceae (2 species each) and remaining 20 families with one species.

However, in the highly disturbed stand, Euphorbiaceae was the dominant family with 9 species and it was followed by Asteraceae (with 7 species), Papilionaceae (6 species), Caesalpiniaceae, fabaceae (5 species each), Commelionaceae, Lauraceae, Mimosaceae, Solanaceae (4 species each), Rosaceae, Rubiaceae, Verbenaceae (3 species each), Acanthaceae, Amaranthaceae, Anacardiaceae, Combreataceae, Convulaceae, Malvaceae, Melastomaceae, Moraceae, Myrtaceae, Rutaceae, Scrophulareaceae, theaceae, Zingiberaceae, (2 species each) and remaining 21 families were represented by single species (Table: 4.14).

Table: 4.14. Distribution of genera and species of angiosperm families in the undisturbed, moderately disturbed and highly disturbed forest stands.

SL.No		**Undisturbed**		**Mid-disturbed**		**Highly disturbed**	
	Family	**Genera**	**Species**	**Genera**	**Species**	**Genera**	**Species**
1	Acanthaceae	1	1	2	2	2	2
2	Amaranthaceae	1	2	1	2	1	2
3	Anacardiaceae	3	3	3	3	2	2
4	Apiaceae	1	1	1	1	-	-
5	Apocynaceae	-	-	1	1	-	-
6	Araliaceae	-	-	1	1	1	1
7	Asteraceae	12	13	11	12	7	7
8	Balsaminaceae	1	1	1	1	1	1
9	Berberidaceae	1	1	-	-	1	1
10	Bignoniaceae	-	-	-	-	1	1
11	Bombacaceae	1	1	-	-	1	1
12	Boraginaceae	1	1	1	1	1	1
13	Burseraceae	-	-	-	-	1	1
14	Caesalpiniaceae	2	5	5	9	3	5
15	Caprifoliaceae	1	1	-	-	-	-
16	Combretaceae	-	-	-	-	2	2
17	Commelionaceae	5	5	3	3	4	4
18	Convolvulaceae	1	1	1	3	2	2
19	Cyperaceae	2	2	2	2	-	-
20	Dioscoreaceae	1	1	1	1	-	-
21	Dipterocarpaceae	1	1	-	-	1	1
22	Elaeocarpaceae	2	2	1	1	1	1
23	Euphorbiaceae	4	6	6	8	6	9
24	Fabaceae	2	2	5	7	3	5
25	Gesneraceae	-	-	-	-	1	1
26	Gramineae	2	2	1	1	1	1

27	Hypericaceae	-	-	-	-	1	1
28	Juglandaceae	-	-	-	-	1	1
29	Labiatae	1	1	1	1	1	1
30	Laganaceae	1	1	-	-	-	-
31	Lauraceae	-	-	3	4	3	4
32	Liliaceae	2	2	-	-	-	-
33	Lobeliaceae	1	1	1	1	-	-
34	Lycopodiaceae	1	1	1	2	-	-
35	Lythraceae	2	2	1	1	1	1
36	Magnoliaceae	-	-	1	2	-	-
37	Malvaceae	3	3	4	4	2	2
38	Melastomaceae	1	2	1	2	1	2
39	Meliaceae	1	1	2	2	1	1
40	Mimosaceae	3	5	3	6	3	4
41	Moraceae	1	1	1	1	2	2
42	Myrtaceae	-	-	4	4	2	2
43	Olacaceae	1	1	-	-	1	1
44	Ophioglossoceae	1	1	1	1	-	-
45	Orchidaceae	1	1	1	1	-	-
46	Papilionaceae	6	7	5	6	4	6
47	Plantaginaceae	1	1	-	-	-	-
48	Poaceae	3	3	1	1	1	1
49	Polydiaceae	2	2	1	1	-	-
50	Polygonaceae	2	2	2	2	-	-
51	Proteaceae	-	-	1	1	-	-
52	Pteridaceae	1	1	1	1	-	-
53	Rosaceae	2	2	2	2	2	3
54	Rubiaceae	2	3	3	4	2	3
55	Rutaceae	-	-	2	2	2	2
56	Sabiaceae	-	-	1	1	-	-
57	Sapindaceae	-	-	-	-	1	1
58	Saurauiaceae	-	-	1	1	-	-
59	Scrophulareaceae	2	2	2	2	2	2
60	Solanaceae	2	5	2	5	2	4
61	Stemonaceae	1	1	-	-	-	-
62	Sterculiaceae	2	2	2	2	1	1
63	Teraceaceae	-	-	-	-	1	1
64	Theaceae	2	2	2	2	2	2
65	Tiliaceae	2	2	-	-	1	1
66	Urticaceae	1	1	2	2	-	-
67	Verbenaceae	3	3	2	2	2	3
68	Vitaceae	1	4	1	5	-	-
69	Zingiberaceae	2	2	1	1	2	2
		102	**120**	**106**	**134**	**87**	**105**

Abbreviation: -, Absent

4.2 Regeneration status of important species

The regeneration efficiency of four important species namely, *Schima wallichii*, *Castanopsis tribuloides*, *Callicarpa arboria and Sterculia villosa* which were common in all three stands was studied (Fig. 4.5 - 4.6). The medicinal value of these four species has been selected and it was found that regeneration potential was highly influenced by disturbance (Table 4.15). There was a sharp decline in percent conversion of seedlings to saplings and saplings to trees from undisturbed to highly disturbed stands, except *Schima wallichii* which showed maximum conversion in the moderately disturbed stand followed by undisturbed and highly disturbed stands. The percentage of seedlings that grew into saplings varied from 31% (*Schima wallichii*) to 41% (*Castanopsis tribuloides*) in the undisturbed stand, 29% (*Callicarpa arboria*) to 43% (*Schima wallichii*) in the moderately disturbed stand and 8% (*Castanopsis tribuloides*) to 19% (*Schima wallichii*) in the highly disturbed stand. However, the percentage of saplings that grew into tree stage was 37% (*Schima wallichii*) to 52% (*Castanopsis tribuloides*) in the undisturbed stand, 30% (*Sterculia villosa*) to 48% (*Schima wallichii*) in the moderately disturbed stand and 14% (*Castanopsis tribuloides*) to 20% (*Sterculia villosa*) in the highly disturbed stand.

Table: 4.15. Medicinal importance of four important species present in all stands

Species	**Family**	**Local name (M)**	**Plant part used**	**Medicinal value**
Callicarpa arborea	Verbenaceae	Hnahkiah	Bark, leave	Aromatic, bitter, tonic, carminative, young leaves in stomach-ache.
Castanopsis tribuloides	Fagaceae	Thingsia	Juice of Stem	Infection of mouth and tongue, whitish endocarp is edible
Schima wallichii	Theaceae	Khiang	Bark, leave	Cuts and wounds, powdered bark is given to cattle to kill the intestinal worms
Sterculia villosa	Sterculiaceae	Khaupui	Decoction of Bark	Dysentery, diarrhoea

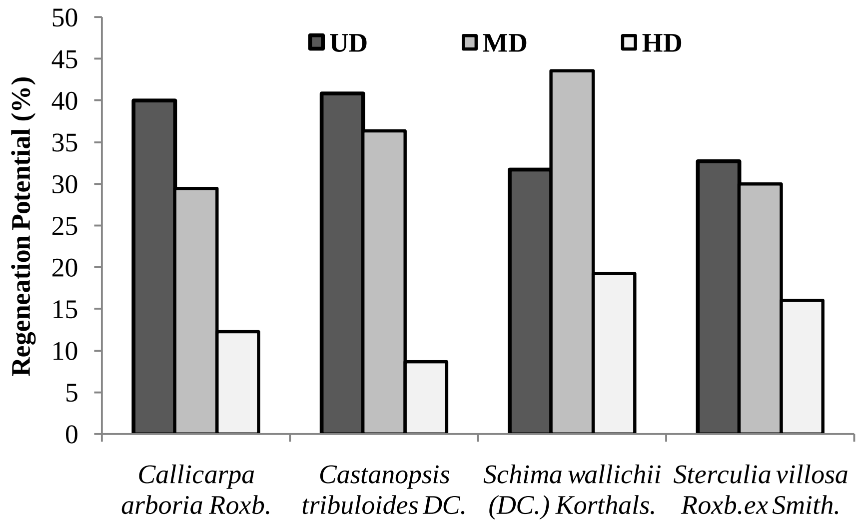


Fig: 4.5. Regeneration efficiency of four important species in terms of percent conversion of seedlings into saplings in the undisturbed (**UD**), moderately disturbed (**MD**) and highly disturbed (**HD**) forest stands.

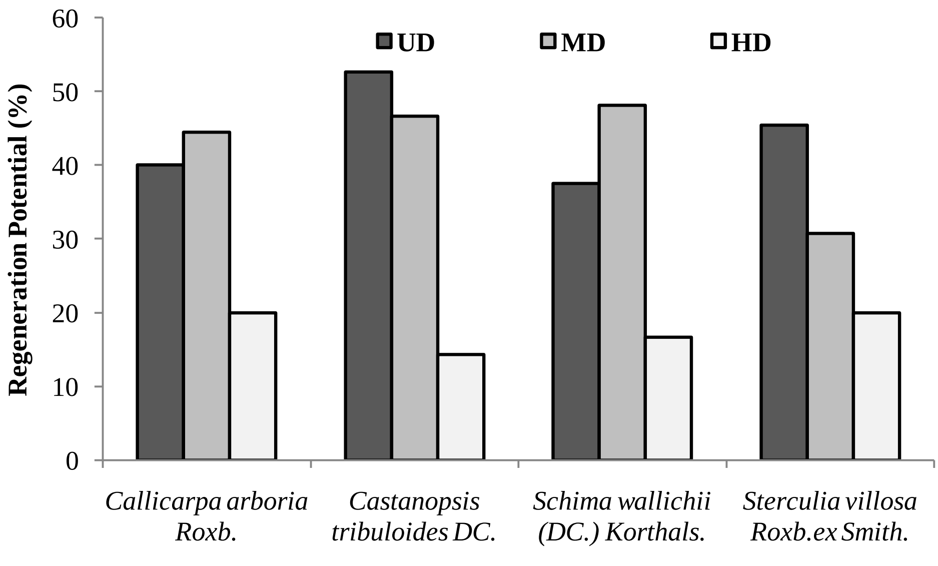


Fig: 4.6. Regeneration efficiency of four important species in terms of percent conversion of saplings into trees in the undisturbed (**UD**), moderately disturbed (**MD**) and highly disturbed (**HD**) forest stands.

4.3 Soil physico-chemical characteristics

4.3.1 Soil moisture content

The soil moisture content of top-soil ranged from 25.2 to 36.8%, 22.6 to 29.3% and 20.3% to 28.9% in the undisturbed, moderately disturbed and highly disturbed stands, respectively. Similarly, values in the sub-soil ranged from 21.8 to 34.1%, 19.5 to 26.5% and 15.6 to 25.7% in the undisturbed, moderately disturbed and highly disturbed stands, respectively. The soil moisture content was maximum in early rain (April) and minimum in early dry (December) in all the cases (Fig. 4.7).

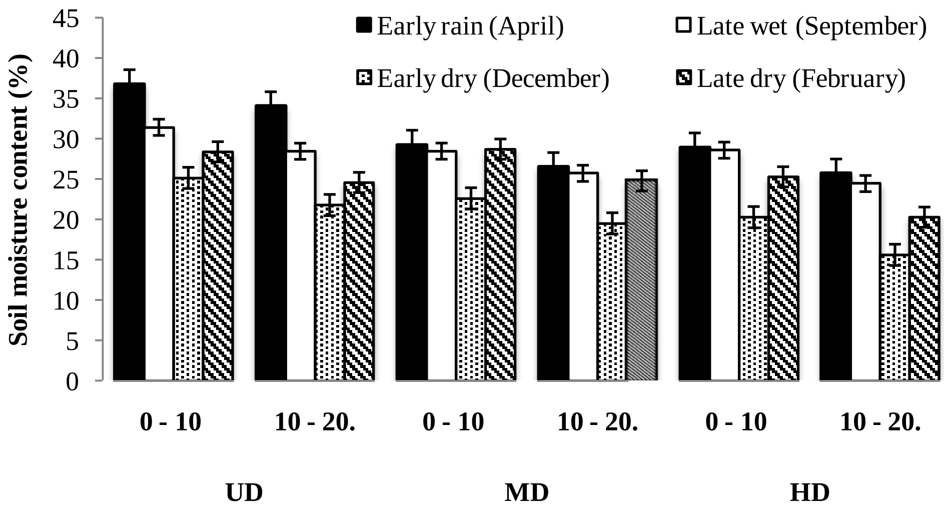


Fig. 4.7. Seasonal variation in soil moisture content (%) in the undisturbed (UD), moderately disturbed (MD) and highly disturbed (HD) forest stands.

4.3.2 Soil pH

The findings reveal that soil in all three sites was acidic in nature. The pH of top-soil ranged from 4.4 to 4.7, 5.4 to 5.6 and 6.2 to 6.4 in the undisturbed, moderately disturbed and highly disturbed stands, respectively. Corresponding values for the pH in sub-soil were 4.2 to 4.6, 5.0 to 5.2 and 5.8 to 6.1 in the undisturbed, moderately disturbed and highly disturbed stands, respectively (Fig. 4.8).

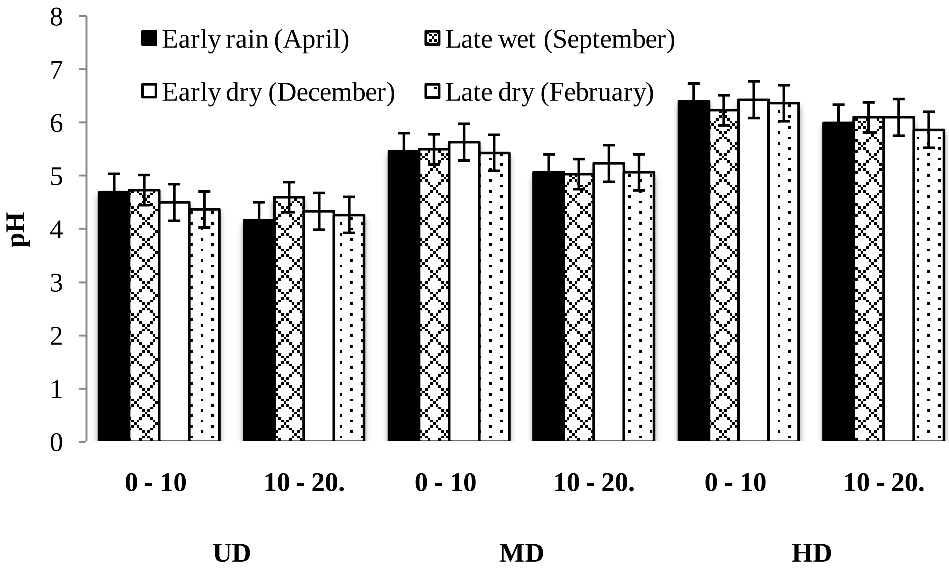


Fig. 4.8. Seasonal variation of pH in the undisturbed (UD), moderately disturbed (MD) and highly disturbed (HD) forest stands.

4.3.3 Soil organic carbon

Soil organic carbon in top soil ranged from 2.2 to 2.7%, 1.13 to 2% and 0.68 to 1.33 in the undisturbed, moderately disturbed and highly disturbed stands, respectively. Corresponding values of soil organic carbon in sub-soil were 1.6 to 2.2%, 1.23 to 1.83 and 0.66 to 0.93% in the undisturbed, moderately disturbed and highly disturbed stands, respectively. Marked seasonal variation in the concentration of soil organic carbon was noted from undisturbed to highly disturbed stands. In the undisturbed stand, organic carbon in top soil was maximum in early rain (April) and late dry (February), and minimum in early dry (December). Sub-soil showed a similar trend in results (Fig 4.10). In moderately disturbed stand, soil organic carbon concentration in top-soil was significantly higher in early rain (April), and lowest in late wet (September). The sub-soil followed a similar trend in results for organic carbon concentration. Concentration of organic carbon in top soil and sub-soil under highly disturbed condition was considerably declined in comparison to other two sites. However, the seasonal variation in organic carbon concentration in both soil depths was almost similar to that of undisturbed stand with few exceptions (Fig. 4.9).

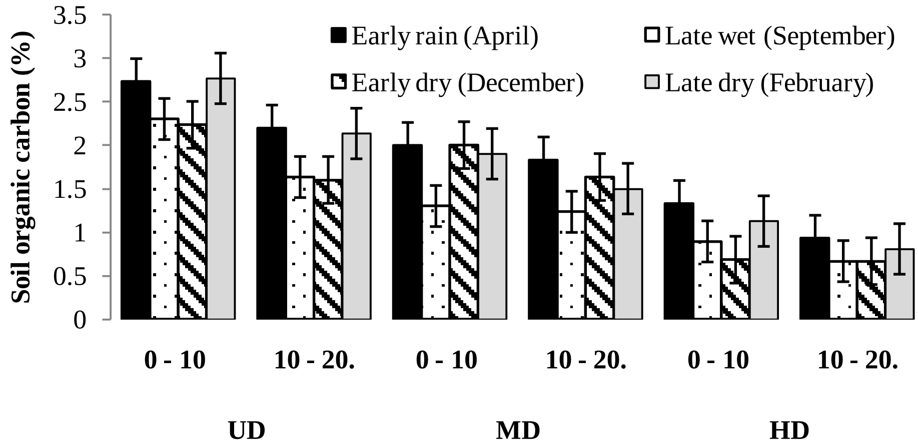


Fig. 4.9. Seasonal variation in soil organic carbon (%) in the undisturbed (UD), moderately disturbed (MD) and highly disturbed (HD) forest stands.

4.3.4 Total nitrogen

Total nitrogen content in top-soil ranged from 0.22 to 0.33%, 0.12 to 0.25% and 0.07 to 0.8% in the undisturbed, moderately disturbed and highly disturbed stands, respectively. Corresponding values of total nitrogen concentration in sub-soil ranged from 0.15 to 0.25%, 0.11to 0.18% and 0.05 to 0.9% in the undisturbed, moderately disturbed and highly disturbed stands, respectively. Nitrogen concentration in the soil also changed seasonally which broadly followed the pattern similar to organic carbon concentration (Fig. 4.10).

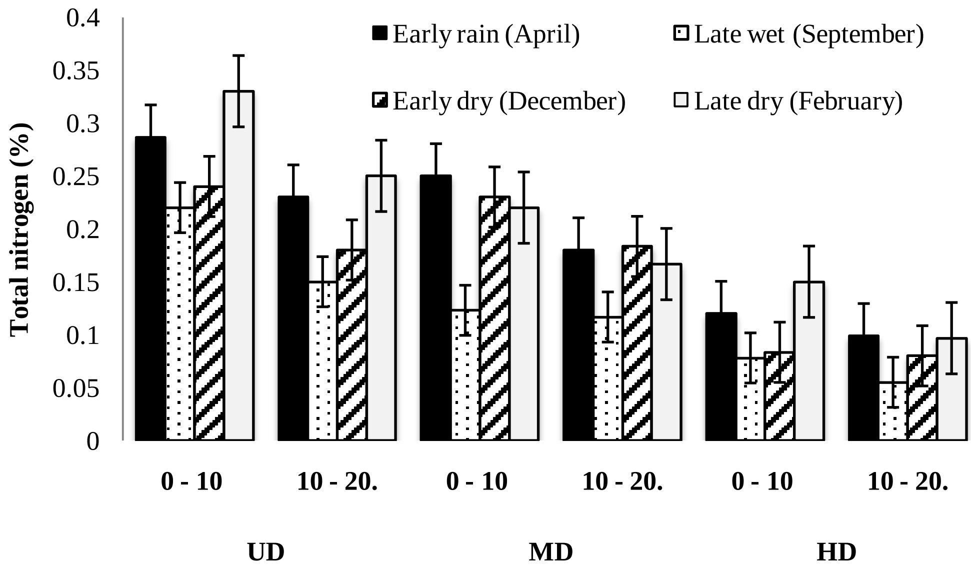


Fig. 4.10. Seasonal variation in total nitrogen (%) in the undisturbed (UD), moderately disturbed (MD) and highly disturbed (HD) forest stands.

4.3.5 Available phosphorus

Available phosphorus concentration in top-soil ranged from 22.3 to 28.6 µg g^{-1}, 11.33 to 16.66 µg g^{-1} and 7 to 14 µg g^{-1} in the undisturbed, moderately disturbed and highly disturbed stands, respectively. Corresponding values of available phosphorus in sub-soil ranged from 12.6 to 21.6 µg g^{-1}, 9 to 14.33 µg g^{-1} and 5.66 to 8 µg g^{-1} in the undisturbed, moderately disturbed and highly disturbed stands, respectively. A marked seasonal variation in the value was noted in soil of different sites at two depths. Available phosphorus content in two depths was higher in the dry seasons compared to wet season in the undisturbed site. The same trend in results continued in the moderately disturbed and highly disturbed stands with few exceptions (Fig. 4.11).

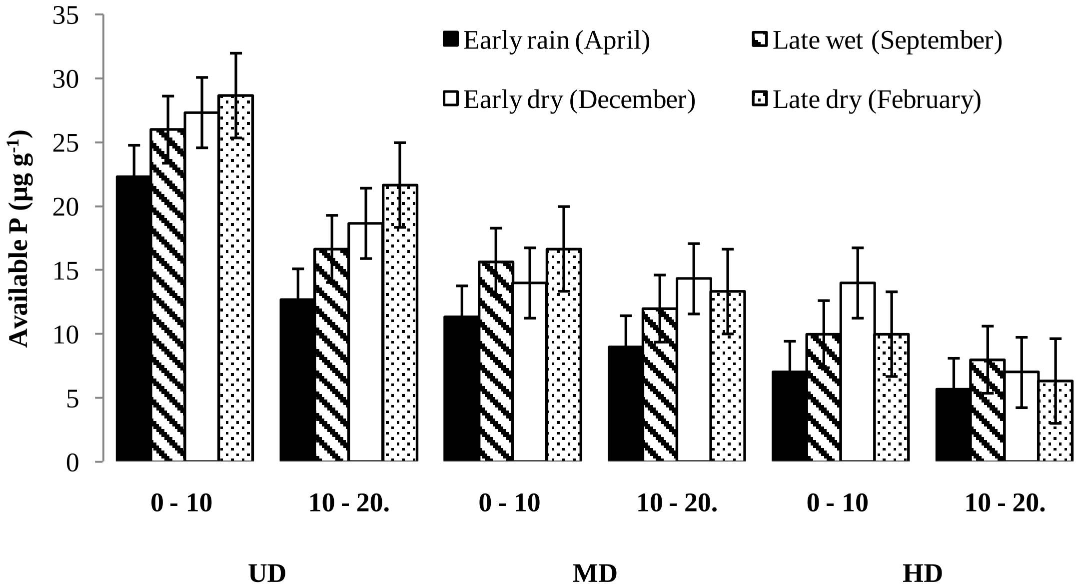


Fig. 4.11. Seasonal variation in available phosphorus (µg g^{-1}) in the undisturbed (UD), moderately disturbed (MD) and highly disturbed (HD) forest stands.

4.3.6 Exchangeable potassium

Exchangeable potassium in top-soil ranged from 178 to 233 µg g^{-1}, 140 to 188 µg g^{-1} and 65 to 110 µg g^{-1} in the undisturbed, moderately disturbed and highly disturbed stands, respectively. Corresponding values of in the sub-soil ranged from 153 to 190 µg g^{-1}, 101 to 152 µg g^{-1} and 55 to 100 µg g^{-1} in the undisturbed, moderately disturbed and highly disturbed stands, respectively. In the undisturbed stand, early rain (April) possessed minimum and early dry (December) showed maximum value of exchangeable potassium. However, in moderately disturbed and highly disturbed stands exchangeable potassium was minimum in early rain (April) and maximum in the late wet (September) (Fig. 4.12).

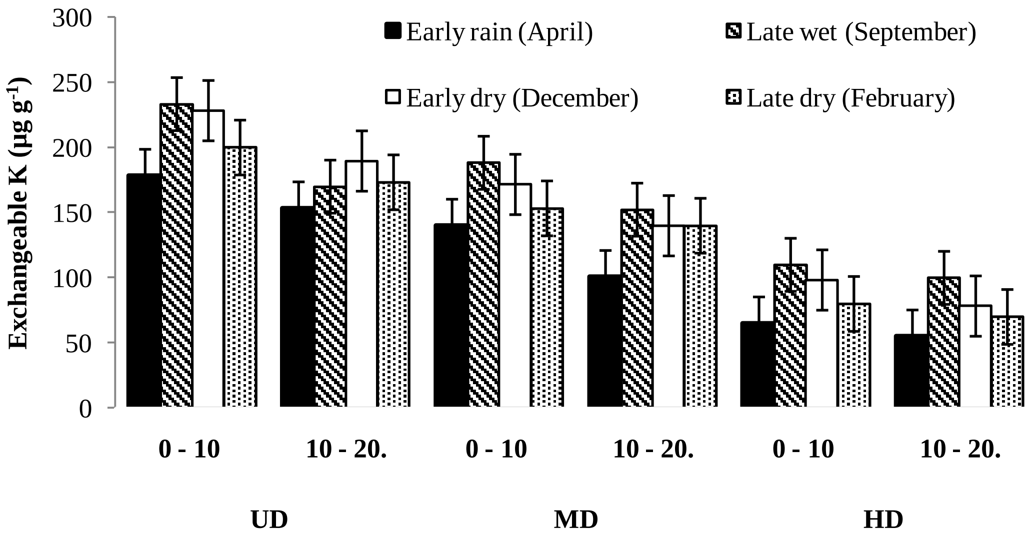
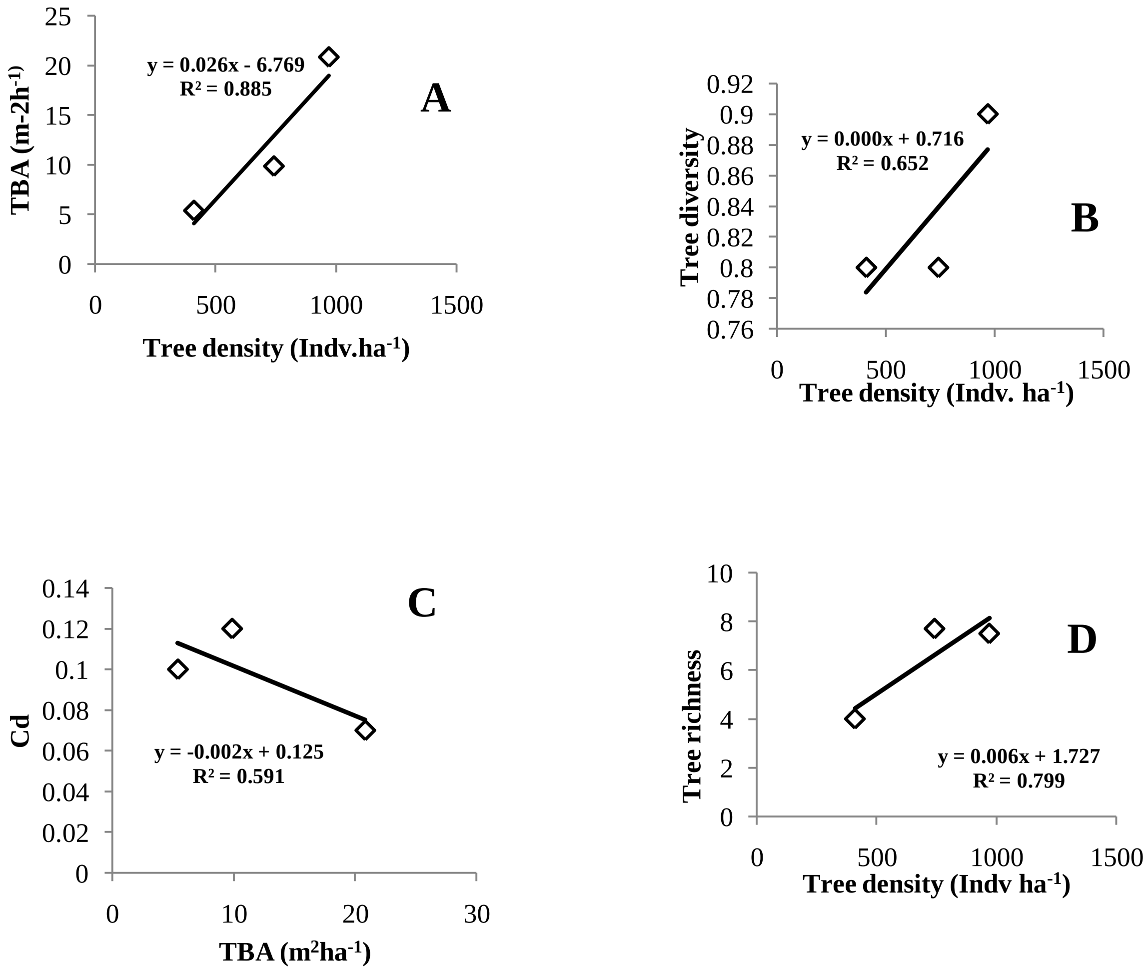


Fig. 4.12. Seasonal variation in exchangeable potassium (µg g^{-1}) in the undisturbed (UD), moderately disturbed (MD) and highly disturbed (HD) forest stands.

4.4 Relationship of Different Vegetation Parameters along Disturbance Gradient

The correlation between different vegetation parameters along disturbance gradient is given in Fig. 4.13. The tree density was positively strongly correlated with the tree basal area, tree diversity and tree richness (Fig. 4.13 A,B,D), whereas, tree basal area was negatively correlated with concentration of dominance (Fig. 4.13). Tree richness was positively correlated with diversity and negatively with concentration of dominance but the relationship was rather weak (Fig. 4.13 E,F).



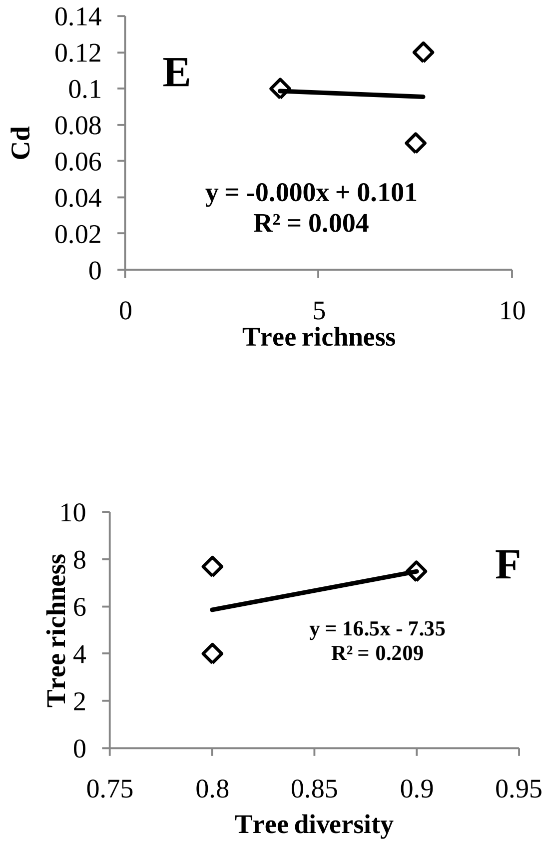


Fig: 4.13. Correlation between various vegetational parameters along disturbance gradient.

4.4.1 Relationship among different soil parameters at two depths along disturbance gradient

The correlation between various soil parameters of top-soil and sub-soil along disturbance gradient is given in Figs. 4.14, 4.15. The soil moisture content showed a positive correlation with soil organic carbon and negative correlation with pH (Fig. 4.14 A,B). However, soil organic carbon showed significant and positive correlation with total nitrogen and exchangeable potassium (Fig. 4.14 C, E). Available phosphorus showed positive and significant correlation with exchangeable potassium, and the total nitrogen showed positive correlation with available phosphorus (Fig. 4.14 D,F).

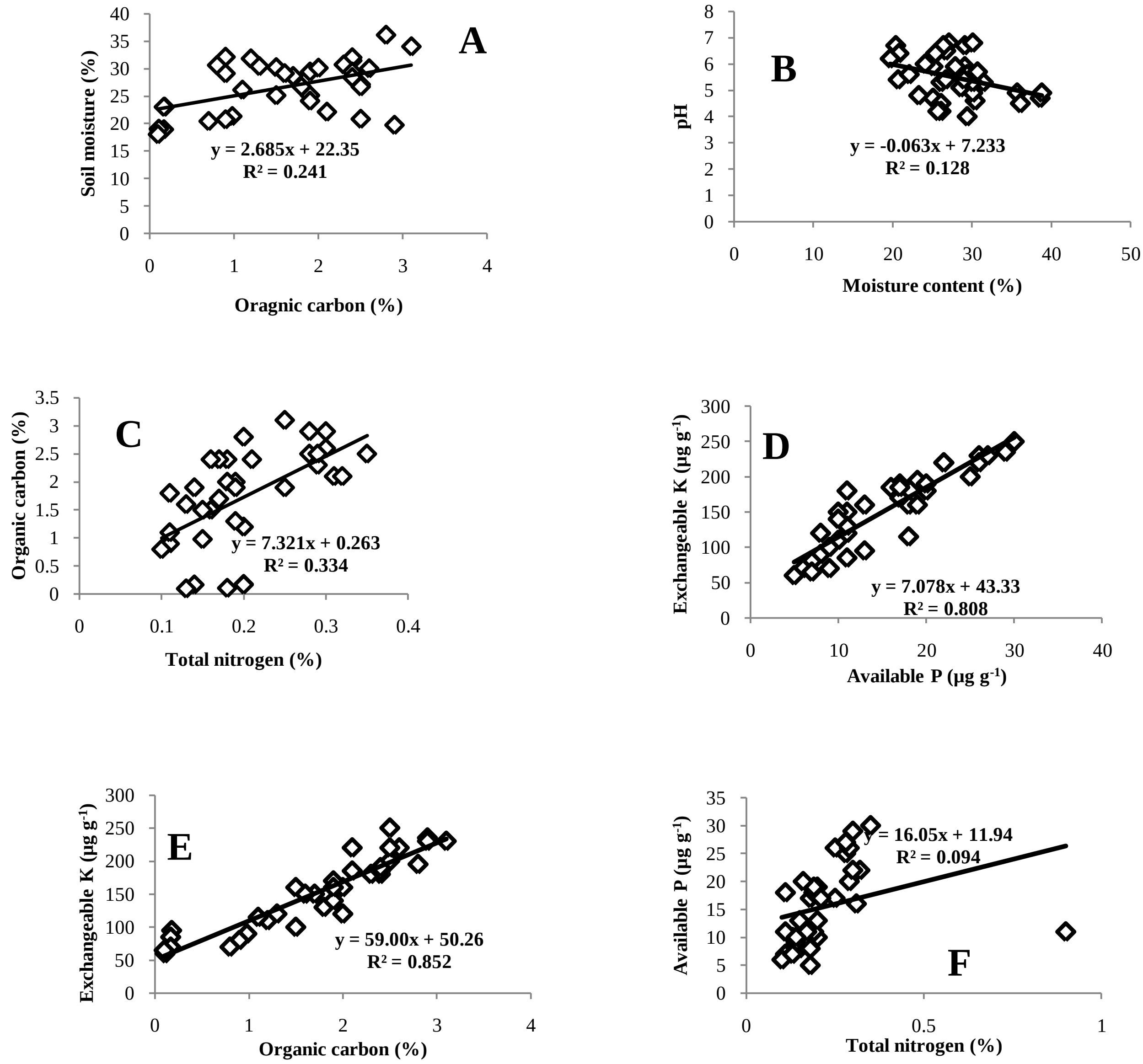


Fig: 4.14. Correlation between various soil parameters for top-soil along disturbance gradient

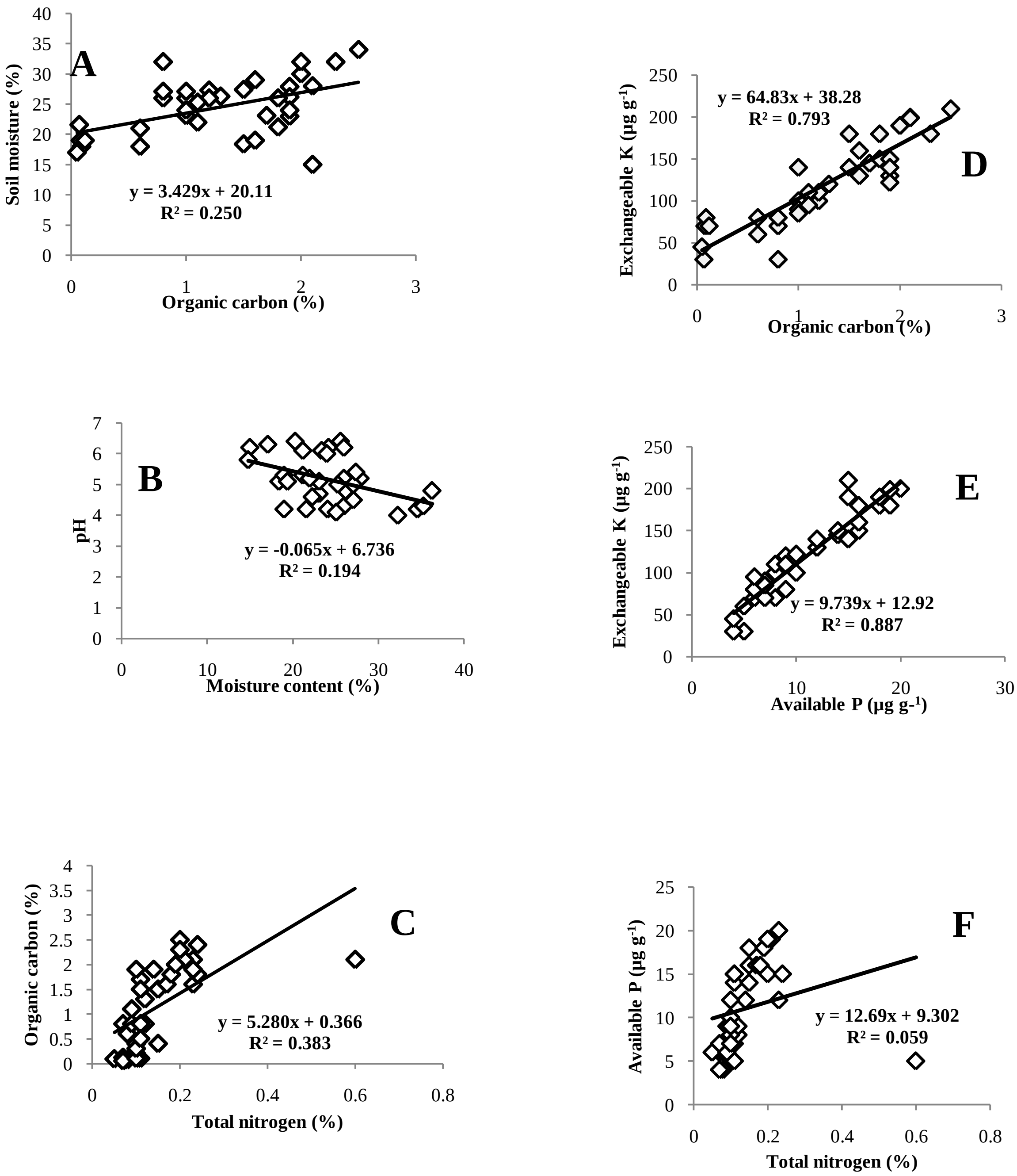


Fig: 4.15. Correlation between various soil parameters for sub-soil along disturbance gradient

4.4.2 Relationship between total basal area and soil organic carbon and nitrogen along disturbance gradient

Important vegetation parameter like total basal area was correlated with carbon and total nitrogen contents for two depths in the undisturbed, moderately disturbed and highly disturbed stands. The total basal area showed significant and positive correlation with soil organic carbon and total nitrogen in two soil depths (Fig. 4.16, 4.17).

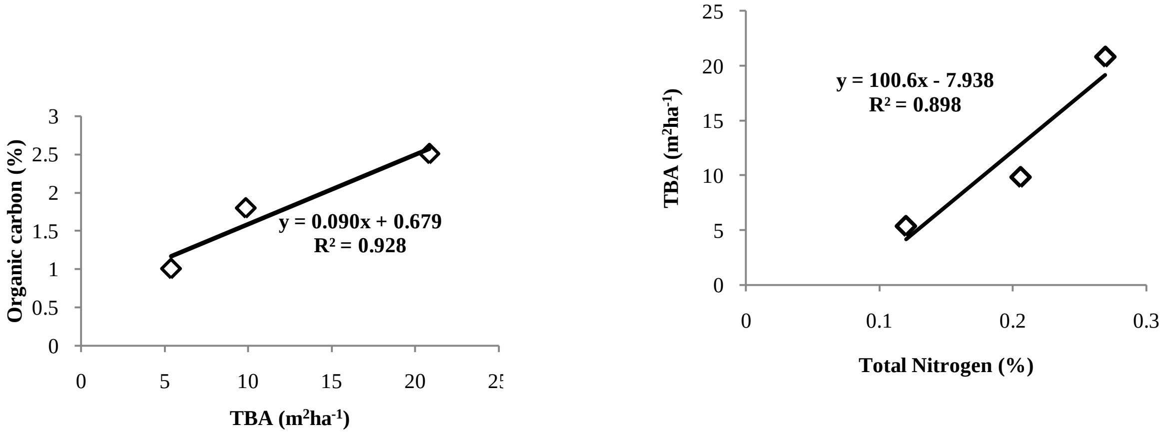


Fig: 4.16. Correlation between total basal area and soil parameters for top-soil along disturbance gradient

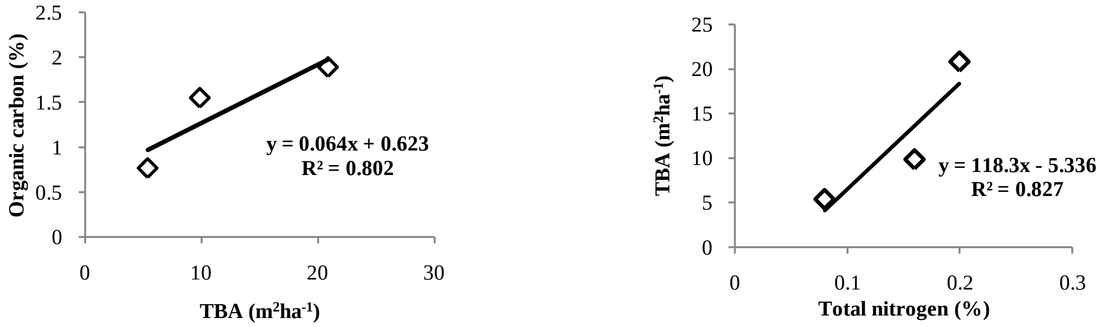


Fig: 4.17. Correlation between total basal area and soil parameters for sub-soil along disturbance gradient

CHAPTER- 5

GENERAL DISCUSSION

5.1 Vegetation analysis

The floristic composition of vegetation can be used as measure of dominance, species richness, abundance and frequency (Lamprecht, 1989). Species diversity is an important attribute of a natural community that influences functioning of an ecosystem (Hengeveld, 1996). Richards (1996) has argued that high species richness may be due to the presence of many synusiae in the forest. The species richness was reported high in the undisturbed and moderately disturbed stand. This could be attributed due to favourable edapho-climatic conditions (high and prolonged rainfall, moderate temperature, high relative humidity, status of soil) that support overall plant diversity. A favourable climatic condition facilitates plants to establish them through seedling emergence, whereas insects serve as pollinators to help plant reproduction. The area experiences seasonal variability and rainy season stands for about 6-7 months with temperature range of 18 ^{0}C to 27 ^{0}C. Prolonged rainy season provides uniformity of climate as well as relative constancy of resources in stable community and resulting in the formation of numerous niches allowing more species to occupy the unit habitat space by evolution of finer specialization and adaptations (Connell and Orias, 1964). The rich diversity may also be due to an increase in spatial heterogeneity because of the various effects of disturbances in lands as well as latitudinal and lavational gradient which are compatible with the maintenance of high diversity. Greater spatial heterogeneity or availability of a wide range of ecological niches favours co-existence of more species due to greater availability of resources and less competition between the species (Simpson, 1964). Evidence suggested that diverse site conditions contribute to the maintenance of species richness (Webb and Peart, 2000; Harms *et al.,* 2001; Philips *et al*., 2003 and Tuomisto *et al*., 2003) although the degree of specialization differs between forest (Kubota *et al*., 2004).

The mined and unmined areas have the similar climatic and physiographic features but altered edaphic conditions that may result in variation in species composition and survival of the individuals. In the disturbed stand, low growth forms and sparse density are related to the ability of the species to adapt to low moisture and nutrient level conditions that are probably the tolerance mechanisms of plants to the harsh physical nature of substrate (Lyngdoh, 1995; Dasgupta, 1999 and Sarma, 2002). This finding is in conformity with the work of Benarjee *et al.,* 2000; Mishra *et al*., 2003, 2004, 2005).

The trend in the results on the species richness, tree density and basal area are similar to the finding of past workers who studied different tropical forest ecosystems over the World (Murphy and Lugo, 1986; Singh and Singh, 1991; Ravan, 1994; Verghese and Menon, 1998; Sunderpandian and Swamy, 2000; Chowdhury *et al.,* 2000; Fox *et al.,* 1997; Khera *et al.,* 2001; Kadavul and Parthasarathy, 1999). Ayyappan and Parthasarathy, 1999; Ganesh *et al*., 1996; Parthasarathy, 1999; Parthasarathy and Karthikeyam, 1997). The sand stone mining has resulted in drastic decrease in species richness, tree density and basal area. Mishra *et al.* (2004) have also reported a similar trend in results. There was sharp shortening in tree girth class from undisturbed to highly disturbed stand. Tree girth class distribution can be used as indicators of changes in population structure and species composition (Singh and Singh, 1987; Newbery and Gartlan, 1996). The tree population structure observed in present study is similar to those reported from the forest at Costa Rica (Nadakarni *et al.,* 1995), Brazalian Amazon (Cambell *et al.,* 1992), Eastern Ghats (Kadavull and Parthasarathy, 1999) and sub tropical humid forest of Meghalaya (Mishra *et al*., 2005).

Girth class distribution indicated reduced number of individuals in higher girth classes and girth size was shortened in the highly disturbed stand. This could be linked with poor nutrient status of soil because of extensive mining operation in the past, leading to loss of nutrients and finally resulting into retarded growth (Mishra *et al*., 2004). Increased number of individuals of adult trees (30-50 cm) has resulted into high basal area contribution. This may be due to fast growth during adult stage. On contrary, despite low tree density, the basal area is high in higher girth class i.e. >90 cm. This could be attributed due to large coverage in term of girth. The findings are in conformity with the work of Mishra *et al.* (2004, 2005).

Schima wallichii was the dominant tree species in all the stands. However, *Castanospsis tribuloides* was the co-dominant species at the undisturbed, moderately disturbed stands which was replaced by *Sterculia villosa* in the highly disturbed stand. The shift in position of species could be linked with disturbance. Moreover, the species tolerant to stress showing better growth and survival under disturbed condition, such species express greater IVI in the disturbed stand. On contrary, the species sensitive to the disturbance either eliminated with increase in degree of disturbance or showing poor growth. Asteraceae was the dominant family in both the undisturbed and moderately disturbed stands, whereas, it was replaced by Euphorbiaceae that was the dominant family in the highly disturbed stand.

Similarly, Papilionaceae and Euphorbiaceae were the co- dominant families in the undisturbed stand while Caesalpinaceae and Euphorbiaceae were in the moderately disturbed stand. Asteraceae and Papilionaceae were co-dominant families in the highly disturbed stand. The shift in position of the species and families along the disturbance gradient could be linked with the levels of anthropogenic disturbance and similar trends was also reported by number of workers in the past (Thorington *et al.*, 1982; Visalakshi, 1995; Parthsarathy and Sethi, 1997; Parthsarathy and Karthikeyan, 1997; Kadavul and Parthasarathy, 1999; Mishra *et al.*, 2003, 2004, 2005 and Mishra and Laloo, 2006).

The finding on Shannon-Wiener diversity index of trees is in conformity with the reports for tropical forest of Kodayar in the Western Ghats of Southern India (Sundarapandian and Swamy, 2000) and sub-tropical forests in Garhwal Himalaya (Kumar *et al.*, 2010). The results on dominance index are similar to the findings in tropical and temperate forests (Knight, 1975; Tripathi *et al*., 1989a; Visalakshi, 1995).

The diversity and dominance indices for shrubs can be compared with the reports from forests of Kumaun Himalaya, Uttarakhand (Saxena and Singh, 1982; Tripathi *et al*., 1989b). Similarly, findings for herbs, Shannon-Weiner and Simpson dominance indices were comparable with the findings of Singh *et al.* (1984) and Pande *et al*. (2002). In different sub-tropical forest of Garhwal Himalaya, Kumar *et al*. (2004) also reported a similar trend in results.

The disturbance leads to change in the dominance of growth forms with respect to plant habit (Bhuyan *et al.*, 2001; Mishra *et al.*, 2004). In the present study, tree species were dominant in the undisturbed stand, whereas, shrubs in the moderately disturbed stand and herbs in the highly disturbed stands. It follow a normal successional pattern that the herbs and shrubs are occupying the open space followed by the trees which then suppresses the species during the course of development (Raizada *et al*., 1998; Bhuyan *et al.,* 2001; Mishra *et al.,* 2004).

Odum (1971) stated that clumped (contagious) distribution is very common in nature where the biotic and abiotic variations exist, and the species aggregate in cluster to exploit the resources in favourable conditions. Whereas, the random occurs in very uniform environment and regular distribution found where individuals are more evenly spaced than would occur by chance to avoid intra-specific competition between the individuals (Panchal and Pandey, 2004). Contagious distribution might be related to the seed dispersal mechanism of tree species and gap formation (Barik *et al.,* 1996). During present investigation, it has been been found that majority of the species showed contagious distribution pattern and few random distribution. Similar, distribution pattern has also been reported by other workers (Greig-Smith, 1957; Singh and Yadav, 1974; Mehta *et al*., 1997).

The patchiness of vegetation or the degree to which individuals are aggregated or dispersed, is crucial to understand how species uses resources. Besides, the distribution pattern of species, population structure is often related to its reproductive biology. It has been indicated that in the absence of disturbance other factors like soil and water conditions play major role in controlling species distribution pattern (Webb *et al*., 1967; Ashton, 1972; Austin *et al*., 1972). The contagious distribution pattern of species indicates the mosaic nature of the forest stand and suggests increase in fragmentation and patchiness of the natural vegetation due to sand stone mining. Similar observation for species distribution pattern was also observed in the coal mining areas of Nokrek biosphere reserve of Meghalaya (Sarma, 2002; 2005).

According to Whittaker (1965), the log normal series describes the partitioning of realized niche space among various species, and it is the consequence of the evolution of diversity in the species along the niche parameters that it exploits. Dominance-diversity curve is used to interpret the dominance of species in the community in relation to resource apportionment and niche space (Whittaker, 1975). The log normal curve indicates stable community and there is equitable sharing of IVI among the species. On contrary, short hooked curve in highly disturbed stand indicates unstable community. The dominance distribution curve of species in the undisturbed and moderately stands resemble the log normal dominance, indicating the stability of the community, while, short hooked curve in the highly disturbed stand indicating unstable community. Past workers have also reported log normal curve in different forests (Khera *et al.,* 2001; Tripathi *et al.*, 2004; Mishra *et al.,* 2004, 2005). Disturbance causes an eco-physiological constraint that has resulted into the decrease in community niche space and loss of species (Grime, 1983).

5.2 Regeneration efficiency

The population structure of a species in any forest conveys its regeneration behaviour (Saxena and Singh, 1984; Tripathi *et al*., 1989; Mishra *et al.,* 2003) such information has been used by several workers to interpret the successional patterns (Shugart and West, 1980). The population structure characterized by the presence of sufficient number of seedlings, saplings and adults, indicates a successful regeneration of forest species (Saxena and Singh, 1984; Tripathi *et al*., 1987; Rikhari *et al*., 1991), and the presence of saplings under canopy also indicates the future composition of a community (Austin, 1977). The Eastern Himalaya, Western Ghats and the north eastern hills are the hotspot of biodiversity in India. Primary forests of Asia, particularly those of the Western Ghats and the Eastern Ghats of peninsular India are depleting at an alarming rate due to anthropogenic activities and are replaced by forests comprising inferior species or change in land use pattern (Parthasarathy, 1999). The disappearance of tropical forests comes at a time when our knowledge on their structure and dynamics is woefully inadequate (Hubbell and Foster, 1992). Understanding of forest processes is necessary for assessment of potential impacts, the amelioration of effects of disturbance, optimization of productivity and rehabilitation of ecosystem (Congdon and Herbohn, 1993).

Seedling recruitment is the most important stage for understanding the dynamic assembly of ecosystems. The presence of good regeneration potential shows suitability of a species to the environment. Climatic factors and biotic interference influence the regeneration of different species in the community. The findings of present study reveal that number of seedling attaining sapling stage is low, this may be due to biotic disturbance and competition for space and nutrient

(Dhaulkhandi *et al.,* 2008). As succession proceeds and if mature trees are not removed, the population in highly disturbed stand may nearly approach those of the undisturbed stand. However, the species composition and the time taken may vary. The density of seedlings, saplings and mature trees indicates a marked loss of individuals during the period of conversion of seedlings to sapling which is a more vulnerable stage in the life cycle of life history of the species as compared to the period during which the saplings developed into the adult trees. High mortality and low growth rate are typical for juvenile stage due to low light level, exposure to physical and biotic disturbance and short term water deficits (Kobe, 1999; Davies *et al.,* 1999).

The percent conversion of seedling to sapling was found high in the undisturbed stand and there was sharp decline with increase in degree of disturbance except in case of *Schima wallichii*, which showed maximum conversion of seedlings into saplings under moderate disturbed condition. This depicts heliophilic nature of species. The disturbance adversely affected growth and survival of plants at juvenile stage (Mishra *et al.,* 2003). The low density of seedlings and saplings of some species in the undisturbed stand could be attributed to low light intensity on the forest floor due to dense overhead canopy (Barik *et al.*, 1992; Tripathi, 2002). The small gaps facilitated conversion of saplings into trees in case of *Callicarpa arboria* and *Schima wallichii* and maximum value was recorded in the moderately disturbed stand followed by undisturbed and highly disturbed stands. However, in case of *Castanopsis tribuloides* and *Sterculia villosa*, there was sharp decline in percent conversion of saplings to tree stage. The former two species were found heliophilic and later two species were found sciophilic in nature (Santos *et al.,* 1999; Bruna, 2002). The disturbance adversely affected regeneration of *Castanopsis tribuloides* and *Schima wallichii* which showed positive response to disturbance in the highly disturbed stand.

The maximum mortality of seedlings was recorded in the highly disturbed stand, which may be due to high degree of disturbance that hinders survival and establishment of seedlings and saplings as well as desiccation and high temperature in surface soil at higher elevation. Higher mortality of seedlings and saplings during the cold and dry month of January indicates vulnerability to cool and dry climatic conditions prevailing during the winter season, which induces high moisture stress. The detrimental effect of soil moisture stress on the survival of tree seedlings has also been reported by other workers (McLaren and McDonald, 2003; Beckage *et al*., 2005; Gomez-Aparicio *et al*., 2005 and Khumbongmayum *et al.,* 2005). Annual fluctuation in the establishment and survival of seedlings can also be caused by biological factors such as seed or seedling predator, abundance or variable seed rain (Beckage and Clark, 2005) as well as other environmental variables besides precipitation (Beckage *et al*., 2005).

The low mortality rate of saplings than seedlings could be attributed to the fact that newly recruited seedlings are more susceptible to environmental stresses than older seedlings which have larger root systems that help them to exploit soil resources more efficiently. Several workers have also observed high mortality rate in young seedlings which declines with age (Connell and Green, 2000; Gilbert *et al*., 2001; Delissio and Primack, 2003 and Uriarte *et al*., 2004b). Variation in the nutrient supply, light intensity and micro-environmental conditions in the gaps plays an important role in differential growth behaviour of seedlings of different tree species. Overall the moderately disturbed forest stand exhibited higher regeneration potential than the undisturbed and highly disturbed stands as implicated by the higher number of seedlings and saplings. It shows that moderate disturbance promotes regeneration of tree species. Thus, properly managed forest with a threshold level of extraction of resources can contributes significantly in the conservation and management of forest thereby helping in maintenance of biodiversity. Mishra *et al.,* (2003, 2004, 2005) have also reported that mild disturbances and small gaps within the forest facilitate natural regeneration.

5.3 Soil nutrients status and soil dynamics

The findings of the present study depict that there is drastic change in the physico-chemical characteristics of soil in two depths (top soil 0- 10 cm and sub soil 10- 20 cm) and anthropogenic activities played significance role for variation in values of soil characteristics for particular soil depth from undisturbed to highly disturbed stand. The soil moisture content, decreases as a function of increasing degree of disturbance during the summer/wet season (early rain and late rain) in both the depths. The higher moisture content during the summer/wet season may be related to high and regular rainfall. However, low moisture content during the winter/dry season could be due to high surface evaporation from the top-soil. The findings are in conformity with the work of several scientists (Tiwari *et al*., 1992; Tripathi *et al*., 2009; Reddy, 2010).

Soil pH is mostly related to the nature of the parent material, climate, organic matter and topographic situation (Tamirat, 1992). The soil at high altitude and those higher slopes had low pH values, probably suggesting the washing out of solutes from these parts (Belay, 1996; Abayneh, 2001; Mohammed *et al.,* 2005). During present study, the soil pH was increased (4.2 to 6.4) with increase in degree of disturbance. Low pH value in the undisturbed stand could be result of greater accumulation of partially decomposed organic matter on the forest floor and runoff and leaching losses of cations. On the contrary, high pH value in highly disturbed stand could be due to low accumulation of decomposed organic matter and extraction of sand stone. The findings of the present study is in conformity with the work of Arunachalam and Pandey (2003) and Mishra (2011) they also reported pH in the range 4.3 to 6.0 in the sub- tropical forest of Meghalaya. Yuan *et al*. (2006)

also reported acidic pH (5.2- 5.4) in three abandoned quarries of 3, 5 and 7 year age in China that supported the findings of the present study.

The soil organic carbon content varied greatly along disturbance gradient and decreased from undisturbed to highly disturbed stand and higher values were reported from top-soil. This could be linked with presence of thick humus layer on forest floor of the undisturbed stand. Litter accumulation on forest floor is positively linked with litter decomposition and plays a significant role in maintenance of soil moisture content and other micro-environmental conditions (Ramakrishnan and Toky, 1981; Arunachalam *et al*., 1996; Reddy, 2010; Mishra, 2010; Tripathi *et al*., 2012). Nayak and Srivastava (1995) have also reported a similar trend in results from the humid sub-tropical soils in north east India.

Soil nitrogen is derived from the organic matter and nitrogen is obtained through fixation by microbes and eventually added to the soil organic matter and become available to the plants. During present investigation, it has been reported that the total nitrogen greatly varied along disturbance gradient and also with increase in soil depth which range from 0.07% to 0.33% (top-soil) and 0.05% to 0.25% (sub-soil), and top-soil had higher values. Ghose (2002) has also reported a similar trend in result for the total nitrogen in soil. With the increase in disturbance, the total nitrogen was decreased markedly; this could be result of lack of adequate mineralizable organic nitrogen and lower mineralization rate. The findings of past workers (Sirajul *et al*., 1995; Arunachalam *et al.*, 1996; Pinjari *et al.*, 1999) support the results of the present study.

Available phosphorus decreased sharply from undisturbed to the highly disturbed stand, and varied greatly in the top-soil (7 to 28.66 µg g^{-1}) and sub-soil

(5.66 to 21.66 µg g^{-1}). The amount of phosphorus is directly linked with rate of decomposition of litter. The findings of present study are in conformity with the work of past workers (Henrot and Robertson, 1994; Soave, 2003; Hanief *et al.*, 2007).

Exchangeable potassium is absorbed on the soil colloidal surface from where it is slowly released to soil solution so as to be available to the plants. Plants then directly absorb potassium from soil solution where it is found in the most readily available form for plant absorption (Brady and Weil, 2002). Findings on exchangeable potassium showed a sharp reduction with increase in degree of disturbance.

5.4 Relationship between various vegetation parameters and soil characteristics

A positive correlation of species richness with diversity index was observed with few exceptions, and findings are in conformity with the report of Tripathi *et al*. (1989) that the species richness is positively correlated with Shannon diversity index in majority of cases in western Himalayan forests. Various diversity indices also followed similar trend (Jha *et al*., 2005; Saxena and Singh, 1982). A positive correlation was observed between total basal area and organic carbon in top-soil and sub-soil. The findings are supported by Sharma *et al.,* 2009.

CHAPTER- 6

SUMMARY AND CONCLUSIONS

With the increasing human population, the demand for the economically important plants is increasing. The anthropogenic pressures including stone mining have resulted in degradation of natural habitats and subsequently loss of biodiversity. Anthropogenic activities are discouraging survival and growth of the sciophilic species and leading to moisture stress condition. This condition promotes emergence of hardy and spiny species having little value for the society (Samant *et al.,* 2000). Biodiversity plays very significant role in modulating ecosystem function and stability which provides to humankind enormous direct economic benefits. Disturbance oriented changes in the components of the earth biodiversity cause concern for ethical and aesthetic reasons because of their strong potential role in altering ecosystem properties and, thus, their ability to provide goods and services to the society. During present investigation it was found that a large forest area have been turned into degraded forest due to extensive stone mining, creating unfavourable habitat conditions for plants. The unfavourable habitat conditions prevailing in the mined areas have reduced the chances of regeneration of many species, thereby reducing the number of species in mined areas. The population structure based on the composition of individuals in different girth classes denotes the regeneration potential and degree of stability of species in different communities. Studies of population dynamics are important for biodiversity manipulation in forest ecosystems and their management.

Therefore, the present study has been carried out with an aim to assess the impact of sand stone mining on plant diversity, natural regeneration of tree species and soil dynamics in the tropical semi- evergreen forest of Mizoram, along disturbance gradient. The study was conducted within and outside the campus of the Mizoram University. For detailed ecological investigation three forest patches namely, undisturbed, moderately disturbed and highly disturbed stands were selected. The undisturbed stand representing natural forest where no stone mining activity was done in the past. The moderately disturbed forest stand representing secondary forest where the stone mining activity was done 7 years back and the highly disturbed forest stand where sandstone mining was done recently (two years back).

The major findings of the present study can be summarized as below:

1. Anthropogenic activities altered community organization through changes in botanical composition. Disturbance has led to increase in the dominance of certain species which are tolerant to the particular disturbance arising out of stone mining.
2. A total of 189 species of plants belonging to 143 genera were recorded from all three forest stands representing 69 families of angiosperms. Of this, 78 tree species representing 34 families, 55 shurbs representing 28 families, 69 of herbs belonging to 31 families and 11 climber belonging to 3 families.
3. Asteraceae was the dominant family in the undisturbed and moderately disturbed stands. Co-dominant families in the undisturbed stand were: Papilionaceae and Euphorbiaceae; in the moderately disturbed stand like

Caesalpinaceae and Euphorbiaceae. Euphorbiaceae was dominant family in the highly disturbed stand followed by Asteraceae and Papilionaceae.

4. The tree species were the dominant form of vegetation in the undisturbed stand, whereas, dominance plant habit shifted to shrubs and herbs in the moderately and highly disturbed stands, respectively.
5. *Schima wallichii* was the dominant species among trees in all stands with highest IVI of 63.8 in the undisturbed, 83.3 in the moderately disturbed stand and 75.9 in the highly disturbed stand. C*astanospsis tribuloides* was co-dominant species in the undisturbed and the moderately disturbed but this species was replaced by *Sterculia villosa* in highly disturbed stand. The disturbance facilitates growth of heliophilic species as a result the dominant species in highly disturbed stands contributed much more IVI.
6. The shift in position of species and families from undisturbed to highly disturbed stands could be linked with degree of disturbance.
7. The tree species sensitive to disturbance as reflected by their reduced abundance or complete absence in the highly disturbed stand (like *Acacia fernesiana, Engelhardtia spicata, Oroxylum indicum*) appear to be more vulnerable to the disturbance.
8. Among the shurbs, *Chromolaena odorata* was the dominant species in all stands but co-dominant species were *Rubus rugosus* in the undisturbed, *Urena lobata* in the moderately disturbed and *Melastoma melabatricum* in the highly disturbed stands.
9. Among herbs, *Costus speciosus* was the dominant species in the undisturbed followed by co-dominant species *Achyranthes aspera* while in the moderately disturbed and highly disturbed stands M*imosa pudica* was the dominant species.

10. Log-normal dominance-distribution curves in the undisturbed and moderately disturbed stand indicating the stability of community, while short hooked curve in the highly disturbed stand indicates unstable community.
11. The shade tolerant species (sciophilic) showed better recruitment of seedlings under close canopy – *Callicarpa arborea, Castanopsis tribuloides* etc. On the contrary, light stimulated seed germination in case of light demanding (heliophilic) species – *Schima wallichii.*
12. Small gaps in the moderately disturbed forest facilitated growth and survival of seedlings, suggesting that mild disturbance supports regeneration in terms of conversion of seedlings to saplings and finally to trees.
13. The disturbance adversely affected the juvenile stage, leading to arrested survival and growth of seedlings and saplings.
14. The rate of seedling mortality decrease from undisturbed to highly disturbed stands. The mortality was higher during the cool and dry months (January-February) and lower during hot-wet months (May-June).
15. The regeneration potential of *Schima wallichii* was comparatively higher in all the stands with highest number of seedlings ha^{-1} in the highly disturbed, followed by undisturbed and moderately disturbed stands.
16. The soil properties greatly varied from undisturbed to highly disturbed stand. The fertility of soil decrease from undisturbed to highly disturbed stand in term of total nitrogen, organic C and available phosphorus. Values of all soil organic C and nutrients (total nitrogen, available phosphorus) were lower in the sub-soil compared to top soil. Details of soil characteristics in different sites are described below:

I. The soil moisture content ranged from 25 to 37 % (0-10 cm) and 22 to 34 % (10-20 cm) in the undisturbed; 23 to 29 % (0-10 cm) and 20 to 27 % (10-20 cm) in the moderately disturbed and 20 to 29 % (0-10 cm) and 16 to 26 % (10-20 cm) in the highly disturbed stand.

II. The soil pH was acidic in nature and ranged from 4.3 to 4.7 (0-10 cm) and 4.1 to 4.6 (10-20 cm) in the undisturbed; 5.0 to 5.4 (0-10 cm) and 5.0 to 5.2 (10-20 cm) in the moderately disturbed and 6.2 to 6.4 (0-10 cm) and 5.8 to 6.1 (10-20 cm) in the highly disturbed stand.

III. The soil organic content ranged from 2.2 to 2.7 % (0-10 cm) and 1.6 to 2.2 % (10-20 cm) in the undisturbed; 1.3 to 2 % (0-10 cm) and 1.2 to 1.8 % (10-20 cm) in the moderately disturbed and 0.6 to 1.3 % (0-10 cm) and 0.6 to 0.9 % (10-20 cm) in the highly disturbed stand.

IV. The total nitrogen content ranged from 0.28 to 0.33 % (0-10 cm) and 0.15 to 0.22 % (10-20 cm) in the undisturbed; 0.12 to 0.25 % (0-10 cm) and 0.11 to 0.18 % (10-20 cm) in the moderately disturbed and 0.07 to 0.83 % (0-10 cm) and 0.09 to 0.96 % (10-20 cm) in the highly disturbed stand.

V. The available phosphorus content ranged from 24 to 29 µg $^{g-1}$ (0-10 cm) and 13 to 21 µg $^{g-1}$ (10-20 cm) in the undisturbed; 11 to 17 µg $^{g-1}$ (0-10 cm) and 9 to 15 µg $^{g-1}$ (10-20 cm) in the moderately disturbed and 7 to 14 µg $^{g-1}$

(0-10 cm) and 6 to 8 µg $^{g-1}$ (10-20 cm) in the highly disturbed stand.

VI. The exchangeable potassium content ranged from 173 to 234 µg $^{g-1}$ (0-10 cm) and 154 to 188 µg $^{g-1}$ (10-20 cm) in the undisturbed; 140 to 188 µg $^{g-1}$ (0-10 cm) and 106 to 152 µg $^{g-1}$ (10-20 cm) in the moderately disturbed and 65 to 110 µg $^{g-1}$ (0-10 cm) and 55 to 100 µg $^{g-1}$ (10-20 cm) in the highly disturbed stand.

The findings of the present study on phytosociological analysis and soil physico-chemical characteristics may be a potential tool for management of abandoned mined areas. The information on vegetation composition and dominance of species and status of soil may be helpful in selecting appropriate species for re-vegetating abandoned mines areas, for conservation of biodiversity and eco-restoration of degraded land.

This study suggests that the species dominant (*Schima wallichii*) and co-dominant (*Sterculia villosa*) at highly disturbed site should be included in reclamation programs of the Mizoram Government to promote the recovery of the highly degraded lands. The analysis of soil chemical parameters is pre-requisite to determine soil fertility. During the later stages of development of soil properties the other species should be introduced which are dominants (*Schima wallichii*) and co-dominants (*Castanopsis tribuloides*) at the moderately disturbed site and undisturbed site so that they may occupy the niche.

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References

Abayneh, E. (2001). Some Physico-chemical Characteristics of the Raya Valley Soils. *Ethiopian Journal of Natural Resources*, **3**(2): 179-193.

Achard, F., Eva, H.D., Stibig, H., Mayaux, P. Gallefo, J., Richards, T. and Malingreau, J. (2002). Determination of deforestation rates of the World's humid tropical forests. *Science*, **297**: 999-1002.

Ackerly, D. (2004). Functional strategies of chaparral shrubs in relation to seasonal water deficit and disturbance. *Ecological Monographs*, **74**: 25-44.

Aksamit, S.E. and Irving F.D. (1984). Prescribed burning for lowland black spruce regeneration in Northern Minnesota. *Canadian Journal of Forest Research*, **14**: 107–113.

Alfred, E. H. and Tom, V.Z. (2008). Land Cover Change and Soil Fertility Decline in Tropical Regions. *Turkish Journal of Agriculture and Forestry*, **32**: 195-213.

Allen, S.E., Grimshaw, H.M., Rowland, A.P. (1976). Chemical analysis. In: Moore, P.D., Chapman, S.B. (Eds.), *Methods in Plant Ecology*. Blackwell, Oxford, pp. 285-344.

Anderson, D.W. (1977). Early stages of soil formation of glacial till mine in a semiarid climate. *Geoderma*, **19**: 11-19.

Anderson, J.M. and Ingram, J.S.I. (1993). Tropical Soil Biology and Fertility. *A Handbook of Methods* (2^{nd} Ed), CAB International, Wallingford, U.K. pp 221.

Anitha, K., Joseph, S., Ramasamy, E.V. and Prasad, S.N. (2009). Changes in structural attributes of plant communities along disturbance gradients in a dry deciduous forest of Western Ghats, India. *Environmental Monitoring and Assessment*, 155: 393-405.

Appolinario, V., Filho, A.O. and Guilherme, F.A.G. (2005). Tree population and community dynamics in a Brazilian tropical semideciduous forest. *Revista Brasileira de Botanica*, **28**(2): 347-360.

Aravind, N.A., D. Rao, G. Vanaraj, J. Poulsen, R. Uma Shankar and K.N. Ganeshaiah. (2001). Anthropogenic pressure in a tropical forest ecosystem in western ghats, India: are they sustainable. *In*: K.N. Ganeshaiah, R. Uma Shankar and K.S. Bawa (Eds.) *Tropical Ecosystems: Structure, Diversity and Human Welfare.* Oxford & IBH, New Delhi, pp. 125-128.

Arifin, A., Karam, D.S., Shamshuddin, J., Majid, N.M., Radziah, O., Hazandy, A.H., and Zahari, I. (2012). Proposing a suitable soil quality index for natural, secondary and rehabilitated tropical forests in Malaysia. *African Journal of Biotechnology,* **11**(14): 3297 – 3309.

Armesto, J. J., and Pickett, S. T. A. (1985). Experiments on disturbance in old-Field plant communities: Impact on species richness and abundance. *Ecology,* **66**: 230–240.

Arunachalam, A. and Pandey, H.N. (2003). Ecosystem restoration of jhum fallows in northeast India: microbial C & N along altitudinal and successional gradient. *Restoration Ecology,* **11**: 168-173.

Arunachalam, A., Arunachalam, K., Bhattacharjee, A. and Nag, A. (2000). Natural revegetation on landslides in humid tropical Arunachal Pradesh: community dynamics and soil properties. *Journal of Tropical Forest Science*, **12**: 282-296.

Arunachalam, A., Boral, L. and Maithani, K. (1994). Effects of ground fire on nutrients in soil and litter in sub-tropical forest of Meghalaya. *Journal of Hill Resources,* **7**: 13-16.

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 northeast India. *Forest Ecology and Management*, **88**: 273-282.

Arunachalam, A., Sarmah, R., Adhikari, D., Majumder, M. and Khan, M.L. (2004). Anthropogenic threats and biodiversity conservation in Namdapha nature reserve in the Indian Eastern Himalayas. *Current Science,* **87**(4):447-454.

Arunachalam, K., Arunnachalam, A, Tripathi, R.S. and Pandey, H.N. (1997). Dynamics of microbial population during the aggregation phase of a selective logged subtropical humid forest in northeast India. *Tropical Ecology*, **38**: 333-341.

Ashton, M.P., Ashton, P.S. and Greig-Smith, P. (1972). The application of Quantitative methods to vegetation Survey III. A re-examination of rainforest data from Brunie. *Journal of Ecology,* **60**: 308-324.

Ashton, P.S. (1972). The Quatemary geomorphological history of western Malesia and lowland forest phytogeography. In: P.S. and Ashton (Eds.), the Quaternary era in Malesia, Transactions of the second Aberdeen-Hull Symposium on Malesian Ecology, 1971. Hull (UK). University of Hull Department of Geography Miscellaneous Series, **13**: 35-62.

Ashton, P.S. (1993). The community ecology of Asian rain forests in relation to catastrophic events. *Journal of Biosciences,* **18**: 501-514.

Ashton, P.S. and Hall P. (1992). Comparisons of structure among mixed dipterocarp forests of northwestern Borneo. *Journal of Ecology*, **80**: 459–481.

Austin, M.P. (1977). Use of ordination and other multivariate descriptive methods to study succession. *Vegetatio*, **35**(3): 165–175.

Austin, M.P., Ashton, P.S. and Smith, P.G. (1972). The application quantitative methods to vegetation survey III. A re-examination of rain forest data from Brunei. *Journal of Ecology,* **60**: 305-324.

Ayyappan, N. and Parthsarathy N. (1999). Biodiversity inventory of trees in a large scale permanent plot of tropical evergreen forest at Varagalaiar, Anamalais, Western Ghats, India. *Biodiversity and Conservation*, **8**: 1533-1554.

Bada, S.O. (1984). *Growth patterns in an untreated tropical rainforest ecosystem. Ph.D thesis, University of Ibadan, Nigeria*.

Baduni, N.P. and Sharma, C.M. (2001). Population structure and community analysis on different aspects of Sal savanna forest type in outer Garhwal Himalaya. *Indian Forester*, **127**(9): 1001– 1011.

Baer, S.G., Blair, J.M., Collins, S.L. and Knapp, A.K. (2004). Plant community responses to resource availability and heterogeneity during restoration. *Oecologia*, **139**: 617-629.

Baillie, I.C., Ashton, P.S., Court, M.N., Anderson, J.A.R., Fitzpatrick, E.A. and Tinsley, J. (1987). Site characteristics and the distribution of tree species in a mixed dipterocarp forest on tertiary sediments in central Sarawak, Malaysia. *Journal of Tropical Ecology*, **3**: 201-220.

Bajrachyarya, R.M., Sitaula, B.K., Sharma, S. and Jeng, A. (2007). Soil quality in the Nepalese context-analytical review. *International Journal of Ecology and Environmental Science*, **33**(2-3): 143-148.

Baltzer, J.L. and Thomas, S.C. (2007). Determinants of whole-plant light requirements in Bormean rain forest tree saplings. *Journal of Ecology*, **95**: 1208-1221.

Banerjee, S.K., Mishra, T.K. and Singh, A.K. (2000). Restoration and reconstructure of coal mine spoils: an assessment of time prediction for total ecosystem development. *Advances in Forestry Research in India*, **23**: 1-28.

Barberis, I.M. and Tanner, E.V.J. (2005). Gaps and root trenching increase tree seedling growth in Panamanian semi-evergreen forest. *Ecology*, **86**(3): 667-674.

Barik, S.K., Pandey, H.N., Tripathi, R.S. and Rao, P. (1992). Micro-environmental variability and species diversity in treefall gaps in sub-tropical broad-leaved forest. *Vegetatio*, **103**: 31-40.

Barik, S.K., Rao, P., Tripathi, R.S. and Pandey, H.N. (1996). Dynamics of tree seedlings population in a humid subtropical forest of northeast India as related to disturbance. *Canadian Journal of Forest Research*, **26**: 584-589.

Barik, S.K., Tripathi, R.S., Pandey, H.N. and Rao, P. (1996). Tree regeneration in a sub-tropical humid forest: effect of cultural disturbance on seed production, dispersal and germination. *Journal of Applied Ecology*, **33**: 1551-1560.

Barton, A.M. (1993). Factors controlling plant distributions: drought, competition and fire in montane pines in Arizona. *Ecological Monographs*, **63**: 367-397.

Barton, J. (1827). *A Lecture on the Geography of Plants*. Harvey and Darton, London.

Battaglia, L.L., Fore, S.A. and Sharitz, R.R. (2000). Seedling emergence, survival and size in relation to light and water availability in two bottomland hardwood species. *Journal of Ecology*, **88**: 1041-1050.

Baumgartner, S. (2005). Measuring Biodiversity. University of Heidelberg, Germany.

Beckage, B. and Clark, J.S. (2005). Does predation contribute to tree diversity? *Oecologia*, **143**: 458-469.

Beckage, B., Lavine, M. and Clark, J.S. (2005). Survival of tree seedlings across space and time: estimates from long term count data. *Journal of Ecology,* **93**: 1177-1184.

Behera, M.D., Kushwala, S.P.S. and Roy, P.S. (2006). Rapid assessment of biological richness in a part of eastern Himalaya: An integrated three-tier approach. *Forest Ecology and Management,* **207**(3): 363–384.

Behera, S.K. and Misra, M.K. (2006). Floristic and structure of the herbaceous vegetation of four recovering forest stands in the Eastern Ghats of India. *Biodiversity and Conservation,* **15**: 2263-2285.

Belal, A.E. and Pringuel, I. (1996). Economic value of plant diversity in arid environments. *Nature and Resources,* **22**(1): 33–39.

Belay, T. (1996). Characteristics of Landscape Relationships of Vertisol and Vertic Luvisols of Melbe, Tigray, Ethiopia. SINET: *Ethiopian Journal of Science,* **20**(2): 151-175.

Berendse, F. (1990). Organic matter accumulation and nitrogen mineralization during secondary succession in heathland ecosystems. *Journal of Ecology,* **78**: 413-427.

Bews, J. W. (1927). Studies in the ecological evolution of the angiosperms. *New Phytology,* **26**: 1-21, 65-84, 129-148, 209-248, 273-294.

Bhandari, B.S. (2003). Blue pine (*Pinus wallichiana*) forest stands of Garhwal Himalaya: composition, population structure and diversity. *Journal of Tropical Forest Sciences,* **15**(1): 26–36.

Bhuyan, P., Khan M.L. and Tripathi, R.S. (2001). Tree diversity and population structure in undisturbed and human impacted tropical wet evergreen forests of Arunachal Pradesh, northeast India. *In*: K.N. Ganeshaiah, R. Uma Shankar and K.S. Bawa (Eds.) *Tropical Ecosystems: Structure, Diversity and Human Welfare.* Oxford & IBH, New Delhi, pp. 114-115.

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 Conservation*, **12(**8): 1753–1773.

Bhuyan, P., Khan, M.L. and Tripathi, R.S. (2002). Regeneration status and population structure of Rudraksh (*Elaeocarpus ganitrus* Roxb.) in relation to cultural disturbances in tropical wet evergreen forest of Arunachal Pradesh. *Current Science*, **83**(11): 1391–1394.

Blundell, A.G. and Peart, D.R. (2001). Growth strategies of a shade-tolerant tropical tree: the interceptive effects of canopy gaps and simulated herbivory. *Journal of Ecology*, **89**: 608-615.

Bock, C.E. (1987). Distribution-abundance relationships of some Arizona land birds—a matter of scale. *Ecology*, **68**: 124–129.

Bock, C.E., and Ricklefs, R.E. (1983). Range size and local abundance of some North American songbirds: a positive correlation. *American Naturalist*, **122**: 295–299.

Bokhari, U.G., Singh, J.S. and Smith, F.M. (1975). Influence of temperature regimes and waterstress on the germination of three range grasses and its possible ecological significance to a shortgrass Praire. *Journal of Applied Ecology*, **12**: 153-163.

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.

Boring, L.R., Monk, C.D. and Swank, W.T. (1981). Early regeneration of a clear cut southern Appalachian forest. *Ecology*, **62**: 1244-1253.

Bormann, F.H. and Likens, G.E. (1979). Pattern and Process in a Forested Ecosystem. Springer- Verlag, New York, USA.

Brady, N. C. and Weil, R. R . (2002). The nature and properties of soil.13rd Ed. New Jersey: Prentice-Hall, Inc. pp 960.

Breckle, S.W. (1997). Population studies on dominant and abundant tree species in the montane tropical rain forests of the Biological Reserve North of San Ramon (Sra, de Tilaran, Costa Rica). *Tropical Ecology*, **38**(2): 259-272.

Brown, J.H. (1984). On the relationship between abundance and distribution of species. *American Naturalist*, **124**: 255–279.

Brown, P.M. and Wu, R. (2005). Climate and disturbance forcing of episodic tree recruitment in a southwestern Ponderosa pine landscape. *Ecology*, **86(**11): 3030-3038.

Bruenig, E.F. (1983). Vegetation structure and growth. In: Golley, F.B. (Ed.) Tropical Rainforest Ecosystems: Structure and Function. *Elsevier Scientific Publishing, Amsterdam*. pp. 44-75.

Bruna, E.M. (2002). Effects of forest fragmentation on Heliconia cuminate seedling recruitment in central Amazonia. *Oecologia*, **132**: 235-243.

Brunig, E.F. (1970). Stand structure, physiognomy and environmental factors in some lowland forests in Sarawak. *Tropical Ecology*, **11**: 26-43.

Busing, R.T. and White, P.S. (1997). Species diversity and small scale disturbance in an old growth temperate forest: a consideration of gap partitioning concept. *Oikos*, **78**: 562-568.

Campbell, D.G., Stone, J.L. and Rosas, A. Jr. (1992). A comparison of the phytosociology and dynamics of three floodplain (Varzea) forest of known ages. Rio Jurua. Western Brazilian Amazon. *Botanical Journal of Linnaean Society*, **108**: 213-237.

Canham, C. D., and Marks, P. L. (1985). The response of woody plants to disturbance: Patterns of establishment and growth. In: S. T. A. Pickett, and P. S. White (Eds.), *The ecology of natural disturbances and patch dynamics*. New York, Academic. pp. 197–216.

Canham, C.D., Lepage, P.T. and Coates, K.D. (2004). A spatially-explicit analysis of canopy tree competition: effects of shading versus crowding. *Canadian Journal of Forest Research*, **34**: 778-787.

Cannon, C.H., Peart, D.R., and Leighton, M. (1998). Tree species diversity in community in commercially logged Bornean rainforest. *Science*, **28**: 1366- 1368.

Cannon, C.H., Peart, D.R., Leighton, M. and Kartawinata K. (1994**).** The structure of lowland rainforest after selective logging in West Kalimantan, Indonesia. *Forest Ecology and Management*, **67**: 49–68.

Cao, M., Zhang, J.H., Feng Z., Deng J. and Deng X. (1996). Tree species composition of a seasonal rain forest in Xishuangbanna, South West China. *Tropical Ecology*, **37**(2): 183–192.

Castro, J., Zamora, R., Hodar, J.A. and Gomez, J.M. (2004). Seedling establishment of a boreal tree species (*Pinus sylvestris*) at its southern- most distribution limit: consequences of being in a marginal Mediterranean area. *Journal of Ecology*, **92**: 266-277.

Ceccon, E., Omstead, I., Vázquez-Yanes, C. and Campo-Alves, J. (2002). Vegetation and soil properties in two tropical dry forests of differing regeneration status in Yucatán. *Agrociencia*, **36**: 621-631.

Champion, H., and Seth, S.K. (1968). *A revised survey of forest types of India*. Government of India Press, New Delhi.

Chandrasekaran, S. and Swamy P.S. (1995). Changes in herbaceous vegetation following disturbance due to biotic interference in natural and man-made ecosystem in Western Ghats. *Tropical Ecology,* **36**: 213-220.

Chandrasekaran, S. and Swamy P.S. (2002). Biomass, litterfall and aboveground net primary productivity of herbaceous community in varied ecosystems at Kodayar in the western ghats of Tamilnadu. *Agriculture, Ecosystems and Environment,* **88**: 61-67.

Chapin, F.S. III, Walker, B.H., Hobbs, R.J., Hooper, D.U., Laroton, H., Sala, H. and Tilman, D. (1997). Biotic control over the functioning of ecosystems. *Science*, **277**: 500-503.

Chapin, F.S. III, Zavaleta, E.S., Eviner, V.T., Naylor, R.L., Vitousek, P.M., Reynolds, H.L., Hooper, D.U., Lavorel, S., Sala, O.E., Hobbie, S.E., Mack, M.C. and Diaz, S. (2000). Consequences of changing biodiversity. *Nature*, **405**: 234–242.

Chapin, F.S., Sala, O.E. and Huber-Sannwald, E. (2001). Global biodiversity in changing environment. *Ecological Studies*, 152, Springer Verlag, 376.

Chaturvedi, A.N. (1994). Biodiversity in managed forest. *Indian Forester*. **120**: 773-780.

Chaturvedi, O.P. and Singh, J.S. (1987). The structure and function of pine forest in central Himalaya II. Nutrient Dynamics. *Annals of Botany*, **60**: 253-267.

Chave, J. and Leigh, E.G. (2002). A spatially explicit neutral model of β-diversity in tropical forests. *Theoretical Population Biology*, **62**: 153-168.

Chazdon, R.L. (1986). Light variation and carbon gain in rain forest understorey palms. *Journal of Ecology*, **74**: 995-1012.

Chowdhury, M.A.M., Auda, M.K. and Iseam, A.S.M.T. (2000). Phytodiversity of Dipterocarpus turbinatus Gaertn. F. (Garjan) undergrowths at Dulahazara ganjan forest, Cos'B Bazar, Bangladesh. *Indian Forester,* **126**: 674-684.

Clark, D.B., Palmer, M.W. and Clark, D.A. (1999). Edaphic factors and the landscape-scale distributions of tropical rain forest trees. *Ecology*, **80**: 2662-2675.

Clausen, J., Keck, D. D. and Hiesey, W. M. (1941). Regional differentiation in plant species. A*merican Naturalist,* **75**: 231-250.

Clement, F. E. (1916). Plant succession: Analysis of the development of vegetation. Cornegie Institution of Washington Publication. **242**: 1-12.

Collins, S.L. (2000). Disturbance frequency and community stability stability in native tallgrass Prairie. *American Naturalist*, **155**: 311-325.

Collins, S.L., Glenn, S.M. and Gibson, D.J. (1995). Experimental analysis of intermediate disturbance and initial floristic composition: decoupling cause and effect. *Ecology*, **76**: 486-492.

Condit R., Foster, R., Hubbell, S.P., Sukumar, R., Leigh, E.G., Monokaran, N., Loo deLao, S., LaFrankie, J.K., and P.S. Ashron. (1998). Assessing forest diversity on small plots: Calibration using species- individual curves from 50ha plots In: Dallmeier, F., & J.A. Comiskey (Eds.). Forest biodiversity research, Monitoring and modeling conceptual background- old World case studies. Paris. pp . 247-268

Condit, R., Pitman, N., Leigh, F.G., Chave, J., Terborgh, J. and Foster, R.B. (2002). Beta-diversity in tropical forest trees. *Science,* **295**: 666-669.

Congdon, R.A. and Herbohn, J.L. (1993). Ecosystem dynamics of disturbed and undisturbed sites in north Queensland wet tropical rain forest I Floristic composition, climate and soil chemistry. *Journal of Tropical Ecology*, **9**: 349–363

Connell, J. H. (1978). Diversity in tropical rainforest and coral reefs. *Science*. **199**: 1302-1309.

Connell, J.H. and Green, P.T. (2000). Seedling dynamics over thirty two years in a tropical rain forest. *Ecology*, **81**: 568-584.

Connell, J.H. and Orias, E. (1964). The ecological regulation of species diversity. *American Naturalist*, **98**: 399-414.

Cornett, M.W., Reich, P.B., Puettmann, K.J. and Frelich, L.E. (2000). Seedbed and moisture availability determine safe sites for early *Thuja occidentialis* (Cupresaceae) regeneration. *American Journal of Botany*, **87**: 1807- 1814.

Crawley, M.J., Brown, S.L., Heard, M.S. and Edwards, G.R. (1999). Invasion-resistance in Experimental grassland communities. Species richness of species identity. *Ecology Letters*, **2**: 140-148.

Curtis, J.T. and R.P. McIntosh 1950. The interrelations of certain analytic and Synthetic phytosociological characters. Ecology 31: 434-455.

Dalesman, R. F. (1968). *A Different Kind of country*. MacMillan Company, New York.

Dalling, J.W. and Hubbell, S.P. (2002). Seed size, growth rate and gap microsite conditions as determinants of recruitment success for pioneer species. *Journal of Ecology*, **90**: 557-568.

Darwin, C. (1859). *On the Origin of Species by Means of Natural Selection.* London: John Murray.

Das Gupta S. (1999). *Studies on vegetal and microbiological processes in coal mining affected area*. Ph.D. Thesis. North Eastern Hill University, Shillong, India.

Daubenmire, R. F. (1943). Vegetational zonation in the rocky mountains. *Botanical Review* **9**: 325-393.

Davidar, P., Arjunan, M., Mammen, P.C., Garrigues, J.P., Puyravaud, J.P. and Roessingh, K. (2007b). Forest degradation in the Western Ghats biodiversity hotspot: Resource collection, livelihood concerns and sustainability. *Current Science*, **93**: 1573-1578.

Davidar, P., Nayak, K.G. and Dharmalingam, M. (2007a). Effects of adult density on regeneration success of woody plants in natural and restored tropical dry evergreen forest fragements in puducherry region, India. *Current Science*, **92**(6): 805-811.

Davidar, P., Puyravaud, J.P. and Leigh, E.G. Jr. (2005). Changes in rain forest tree diversity, dominance and rarity across a seasonality gradient in the Western Ghats, India. *Journal of Biogeography*, **32**: 493-501.

Davies, S.J. (2001). Tree mortality and growth in 11 sympatric Macaranga sps. In Bornea. *Ecology*, **82**: 920-932.

Davies, S.J., Palmiotto, P. and Ashton, P.S. (1999). Phenology and fecundity in II sympatric pioneer species of Macaranga (Euphorbiaceae) in Borneo. *American Journal of Botany*, **86**: 1786-1795.

Death, R. G., and Winterbourn, M. J. (1995). Diversity patterns in stream benthic invertebrate communities: The influence of habitat. *Ecology,* **76**: 1446–1460.

Delissio, L.J. and Primack, R.B. (2003). The impact of drought on the population dynamics of canopy-tree seedlings in a seasonal Malaysia rain forest. *Journal of Tropical Ecology*, **19**: 489-500.

Delissio, L.J., Primack, R.B., Hall, P. and Lee, H.S. (2002). A decade of canopy tree seedling survival and growth in two Bornean rain forests: persistence and recovery from suppression. *Journal of Ecology*, **18**: 645-658.

deMaynadier, P. and Hunter, M.L. (1994). Keystone support. *Bioscience*, **44**: 2.

Denslow, J. S., Ellison, A. E., and Sanford, R. E. (1998). Treefall gap size effects on above- and below-ground processes in tropical wet forests. *Journal of Ecology,* **86**: 597–606.

DeSteven, D. (1994). Tropical tree seedling dynamics: recruitment patterns and their population consequences for three canopy species in Panama. *Journal of Tropical Ecology*, **10**: 369-383.

Devi, U. and Behera, N. (2003). Assessment of plant diversity in response to forest degradation in a tropical dry deciduous forest of Eastern Ghats in India. *Journal of Tropical Forest Science*, **15**: 147-163.

Dhaulkhandi, M., Dobhal, A., Bhatt, S. and Kumar, M. (2008). Community structure and regeneration potential of natural forest sites in Gangotri, India. *Journal of Basis and Applied Science*, **4**: 49-52.

Duchok, R., Kent, K., Khumbongmayum, A.D., Paul, A. and Khan, M.L. (2005). Population structure and regeneration status of medicinal tree *Illicium griffithii* in relation to disturbance gradients in temperate broad- leaved forest of Arunachal Pradesh. *Current Science*, **89**(4): 673-676.

Duvigneaud, P., Delayers de-Smet, S. (1970). Biological cycling of minerals in temperate decidous forests. In: Reichle, D.E.M. (Ed.). Analysis of Temperate Forest Ecosystems Springer Verlag, New York. pp.199-225.

Ehrlich, P.R. and Wilson, E.O. (1991). Biodiversity studies; Science and policy. *Science,* **253**: 758-762.

Elderd, B.D. (2003). Changing flow regimes: its impacts on riparian vegetation and a common riparian species, *Mimulus guttatus*. *Ecological Applications*, **13**: 1610-1625.

Elderd, B.D. and Doak, D.F. (2006). Comparing the direct and community mediated effects of disturbance on plant population dynamics: flooding, herbivory and *Mimulus guttatus*. *Journal of Ecology*, **94**: 656-669.

Engelmark, O., Bradshaw, R. and Bergeron, Y. (1999). Disturbance dynamics in boreal forest: introduction. *Journal of Vegetation Science*, **10**: 730-732.

Enoki, T. and Abe, A. (2004). Saplings distribution in relation to topography and canopy openness in an evergreen broad- leaved forest. *Plant Ecology*, **173**: 283-291.

Fahey, T.J. (2001). Forest Ecology. *Encyclopedia of Biodiversity*, Academic Press, USA. **3**: 41-53.

Fargione, J., Brown, C.S. and Tilman, D. (2003). Community assembly and invasion: an experimental test of neutral versus niche processes. *Proceeding of the National Academy of Sciences*, U.S.A. **100**: 8916-8920.

Fargione, J.E. and Tilman, D. (2005). Diversity decreases invasion via both sampling and complementarity effects. *Ecology letters*, **8**: 604-611.

Fatubarin, A. (1987). Observations on the natural regeneration of the woody plants in a savanna ecosystem in Nigeria. *Tropical Ecology*, **28**: 1-8.

Finer, L., Mannerkoski, H., Pinrainer, S. and Starr, M. (2003). Carbon and nitrogen pools in an old growth, Norway spruce mixed forest in eastern Finland and changes associated with clear-cutting forest. *Forest Ecology and Management*, **174**: 51-63.

Forbis, T.A., Larmore, J. and Addis, E. (2004). Temporal patterns in seedling establishment on pocket gopher disturbances. *Oecologia*, **138**: 112-121.

Forman, T.T.R. and Godron, M. (1986). *Landscape ecology*. John Wiley & Sons, New York, USA, pp 83–120.

Foster, D. (1988). Disturbance history, community organization and vegetation dynamics of the old-growth Pisgah Forest, South-western New Hampshire, U.S.A. *Journal of Ecology*, **76**: 105-134.

Fowler, N.L. (1995). Density- dependent demography in two grasses: a five year study. *Ecology*, **76**: 2145-2164.

Fox, B.J., Taylor, J.E., Fox, M.D. and Williams, C. (1997). Vegetation changes across edges of rainforest remnants. *Biological Conservation*, **82**: 1-13.

Fralish, J. S., Franklin, S. B. P., Robertson, A., Kettler, S. M. and Crooks, F. B. (1993). An ordination of compositionally stable and unstable forest communities at land between the lakes, Kentucky and Tennessee. In: Fralish, J. S., R. P. McIntosh, and O. L. Loucks (Eds.) Fifty Years of Wisconsin Plant Ecology. The Wisconsin Academy of Sciences, Arts, and Letters. pp. 247-267.

Freckleton, R.P. and Watkinson, A.R. (2001). Asymmetric concentration between plant species. *Functional Ecology,* **15**: 615-623.

Funakawa, S., Tanaka, S., Kaewkhongkha, T., Hattori, T. and Yonebayashi, K. (1997). Physiochemical properties of the soils associated with shifting cultivation in northern Thailand with special reference to factors determining soil fertility. *Soil Science and Plant Nutrition,* **43**: 665-679.

Ganesh, T., Ganesan, R., Devy, M.S., Davidar, P. and Bawa, K.S. (1996). Assessment of plant biodiversity at mid-elevation evergreen forest of Kalakand Mundanthuari Tiger Reserve, Western Ghats, India. *Current Science,* **71**: 379-392.

Gaston, K.J. (2000). Global pattern in biodiversity. *Nature*, **405**: 220-227.

Gaston, K.J., Blackburn, T.M. and Lawton, J.H. (1997). Interspecific abundance range size relationships: An appraisal of mechanisms. *Journal of Animal Ecology*, **66**: 579–601.

Gautier, L. and Goodman S.M. (2003). Introduction to the Flora of Madagascar. *The Natural History of Madagascar,* S.M. Goodman and J.P. Benstead (Eds). Chicago: University of Chicago Press. pp. 229-250

Gentry, A.H. (1988a). Tree species richness of upper Amazonian forests. *Proceeding of the National Academy of Sciences*, **85**: 156-159.

Gentry, A.H. (1988b). Changes in plant community diversity and floristic composition on environmental and geographical gradients. *Annals of the Missouri Botanical Garden*, **75**: 1-34.

Ghose, M.K. (2002). Effects of erosion on some properties of soil within the top 0.2m of storage dumps. *Land contamination and Reclamation*, **10**(2): 107-114.

Gilbert, G.S., Harms, K.E., Hamill, D.N. and Hubbell, S.P. (2001). Effects of seedling size, El Nino drought, seedling density, and distance to nearest nonspecific adult on 6 year survival of Ocotea whitie seedlings in Panama. *Oecologia*, **127**: 509-516.

Gilliam, F.S. (2002). Effects of harvesting on herbaceous layers diversity of a central Appalachian hard wood forest in west Virginia, USA. *Forest Ecology and Management,* **155**: 33-43.

Gleason, H. A. (1917). The structure and development of the plant association. *Bulletin of the Torrey Botanical Club*. **53**: 7-26.

Gleason, H.A. (1926). The individualistic concept of the plant association. *Bulletin of the Torrey Botanical Club*.

Gomez-Aparicio, L., Gomez, J.M. and Zamora, R. (2005). Microhabitats shift rank in suitability for seedling establishment depending on habitat type and climate. *Journal of Ecology*, **93**: 1194-1202.

Good, N.F. and Good, R.E. (1972). Population dynamics of tree seedlings and saplings in mature eastern hard wood forests. *Bulletin of the Torrey Botanical Club*, **99**: 172-178.

Greenland, D. J. and Herrera, R. (1975). *Shifting cultivation and agricultural practices* (Ibadan: IIT A).

Greig-Smith, P. (1957). *Quantitative Plant Ecology*. Butterworth, London: Cambridge University Press, p.233.

Grime, J. P. (1979). Plant Strategies and Vegetation process. John Wiley, New York. pp. 222.

Grime, J.P. (1973). Competitive exclusion in herbaceous vegetation. *Nature*, **242**: 344-347.

Grime, J.P. (1983). *Plant Strategies and Vegetation Processes*. John Wiley and Sons, New York.

Grubb, P. J. (1974) Factors controlling the distribution of forest types on tropical mountains: New facts and a new perspective. In: J. R. Flenley (Eds.) *Altitudinal zonation in Malaysia*.University of Hull, Department of Geography, *Miscellaneous Series*, **16**: 13–46

Grubb, P.J. (1977). The maintenance of species- richness in plant communities: the importance of the regeneration niche. *Biological Reviews*. **52**: 107-145.

Gunawardene, R.N., Daniels A.E.D., Gunatilleke, I.A.U.N., Gunatilleke, C.V.S., Karunakaran, P.V., Nayak, K.G., Prasad, S., Puyravaud, P., Ramesh, B.R., Subramanian, K.A. and Vasanthy, G. (2007). A brief overview of the Western Ghats- Sri Lankan biodiversity hotspot. *Current Science*, **93**: 1567-1572.

Gundale, M.J., DeLuca, T.H., Fiedler, C.E., Ramsey, P.W., Harrington, M.G. and Gannon, J.E. (2005). Restoration treatments in a Montana Ponderosa pine forest: Effects on soil physical, chemical and biological properties. *Forest Ecology and Management*, **213**: 25-38.

Gupta, S. and Narayan, R. (2006). Species diversity in four contrasting sites in a peri-urban area in Indian dry tropics. *Tropical Ecology*, **47**(2): 229-241.

Gutierrez, A.G., Armesto, J.J. and Aravena, J.C. (2004). Disturbance and regeneration dynamics of an old growth North Patagonian rain forest in Chiloe Island, Chile. *Journal of Ecology*, **92**: 598-608.

Hall, J.S., Mckenna, J.J., Ashton, P.M. and Gregoire, T.G. (2004). Habitat characterizations underestimate the role of edaphic factors controlling the distribution of Entandrophragma. *Ecology*, **85**: 2171-2183.

Hanief, S. M., Thakur, S.D. and Gupta, B. (2007). Vegetal profile of natural plant succession and artificially reclaimed vegetated limestone mines in Himachal Pradesh, India. *Journal of Tropical forestry,* **23**(I & II): 128-135.

Hanski, I. (1982). Dynamics of regional distribution: the core and satellite species hypothesis. *Oikos,* **38**: 210–221.

Haridasan, K. and Rao, P.R. 1985-1987. Forest Flora of Meghalaya. Vol. 1 & 2. ((Bishen Singh Mahendra Pal Singh, Dehra D un).

Harms, K., Condit, R., Hubbell, S.P. and Foster, R.B. (2001). Habitat associations of trees and shrubs in a 50 ha neotropical forest plot. *Journal of Ecology,* **89**: 947-959.

Harper, J.L. (1977). *Population Biology of Plants.* Academic Press. London, pp 892.

Hartshorn, G.S. (1980). Neotropical forest dynamics. *Biotropica,* **12**: 23-30.

Haugasen, T., Barlow, J. and Peres, C.A. (2003). Surface wildfires in central Amazonia: Short-term impact on forest structure and carbon loss. *Forest Ecology Management,* **179**: 321-331.

Hawthorne, W.D. (1993). Forest regeneration after logging: findings of a study in the Bia South Game Production Reserve, Ghana. ODA Forestry Series. Natural Resources Institute, Chatham.

He, F. and Legendre, P. (2002). Species diversity patterns derived from species area madels. *Ecology*. **83**(5): 1185-1198.

Hector, A., Dobson, K., Minns, A., Bazeley- White, E. and Lawton, J.H. (2001). Community diversity and invasion resistance: an experimental test in a grassland ecosystem and a review of comparable studies. *Ecological Research,* **16**: 819-831.

Heinrich, A. and Hurka, H. (2004). Species richness and composition during sylvigenesis in a tropical dry forest in North-western Costa Rica. *Tropical Ecology,* **45**(1): 43-57.

Hengeveld, R. (1996). Measuring ecological biodiversity. *Biodiversity Letters,* **3**: 58-65.

Henle, K., Sarre S. and Wiegand K. (2004). The role of density regulation in extinction processes and population viability analysis. *Biodiversity and Conservation*, **13**: 9-52.

Henrot, J. and Robertson, G.P. (1994). Vegetation removal in two soils of the humid tropics. Effect on microbial biomass. *Soil Biology and Biochemistry,* **15**: 111-114.

Herrera, C.M. (2002). Topsoil properties and seedling recruitment: stage dependence and spatial decoupling of influential parameters. *Oikos,* **97**: 260-270.

Hill, J.L. and Curran, P.J. (2003). Area, shape and isolation of tropical forest fragments: effects on tree species diversity and implications for conservation forest area. *Journal of Biogeography,* **30**: 1391–1403.

Hooper, D. and Vitousek, P.M. (1997). The effects of plant composition and diversity on ecosystem processes. *Science,* **277**: 1302-1305.

Hooper, D.U., Chapin III, F.S., Ewel, J.J., Hecfor. A., Inchausti, P., Lavorel, S., Lawton, J.H., Lodge, D.M., Loreau, M., Naeem, S., Schmid, B., Setala, H., Symstad, A.J., Vandermur, J. and Wardle, D.A. (2005). Effects of biodiversity on ecosystem functioning: A consensus of current knowledge. *Ecological Monographs,* **75**(1): 3-35.

Hooper, E. R., Legendre, P. and Condit, R. (2004). Factors affecting community composition of forest regeneration in deforested, abandoned land in Panama. *Ecology,* **85**: 3313–3326.

Hubbel, S.P., Foster, R.B., O'Brien, S.T., Harms, K.E., Condit, R., Wechsler, B., Wright, S.J. and Lodde Lao. S. (1999). Light gap disturbance, recruitment limitation and tree diversity in a Neotropical forest. *Science*, **283**: 554- 557.

Hubbell, S.P. (2001). *The Unified Neutral Theory of Biodiversity and Biogeography.* Princeton University Press, Princeton, NJ.

Hubbell, S.P. and Foster, R.B. (1992). Short-term dynamics of a neotropical forest: why ecological research matters to tropical conservation and management. *Oikos,* **63**: 48–61

Hunter, M.L., Jr. (1990). Wildlife, forest and forestry: Principles of managing forests for biological diversity. Prentice- Hall, Englewood cliffs, New Jersey, USA.

Hurlbert, S. H. (1971). The non concept of species diversity: a critique and alternative parameters. *Ecology,* **2**: 577-586.

Huston, M. A. (1979). A general hypothesis of species diversity. *American Naturalist,* **113**, 81–101.

Huston, M. A. (1994). *Biological diversity*. Cambridge, UK: Cambridge University Press.

Huston, M.A. (1980). Soil nutrients and tree species richness in Costa Rican forests. *Journal of Biogeography***,** **7**: 147-157.

IIRS. (2002). *Biodiversity characterisation at landscape level in north-eastern India using satellite remote sensing and geographic information systems*. Indian Institute of Remote Sensing. Dehradun, India, pp 296.

IIRS. (2003a). *Biodiversity characterization at landscape level in Andaman and Nicobar Islands, India using satellite remote sensing and Geographical Information System*. In Joint project report of Department of Biotechnology (DBT) and Department of Space (DoS), Government of India (GoI); Indian Institute of Remote Sensing, Dehradun.

IIRS. (2003b). *Biodiversity characterization at landscape level in North East India using satellite remote sensing and Geographical Information System*. In Joint project report of DBT and DoS, GoI; Indian Institute of Remote Sensing, Dehradun.

IIRS. (2003c). *Biodiversity characterization at landscape level in Andaman, Western Ghats, India using satellite remote sensing and Geographical Information System.* In Joint project report of DBT and DoS, DoI; Indian Institute of Remote Sensing, Dehradun.

IIRS. (2003d). *Biodiversity characterization at landscape level in Western Himalayas, India using satellite remote sensing and Geographical Information System*. In Joint project report of DBT and DoS, GoI; Indian Institute of Remote Sensing, Dehradun.

IIRS. (2011a). *Biodiversity characterization at landscape level in Jammu and Kashmir using satellite remote sensing and Geographical Information System.* In Joint project report of DBT and DoS, GoI; Indian Institute of Remote Sensing, Dehradun, 2007, 2011.

IIRS. (2011b). *Biodiversity characterization at landscape level in northwest India and Lakshadeep using satellite remote sensing and Geographical Information System.* In Joint project report of DBT and DoS, GoI; Indian Institute of Remote Sensing, Dehradun, 2007, 2011.

IIRS. (2011c). *Biodiversity characterization at landscape level in Deccan Peninsula using satellite remote sensing and Geographical Information System.* In Joint project report of DBT and DoS, GoI;Indian Institute of Remote Sensing, Dehradun, 2007, 2011.

IIRS. (2011d). *Biodiversity characterization at landscape level in northern plains using satellite remote sensing and Geographical Information System.* In Joint project report of DBT and DoS, GoI, Indian Institute of Remote Sensing, Dehradun, India, 2007, 2011.

IIyas, O. and Khan, J.A. (2005). Assessment of tree mortality and post fire regeneration pattern in Binsar wildfire Sanctuary, Kumaon Himalaya. *Tropical Ecology*, **46**(2): 157-163.

Jackson, M.L. (1958). *Soil Chemical Analysis*. Prentice-Hall, Inc., Englewood Cliffs, NJ.

Jain, S.K. (1987). The problem of endangered species: Its study and solution. Presidential address, Biological Sciences 57th Session of National Academy of Sciences, Allahabad.

Jamir, S.A. (2000). *Studies on plant biodiversity, community structure and population behaviour of dominant tree species of some sacred groves of Jaintia hills, Meghalaya*. Ph.D. Thesis, North-eastern Hill University, Shillong.

Jankowskil, J.E. and Rabenold, K.N. (2007). Endemism and local rarity in birds of Neotropical montane rainforest. *Biological Conservation,* **138**: 453–463.

Jenkins, M. (2003). Prospects for biodiversity. *Science,* **302**: 1175-1177.

Jha, C.S., Goparaju, L., Tripathi, A., Gharai, B., Raghubanshi, A.S. and Singh, J.S. (2005). Forest fragmentation and its impact on species diversity: an analysis using remote sensing and GIS. *Biodiversity and Conservation,* **14**: 1681-1698.

Jordan, C.F. (1983). Productivity of tropical rainforest ecosystems and the implications for their use as future wood and energy sources. In: Golley, F.B. (Ed.) *Tropical Rain Forest Ecosystems: Structure and Function*. Elsevier Scientific Publishing, Amsterdam. pp. 117-136.

Jose, S., Allen, S.C. and Nair, P.K.R. (2008). Tree-crop interactions: lessons from temperate alley-cropping systems. In: D.R. Batish, R.K. Kohli, S. Jose and H.P. Singh (Eds.) Ecological Basis of Agroforestry. CRC Press, Boca Raton, Fl. pp. 15-36.

Kadavul, K. and Parthasarathy, N. (1999). Structure and composition of woody species in tropical semi evergreen forest of Kalrayan hills, Eastern Ghats, India. *Tropical Ecology,* **40**(2): 247-260.

Kadmon, R. and Shmida, A. (1990). Spatiotemporal demographic processes in plant populations: an approach and a case study. *American Naturalist,* **135**: 382-397.

Kanjilal, U.N., P.C. Kanjilal, A. Das, R.N. De and N.L. Bor. 1934-40. Flora of Assam. 5 vols., Government Press, Shillong.

Karpachevsky, L.O. (1977). *Variability of Soil Cover in Forest Ecosystem.* Moscow University Publishing House, Moscow.

Kawahara, T. And Tsutsumi, T. (1972). Studies on the circulation of carbon and nitrogen in forest ecosystem. *Bulletin of the Kyoto University Forestry*, **44**: 141-158.

Kelly, C.K. (1996). Identifying plant functional types using floristic databases: ecological correlates of plant range size. *Journal of Vegetation Science,* **7**: 417–424.

Kennard, D.K., Gould, K., Putz, F.E., Fredericksen, T.S. and Morales, F. (2002). Effect of disturbance intensity on regeneration mechanisms in a tropical dry forest. *Forest Ecology and Management,* **162**: 197–208.

Keylock, C.J. (2005). Simpson diversity and the Shannon-Weaver index as a special case of a generalized entropy. *Oikos,* **109**: 203-207.

Khan, M.L., Menon, S. and Bawa, K.S. (1997). Effectiveness of the protected area network in biodiversity conservation: a case study of Meghalaya, India. *Forest Ecology and Management,* **14**: 293-304.

Khan, M.L., Rai, J.P.N. and Tripathi R.S. (1987). Population structure of some tree species undisturbed and protected sub-tropical forests of north-east India. *Acta Oecologica Oecol. Application,* **8**(3): 247–255.

Kharkwal, G., Mehrotra, P., Rawat, Y.S. and Pangtey, Y.P.S. (2005). Phytodiversity and growth form in relation to altitudinal gradient in the Central Himalayan (Kumaun) region of India. *Current Science*. **89** (5): 873-878.

Khera, N. and Singh, R.P. (2005). Germination of some multipurpose tree species in five provenances in response to variation in light, temperature, substrate and water stress. *Tropical Ecology,* **46**(2): 203-217.

Khera, N., Kumar, A., Ram, J. and Tewari, A. (2001). Plant biodiversity assessment in relation to disturbance in mid-elevational forest of central Himalaya, India. *Tropical Ecology,* **42**(1): 83-95.

Khoshoo, T.N. (1995). Census of India's biodiversity: tasks ahead. *Current Science,* **69**: 14–17.

Khoshoo, T.N. (1996). Biodiversity in the developing countries. In: Castri, F. and Younes, T. (Ed.), *Biodiversity, science, and development: Toward a newpartnership*. CAB International IUBS, University Press, Cambridge, England, pp. 304–311.

Khumbongmayum, A.D., Khan, M.L. and Tripathi, R.S. (2005). Survival and growth of seedlings of a few tree species in the four sacred groves of Manipur, Northeast India. *Current Science,* **88**(11): 1781-1788.

Knight, D.H. (1975). A phytosociological analysis of species rich tropical forest on Barro Colorando Island, Panama. *Ecological Monograph,* **45**: 259-284.

Kobayashi, S. (2007). An overview of techniques for the rehabilitation of degraded tropical forests and biodiversity conservation. *Current Science,* **93**: 1596-1603.

Kobe, R.K. (1996). Intraspecific variation in sapling mortality and growth predicts geographic variation in forest composition. *Ecological Monograph,* **66**: 181–201.

Kobe, R.K. (1999). Light gradient partitioning among tropical tree species through differential seedling mortality and growth. *Ecology,* **80**: 187-201.

Kobe, R.K., Pacala, S.W., Silander, J.A. and Canham, C.D. (1995). Juvenile tree survivorship as a component of shade tolerance. *Ecological Applications,* **5**: 517-532.

Koh, L.P., Dunn, R.R., Sodhi, N.S., Colwell, R.K., Proctor, K.C. and Smith, V.S. (2004). Species co-extinctions and biodiversity crisis. *Science* **305**: 1632-1634

Koike, F. (2001). Plant traits as predictors of woody species dominance in climax forest communities. *Journal of Vegetation Science,* **12**: 327–336.

Kollmann, J. (2000). Dispersal of freshy-fruited species: a matter of spatial scale. Perspectives in Plant Ecology. *Evolution and Systematics*, **3**: 29-51.

Korner, Ch. (1994). Scaling from species to vegetation: the usefulness of functional groups. In: Schultze, E.D. and Mooney, A.H. (Eds.). Biodiversity and ecosystem function. Springer-verlag, Berlin, Heidelberg, 117-140.

Kubota, Y., Murata, H. and Kikuzawa, K. (2004). Effects of topographic heterogeneity on tree species richness and stand dynamics in a sub-tropical forest in Okinawa Island, South Japan. *Journal of Ecology*, **92**: 230-240.

Kumar, A., Marcot, B.G. and Saxena, A. (2006). Tree species diversity and distribution patterns in tropical forests of Garo Hills. *Current Science*, **91**(10): 1370-1381.

Kumar, M., Joshi, M. and Todaria, N.P. (2010). Regeneration status of a sub-tropical *Anogeissus latifolia* forest in Garhwal Himalaya, India. *Journal of Forestry Research*, **21**(4): 439-444.

Kumar, M., Rajwar, G.S. and Sharma, C.M. (2004). Disturbance and dynamics in the subtropical forests of Garhwal Himalaya. *Bulletin of the National Institute of Ecology*, **14**: 43-50.

Kumar, V. and Asija. (2000). Biodiversity Conservation in: *Biodiversity-Principles and Conservation*. Agrobiosis (India), Jodhpur.

Kunte, K.A., Joglekar, A., Ghate, U. and Pramod, P. (1999). Patterns of butterfly, birds and tree diversity in the Western Ghats. *Current Science*, **77**: 577-586.

Kushwaha, S.P.S., Behera, M.D. and Roy, P.S. (2000). *Biodiversity characterization using remote sensing and GIS*. Procedings of the symposium on biodiversity in India, 8–11 November, Darjeeling, India. LAL, J.B. 1989. *India's forests: myth and reality*. Natraj Publishers, Dehradun, India. pp. 320–325.

Kusipalo, J., Jafarsidik, Y., adjers, G. and Tuomela, K. (1996). Population dynamics of tree saadlings in a mixed diptercarp rainforest before and after logging and crown liberation. *Forest Ecology and Management*, **81**: 85-94.

Kvalseth, T.K. (1991). Note on biological diversity evenness and homogeneity measures. *Oikos*, **62**: 123-127.

Lacy, R.C. and Bock, C.E. (1986). The correlation between range size and local abundance of some North-American birds. *Ecology*, **67**: 258–260.

Ladd, B.M. and Facelli, J.M. (2005). Effects of composition, resource availability and invertebrates on tree seedling establishment. *Journal of Ecology*, **93**: 968-977.

Laidlaw, M., Kitching, R., Goodall, K., Small, A. and Stork, N. (2007). Temporal and spatial variation in an Australian tropical rainforest. *Austral Ecology*, **32**: 10–20.

Lalchhuanawma, (2008). *Ecological studies on plant diversity and productivity of herbaceous species in Mizoram University campus at tanhril, Aizawl, Mizoram (N.E. India).* Ph.D thesis, Mizoram University, Mizoram.

Lalfakawma, Sahoo, U.K., Roy, S., Vanlalhriatpuia, K. and Vanalalhluna, P.C. (2009). Community composition and tree population structure in undisturbed and disturbed tropical semi-evergreen forests of Northeast India. *Applied Ecology and Environmental Research*, **7**(4): 303-318.

Lalfakawma. (2007). *Studies on community composition and natural regeneration of some dominant tree species in a tropical semi-evergreen forest of Mizoram*. Ph. D. thesis (unpublished). Mizoram University, Aizawl.

Lalnunmawia, F. (2003*). Comparative study on growth and productivity of three bamboo species grown with ginger crop*. Ph.D (unpublished), Mizoram University, Mizoram.

Lalnuntluanga, (2007). *Study on taxonomy, distribution and utilization of canes and rattan in Mizoram.* Ph.D. thesis (unpublished). Mizoram University, Mizoram.

Laloo, R.C., Kharlukhi, L., Jeeva, S. and Mishra, B.P. (2006). Status of medicinal plants in the disturbed and the undisturbed scared forest of Meghalaya North-east India: Population structure and regeneration efficacy of some important species. *Current Science*, **90**(2): 225-231.

Lalramenga, P.C. (2006a). *Studies on plant diversity of undisturbed forest in Mizoram University campus, Tanhril*. Msc. Project report, Mizoram University, Aizawl, India.

Lalramenga, P.C. (2006b). *Ecological analysis of herbaceous plant in open grassland and secondary forest of Mizoram University campus, Tanhril*. Msc. Project report, Mizoram University, Aizawl, India.

Lalramnghinglova, H. (2003). *Enthnomedicinal plants of Mizoram*. Bishen Singh Mahendra Pal Singh, Dehradun, pp 333.

Laltlanchhuang, S.K. (2006). *Studies of the impact of disturbance on secondary productivity of forest ecosystem with special reference to surface, sub-surface litter insect and other non-insect groups.* M.sc. Dissertation. Mizoram University.

Lamprecht, H. (1989). Silviculture in Tropics. Berlin: Technical Cooperation of Federal Republic of Germany, Berlin, 296.

Landis, R.M. and Peart, D.R. (2005). Early performance predicts canapy attainment across life histories in subalpine forest trees. *Ecology*, **86**(1): 63-72.

Latham, P.A., Zuring, H.R. and Coble, D.W. (2005). A method for quantifying vertical forest structure.

Lavorel, S., McIntyre, S. Langsberg, J. and Forbes, T.D.A. (1997). Plant functional classifications: from general functional groups to specific groups of response to disturbance. *Trends in Ecosystem and Evolution*, **12**: 474-478.

Legendre, P., Borcard, D. and Peres-Neto, P.R. (2005). Analyzing beta diversity: partitioning the spatial variation of community composition data. *Ecological Monographs*, ***75***(4): 435-450.

Lieberman, D., Leiberman, M., Peralta, R. and Hartshorn, G.S. (1996). Tropical forest structure and composition on a large scale altitudinal gradient in Costa Rica. *Journal of Ecology*, **84**: 137-152.

Lieberman, D., Lieberman, M. (1984). The causes and consequences of synchronous flushing in a dry tropical forest. *Biotropica*, **16**: 193-201.

Lin, J., Harcombe, P.A., Fulton, M.R. and Hall, R.W. (2004). Sapling growth and survivorship as affected by light and flooding in a river flood-plain forest of Southeast Taxas. *Oecologia*, **139**: 399-407.

Loarie, S.R., Joppa, L.N. and Pimm, S.L. (2007). Satellites miss environmental priorities. *Trends in Ecology Evolution,* **22**: 630-632.

Lovejoy, T.E. (1980). Changes in biological diversity. In.G.O. Barney (Ed.). The Global 2000 report to the president, Vol 2. The technical report. Pengiun Books, Harmondsworth, U.K. pp. 327-332.

Lowry, P.P., Schatz, G.E., and Phillipson, P.B. (1997). The Classification of Natural Anthropogenic Vegetation in Madagascar. In: S.M. Goodman (Ed.) *Natural Change and Human Impact in Madagascar*. pp. 93-123.

Lyngdoh, T. (1995). *Community dynamics and edaphic changes in relation to coal mining in Jaintia Hills, Meghalaya*. Ph. D. Thesis, North Eastern Hill University, Shillong, India.

Lyon, J.G. (1983). Landsat-derived land cover classification for locating potential kestrel nesting habitat. *Photogrammetric Engineering & Remote Sensing*, **49**(2): 245–250.

Madoffe, S., Hertel, G.D., Rodgers, P., O'Connell, B., Killenga, R. (2006). Monitoring the health of selected eastern arc forests in Tanzania. *African Journal of Ecology*, **44**: 171-177.

Magurran, A. E. (1988). *Ecological Diversity and its Measurement*. Prenceton University Press, New Jersey.

Maithani, K., Arunachalam, A., Tripathi, R.S. and Pandey, H.N. (1998). Nitrogen mineralization as influenced by climate, soil and vegetation in a subtropical humid forest in Northeast India. *Forest Ecology and Management*, **109**: 71-101.

Maram, K.M. and Khan M.L. (1998). Regeneration status of trees in various categories of forests in Manipur. *Journal of Hill Research*, **11**(2): 178–182.

Maranon, T., Zamora, R., Villar, R., Zavala, M.A., Quero, J.L., Perez-Ramos, I., Mendoza, I. and castro, I. (2004). Regeneration of tree species and restoration under contrasted Mediteranean habitats: Field and Glasshouse experiments. *International journal of Ecology and Environmental Science*, **30**(3): 187-196.

Margalef, D. R. (1958). *Perspective in ecologically theory.* University of Chicago press. Chicago.

Marks, P.I. (1974). The role of pine cherry (Prunus pensylvania L.) in the maintenance of stability in northern hardwood ecosystems. *Ecological Monographs,* **44**: 73–88.

Massey, F.P., Massey, K., Press, M.C. and Hartley, S.E. (2006). Neighbourhood composition determines growth, architecture and herbivory in tropical rain forest tree seedlings. *Journal of Ecology*, **94**: 646-655.

Matthes, U. and Larson, D.W. (2006). Microsite and climatic controls of tree population dynamics: an 18 year study on cliffs. *Journal of Ecology*, **94**: 402-414.

McCabe, D. J. and Gotelli, N. J. (2000). Effects of disturbance frequency, intensity, and area on assemblages of stream macroinvertebrates. *Oecologia,* **124**: 270–279.

Mc Grady-Steed, J., Harris, P. and Morin, P. (1997). Biodiversity regulate ecosystem predictability. *Nature,* **390:** 162-165.

McIntosh, R. P. (1967). The continuum concept of vegetation. *Bot. Rev*. **33**: 133-137.

McLaren, K.P., and McDonald, M.A. (2003). The effects of moisture and shade on seed germination and seedling survival in a tropical dry forest in Jamiaca. *Forest Ecology and Management,* **183**: 61-75.

Meffe, G.K., Nielson, L.A., Knight, R.L. and Schenborn, D.A. (2002). Ecosystem management: Adaptive community based conservation. Island press, Washington D.C.

Mendelson, R. and Rosenberg, N.J. (1994). Framework for integrated assessments of global warming impacts. *Clim Change*, **28**:15–44

Menge, B.A, Berlow, E.L., Blanchette, C.A., Navarrvete, S.A. and Yamada, S.B. (1994). The keystone species concept: variation in interaction strength in a rocky intertidal habitat. *Ecological Monographs***, 64**: 249-286.

Menge, B.A. and Sutherland, J.P. (1987). Community regulation: variation in disturbance, competition and predation in relation to environmental stress annnd recruitment. *American Naturalist*, **130**: 730-757.

Metha, J.P., Tewari, S.C. and Bhandari, B.S. (1997). Phytosociology of woody vegetation under different management regimes in Garhwal Himalaya. *Journal of Tropical Forest Science*, **10**: 24-34.

Mills, L.S., Soul, M.E. and Doak, D.F. (1993). The keystone species concept in ecology and conservation. *Bioscience,* **43**: 219-224.

Mishra, B.P. (2010). A study on the micro-environment, litter accumulation on forest floor and available nutrients in the soils of broad-leaved, mixed pine and pine forests at two district altitude in Meghalaya, northeast India. *Current Science,* **90**(12): 1829-1833.

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. and Jeeva, A.S. (2012). Plant diversity and community attribute 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. In: P.C. Trivedi (Ed.), Advances in Plant Physiology. I.K. International Publishing House, New Delhi, pp. 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**: 241- 251.

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, North-east India. *Biodiversity and Conservation*, **13**: 421-436.

Mishra, B.P., Tripathi, R.S., Tripathi, O.P. and Pandey, H.N. (2003). Effects of disturbance on the regeneration of four dominant and economically important woody species in a broad- leaved subtropical humid forest of Meghalaya, Northeast India. *Current Science*, **84**(11): 1449-1453.

Misra, R. (1968). *Ecology workbook*. Oxford and IBH Publishing Co., Calcutta.

Miura, M., Manabe, T., Nishimura, N. and Yamamoto, S. (2001). Forest canopy and community dynamics in a temperate old growth evergreen broad leaved forest, South-Western japan: a 7 year study of a 4ha plot. *Journal of Ecology*, **89**: 841-849.

MoEF. (1999). National Policy and macrolevel action strategy on biodiversity. Ministry of Environment and Forests, Government of India, New Delhi, India.

Mohammed Assen, P.A.L., Leroux, C.H., Barker, Heluf Gebrekidan, (2005). Soil of Jelo Micro Catchment in the Central Highlands of Eastern Ethiopia. I. Morphological and Physiochemical Properties. Ethiopian *Journal Natural Resource*, **7**(1):55-81.

Molino, J. and Sabatier, D. (2001). Tree diversity in tropical rain forests: a validation of the intermediate disturbance hypothesis. *Science*, **294**: 1702-1704.

Montgomery, R.A. and Chazdon, R.L. (2001). Forest structure, canopy architecture and light transmittance in tropical wet forests. *Ecology*, **82**(10): 2707-2718.

Mueller-Deombois, D. and Ellenberg, H. (1974). *Aims and methods in vegetation ecology*. New York: John Wiley & Sons. Pp.547.

Murali, K.S. and Setty, R.S. (2001). Effect of weed *Lantana camara* and *Chromelina odorata* growth on the species diversity, regeneration and stem density of tree and shrub layer in BRT sanctuary. *Current Science*, **80**: 675–678.

Murphy, P.G. and Lugo, A.E. (1986). *Ecology of tropical dry forest*. Annual Review of Ecology and Systematics, 17: 67-88.

Murthy, I.K., Murali, K.S., Hedge, G.T., Bhat. P.R. and Ravindranath, N.H. (2002). A comparative analysis of regeneration in natural forests and joint forest management plantations in Uttara Kannada district, Western Ghats. *Current Science*, **83**(11): 1358-1364.

Mwangi, P.N., Schmitz, M., Scherber, C., Roscher, C., Schumacher, J., Scherer-Lorenzen, M., Weisser, W.W. and Schmid, B. (2007). Niche pre-emption increases with species richness in experimental plant communities. *Journal of Ecology*, **95**:65-78.

Myers, N. (1988). Tropical forests, Much more than stocks of wood. *Journal of Tropical Environmentalists*, **10**(4): 243-255.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A. and Kent J. (2000). Biodiversity hotspots for conservation priorities. *Nature*, **403**: 853-858.

Nadakarni, N.M., Matelson, T.J. and Haber, W.A. (1995). Structure characteristics and floristic composition of neotropical cloud forest, Montenerde, Costa Rica. *Journal of Tropical Ecology*, **11**: 482-495.

Naeem, S., Thomson, L.J., Lawler, S.P., Lawton, J.H. and Woodfin, R.M. (1994). Declining biodiversity can alter the performance of ecosystems. *Nature*, **368**: 734-737.

Nagaike, T., Kamitani, T. and Nakashizuka, T. (1999). The effect of shelterwood logging on the diversity of plant species in a beech (*Fagus crenata*) forest in Japan. *Forest Ecology and Management*, **118**: 161–171.

Nagendra, H. and Gadgil, M. (1999). Satellite imagery as a tool for monitoring species diversity: an assessment. *Journal of Applied Ecology*, **36**: 388-397.

Nauch, Z. and Whittaker, R. H. (1979). Structural and floristic diversity of shrublands and woodlands in northern Israel and other Mediterranean areas. *Vegetatio***. 41**: 171-190.

Nayak, D.C. and Srivastava, R. (1995). Soil of shifting cultivated areas in Arunachal Pradesh and their suitability for land use planning. *Journal of Indian Society of Soil Science*, **43**: 246-251.

Negi, K.S., Rawat, Y.S. and Singh, J.S. (1983). Estimation of biomass and nutient storage in a Himalayan moist temperate forest. *Canadian Journal of Forest Research*, **13**: 1185- 1196.

Newbery, D.M.C. C. and Gartlan, J.S. (1996). A structure analysis of rain forests at Korup and Douala-Edea, Cameroon. *Proceedings of Royal Society Edinburgh*, **104**: 107-224.

Ninemetes, (2006). The controversy over traits conferring shade-tolerance in trees: ontogenetic changes revisited. *Journal of Ecology*, **94**: 464-470.

Nirmal Kumar, J.I., Kumar, R.N. and Joseph, S. (2001). Tree species diversity of Khatana forest of south Gujarat. *Journal of Nature Conservation* **13**: 149- 166.

Nirmal Kumar, J.I., Kumar, R.N. and Joseph, S. (2002). Tree species diversity of Waghai forest of the Northern part of Western Ghats. *International Journal of Ecology, Environment and Conservation* **8**: 235-248.

Norse, E.A. and McManus, R.E. (1980). Ecology and living resources biological diversity. In Environment quality 1980. The eleventh annual report of the council on Environment Quality, Washington DC. Council on Environment Quality. pp 31-80.

Norse, E.A., Rosenbaum, K.L., Wilcane, D.S., Wilcox, B.A., Romme, W.H., Johnston, D.W. and Stout, M.L. (1986). Conserving biological diversity in our National forests. Washington DC. The wilderness society.

Noss, R.F., Quighley, H.B., Hornocker, M.G., Merill, T. and Paquet, P.C. (1996). Conservation biology and carnivore conservation in the Rocky mountains. *Conservation Biology*, **10**: 949-963.

NRSA. (2007a). *Biodiversity characterization at landscape level in Eastern Ghats and east coast of India using satellite remote sensing and Geographical Information System*. In Joint project report of DBT and DoS, GoI; National Remote Sensing Agency, Hyderabad.

NRSA. (2007b). *Biodiversity characterization at landscape level in Central India and West Bengal using satellite remote sensing and Geographical Information System.* In Joint project report of DBT and DoS, GoI, National Remote Sensing Agency, Hyderabad.

Odum, E. P. (1950). Bird populations of the highlands (North Carolina) plateau in relation to plant succession and avian invasion. *Ecology* **31**: 587-605.

Odum, E.P. (1971). *Fundamentals of Ecology*. Philadelphia, W.B. Saunders. P. 574.

Ojo, L.O. and Ola-Adams, B.A. (1996) Measurement of tree diversity in the Nigerian rainforest. *Biodiversity and Conservation,* **5**: 1253-70.

Orloci, L. (1975). *Multivariate Analysis in vegetation Research*. Dr. W. Junk Publishers, The Hague, the Netherlands.

Orloci, L. (1991). *Entropy and Information*: Ecological Computation Series Vol. 3. SPB Academic Publishing, The Hague, The Netherlands.

Paine, R.T. (1966). Food web complexity and species diversity. *American Naturalist*, **100**: 65-75.

Paine, R.T. (1969). A note on trophic complexity and community stability. *American Naturalist*, **103**: 91-93.

Palmiotto, P.A., Davies, S.J., Vogt, K.A., Ashton, M.S., Vogt, D.J. and Ashton, P.S. (2004). Soil related habitat specialization in depterocarp rain forest tree species in Bornea. *Journal of Ecology*, **92**: 609-623.

Panchal, N.S. and Pandey, A.N. (2004). Analysis of vegetation of Rampara forest in Saurashtra region of Gujarat state of India. *Tropical Ecology*, **45**: 223-231.

Pande, P.K., Negi, J.D.S. and Sharma, S.C. (2002). Plant species diversity, composition, gradient analysis and regeneration behaviour of some tree species in a moist temperate western Himalayan forest ecosystem. *Indian Forester*, **128**(8): 869–886.

Pandey, O.N. (1980). *Cycling of nitrogen, phosphorus and potassium in the soil vegetation system of Tropical Dry Decidous Forest of Chandra Prabha Region Varanasi*. Ph. D. Thesis, Banaras Hindu University, Varansi, India.

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*, 77: 814–818.

Pandey, S.K. and Shukla, R.P. (2001). Regeneration strategy and plant diversity status in degraded sal forests. *Current Science*, **81**: 95-102.

Paoli, G.D., Curran, L.M. and Zak, D.R. (2006). Soil nutrients and beta diversity in the Bornean Dipterocarpaceae: evidence for niche partitioning by tropical rain forest trees. *Journal of Ecology*, **94**: 157-170.

Pariona, W., Fredericksen, T.S. and Licona, C. (2003). Natural regeneration and liberation of timber species in logging gaps in two Bolivian tropical forests. *Forest Ecology and Management*, **18**(3): 313-322.

Parker, I.M., Simberloff, D., Lonsdale, W.M., Goodell, K. and Wonham, M. (1999). Impact: toward a framework for understanding the ecological effects of invaders. *Biological Invasions*, **1**: 3-19.

Parthasarathy, N. (1999). Tree diversity and distribution in undisturbed and human-impacted sites of tropical wet evergreen forest in southern Western Ghats, India. *Biodiversity and Conservation*, **8**: 1365–1381.

Parthasarathy, N. (2001). Changes in forest composition and structure in three sites of tropical evergreen forest around Sengaltheri, Western Ghats. *Current Science*, **80**(3): 389–393.

Parthasarathy, N. and Karthikeyam, R. (1997). Plant biodiversity inventory and conservation of two tropical dry evergreen forests on Coromandal Coast, South India. *Biodiversity and Conservation*, **6**: 1063-1083.

Parthasarathy, N. and Sethi, P. (1997). Tree and liana species diversity and population structure in a tropical dry evergreen forest in south India. *Tropical Ecology*, **38**, 19-30.

Parthasarathy, N., Kinhal, V. and Praveenkumar, L. (1992). Plant species diversity and human impacts in the tropical wet evergreen forest in Courtallum reserve forest, Western Ghats, India. *Tropical Ecology*, **32**(2): 297-306.

Pathak, P.S., and Gupta, S.K. (2004). Eco-restoration of degraded lands in Central India Through assisted Natural regeneration. *International Journal of Ecology and Environmental Science*, **30**(3): 241-249.

Pathak, S.D. and Shukla, R.P. (2004). Population structure and sex ratio of Mallotus philippensis Muel. Arg. Within forest vegetation of northeastern U.P., India. *Tropical Ecology*, **42**(2): 271-280.

Paul, A., Khan, M.L., Arunachalam, A. and Arunachalam, K. (2005). Biodiversity and Conservation of rhododendrons in Arunachal Pradesh in the Indo-Burma biodiversity hotspot. *Current Science*, **89**(4): 623-634.

Payton, I.J., Fenner, M. and Lee, W.G. (2002). Keystone species: the concept and its relevance for conservation management in New Zealand. *Science for conservation*, **203**: 29.

Pearson, T.R.H., Burslem, D.F.R.P., Goeriz, R.E. and Dalling, J.W. (2003). Regeneration niche partitioning in neotropical pioneers: effects of gap size, season drought and herbivory on growth and survival. *Oecologia*, **137**: 456-565.

Peet, R. K. (1974). The measurement of species diversity. *Annual Review of Ecology and Systematic***, 5**: 285-307.

Peres, C.A. (2000). Identifying keystone plant resources in tropical forests: the case of gums from Parkia pods. *Journal of Tropical Ecology*, **16**(2): 287-317.

Peterson, G., Allen, C.R. and Holling, C.S. (1998). Ecological resilience, biodiversity and scale Ecosystems. **1**: 6-18.

Petraitis, P. S., Latham, R. E. and Niesenbaum, R. A. (1989). The maintenance of species diversity by disturbance. *Quarterly Review of Biology*, **64**: 393-418.

Phillips, E.A. (1959*). Methods of vegetation study*. Henery Holt and co.Inc. pp107.

Phillips, O.L., Vargas, N.P., Monteagudo, A.P., Cruz, M.E.C., Zans, W.G., Sanchez, M., Yli-Halla and Rose, S. (2003). Habitat association among Amazonian tree species: a landscape- scale approach. *Journal of Ecology*, **91**: 757-775.

Pianka, E.R. (1966). Latitudinal gradients in species diversity: a review of concepts. *American Naturalist,* **100**, 33-46.

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

Pielou, E. C. (1975). Ecological models on an environmental gradient: In Gupta, R. P. (Ed.) Proc. Symp. *Applic, of ststatics.* North Holland America Elasevier.

Pierce, S., Luzzaro, A., Caccianiga, M., Ceriane, R.M. and Cerabolini, B. (2007). Disturbance is the principal α-scale filter determining niche differentiation, coexistence and biodiversity in an alpine community. *Journal of Ecology,* **95**: 698-706.

Pimm, S. L., Russell, G. J., Gittleman, J. L. and Brooks, T. M. (1995). The future of biodiversity. *Science.* **269**: 347-350.

Pimm, S.L. and Raven, P. (2000). Extinction by numbers. *Nature,* **403**: 843-844.

Pinjari, F., Allesandra, T., Anna, B. and Paolo, S. (1999). Use of biochemical indices in the Mediterranean environment: Comparison among soils under different forest vegetation. *Journal of Microbiological Methods,* **36**: 21-28.

Pitman, N.C.A., Terborgh, J.W., Silman, M.R., Percy, N.V., Neill, D.A., Ceron, C.E, Palacios, W.A. and Aulestia, M. (2002). A comparison of tree species diversity in two upper Amazonian forests. *Ecology*, **83**: 3210-3224.

Pokhriyal, P., Uniyal, P., Chauhan, D.S. and Todaria, N.P. (2010). Regeneration status of tree species in forest of Phakot and Pathri Rao watersheds in Garhwal Himalaya. *Current Science,* **98**(2): 171-175.

Pollman, W. and Veblen, T.T. (2004). Nothofagus regeneration dynamics in South-Cenral Chile: A test of a general model. *Ecological Monographs,* **74**(4): 615-634.

Ponce-Hernandez, R. (2004). Assessing carbon stock and modelling. Win-win scenarios of carbon registration through land use changes. FAO, Rome, Chapter IV.

Poorter, L. and Arets, E.J.M.M. (2003). Light environment and tree strategies in a Bolivian tropical moist forest: a test of the light partitioning hypothesis. *Plant Ecology,* **166**: 295-306.

Potts, D.M., Ashton, P.S., Kaufman, L.S. and Plotkin, J.B. (2002). Habitat patterns in tropical rain forest: a camparision of 105 plots in North west Borneo. *Ecology,* **166**: 295-306.

Power, M.E., Tilman, D., Estes, J.A., Menge, B.A., Bond, W.J., Mills, L.S., Gretchen, D., Castilla, J.C., Lubehenco, J. and Paine, R.T. (1996). Challenge in the Quest for keystone. *Bioscience*, **46**(8): 609-620.

Pritts, M.P. and Hancock J.E. (1983). The effect of population structure on growth patterns of the weedy goldenrod Solidago pauciflos culose. *Canadian Journal of Botany,* **61**: 1955–1958.

Proctor, J., Lee, Y.E., Langley, A.M., Munro, W.R.C. and Nelson, T. (1988). Ecological studies on Gunung Silam, a small ultra basic mountain in Sabah, Malaysia. Environmental, Forest structure and Floristic. *Journal of Ecology,* **76**: 320-340.

Rai, P.K. and Lalramnghinglova, H. (2010). Lesser known enthnomedicinal plants of Mizoram Northeast India: An Indo-Burma hotspot region. *Journal of medicinal plant research,* **4**(13): 1301-1307.

Raizada, A., Joshi, S.P. and Srivastava, M.M. (1998). Composition and vegetation diversity in an alpine grassland in the Garhwal Himalayas. *Tropical Ecology*, **39**: 133-141.

Rajwar, G.S., Dhaulakhandi, M. and Kumar, P. (1999). Regeneration status of an oak forest of Garhwal Himalaya. *Indian Forester*, 623-629.

Ralhan, P.K., Sexena, A.K. and Singh, J.S. (1982). Analysis of forest vegetation at and around Nainital in Kumaon Himalaya. *The Proceeding of the Indian National Academy of Sciences,* **348**: 121-137.

Ram, J., Tewari, B. and Arya, N. (2005). Variation in plant biodiversity of chir-pine and baj-oak forests of Uttaranchal Himalaya. In Muthuchelian (Ed.). Biodiversity resources management and sustainable use. *Centre for biodiversity and forest studies,* Madurai. Pp 54-56.

Ramakrishnan, P.S. (2003). Linking natural resource management with sustainable development of traditional mountain societies. *Tropical Ecology* **44**: 43- 54.

Ramakrishnan, P.S. and Toky, O.P. (1981). Soil nutrient status of hill agro-ecosystem and recovery pattern after slash and burn agriculture (jhum) in north-east India. *Plant and Soil*, **60**: 41- 64.

Ramanujam, M.P. and Kadambam, D. (2001). Plant biodiversity of two tropical dry evergreen forests in the Pondicherry region of South India and the role of belief systems in their conservation. *Biodiversity and Conservation*, **10**(7): 1203-1217.

Ramesh, B.R. (2001). Patterns of richness and endemism of arborescient species in the Western Ghats, India. Ganeshaiah, K.N., Uma Shannkar, R. and Bawa, K.S. (Eds). In proceedings of International Conference on Tropical Ecosystems: Structure, Diversity and Human Welfare Oxford IBH, New Delhi, pp 539-544.

Ramirez-Marcial, N., Gonzalez-Espinosa, M. And Williams-Linera, G. (2001**).** Anthropogenic disturbance and tree diversity in Montane Rain Forests in Chiapas, Mexico. *Forest Ecology and Management,* **154**: 311–326.

Rao, M.R., Nair, P.K.K. and Ong, C.K. (1998). Biological interactions in tropical agroforestry systems. *Agroforestry Systems,* **38**: 3-50.

Rao, P.B. (1988). Effects of environmental factors on germination and seedling growth in Querscus floribunda and Cupressus torulosa, tree species of central Himalaya. *Annals of Botany,* **61**: 531–540

Rao, R.R. and Hajra, P.K. (1986). Foristic diversity eastern Himalaya in a conservation perspective. *The Proceeding of the Indian National Academy of Sciences*,103-125.

Raunkiaer, C. (1934). *The Life Form of Plants and Statistical Plant Geography*. Oxford, UK, The Clarendon Press.

Ravan, S.A. (1994). *Ecological Analysis of Vegetation Form Satellite Remote Sensing at Madhav National park Sivapuri (M.P.)*. Ph.D. Thesis, Unpublished. Srinagar: HNB Garhwal University.

Rawat, Y.S. and Singh, J.S. (1988). Structure and function of oak forests in Central Himalaya I. Dry Matter Dynamics. *Annals of Botany*, **62**: 397-411.

Reddy, M.B.K. (2010). Vegetation types and their influence on some secondary nutrients and micro nutrients in soils of Meghalaya forests. *Indian Forester*, 1445-1459.

Richards, P.W. (1986). *The nature of tropical forest ecosystems*. In Nicholas Polunin (Ed.) Ecosystems theory and application. A John Wiley International Publication, pp. 131-171.

Richards, P.W. (1996). Tropical rain forests, an ecological study 2nd ed. Cambridge University press, Cambridge, U.K.

Richardson, D.M., Pyešk, P., Rejmánek, M., Barbour, M.G., Panetta, F.D. and West, C.J. (2000). Naturalization and invasion of alien plants: concepts and definitions. *Diversity and Distribution,* **6**: 93–107.

Rikhari, H.C., Singh, R.S. and Tripathi, S.K. (1991). Patterns of species distribution, community characters and regeneration in major forest communities along an elevational gradient in central Himalaya. *International Journal of Ecology and Environmental Sciences,* **17**: 167-174.

Rikhari, H.C., Tiwari, J.C., Rana, B.S. and Sharma, S. (1991). Woody vegetation and regeneration status in a mixed Oak forest of Kumaon Himalaya. *Indian Forester,* **117**: 274-283.

Roach, J. (2005). *Conservationists name nine new "Biodiversity Hotspots*". National Geographic News, Feb. 2, 2005.

Rodin, L.E. and Bazilevich, N.I. (1967). Production and Mineral Cycling in Terrestrial Vegetation. Oliver and Boyd, Edinburgh.

Romme, W.H. (1982). Fire and landscape diversity in subalpine forests of Yellowstone National park. *Ecological Monographs,* **52**: 199-221.

Roy, A. and Srivastava, V.K. (2012). Geospatial approach to identification of potential hotspots of land-use and land-cover change for biodiversity conservation. *Current Science*, **102**: 1174-1180

Roy, A., Tripathi, S.K. and Basu, S.K. (2004). Formulating diversity vector for ecosystem comparison. *Ecological Modeling*, **179**: 499–513.

Roy, P. S., Harish, K., Kushwaha, S. P. S., Roy, A. and Saran, S. (2012a). India's plant diversity database at landscape level on geospatial platform: prospects and utility in today's changing climate. *Current Science*, **102**: 1136-1142.

Roy, P. S., Kushwaha, S. P. S. and Roy, A. (2012b). Landscape level biodiversity databases in India: Status and the Scope. *Proceedings of the National Academy of Sciences, India, Section B: Biological Science,* **82**(2): 261–269.

Roy, P. S., Padalia, H., Chauhan, N., Porwal, M. C., Gupta, S., Biswas, S. and Jagdale, R. (2005). Validation of geospatial model for biodiversity characterization at landscape level – a study in Andaman and Nicobar Islands, India. *Ecological Modeling*, **185**: 349–369.

Roy, P.S. and Tomar, S. (2000). Biodiversity characterization at landscape level using geospatial modelling. *Biological Conservation,* **95**: 95–109.

Runkle, J., Stewart, G. and Veblen, T. (1995). Sapling diameter growth in gaps for the two *Nothofagus sps*. in New Zealand. *Ecology*, **76**: 2107-2117.

Sagar, R. and Singh, J. S. (2004). Local plant species depletion in a tropical dry deciduous forest of northern India. *Environmental Conservation,* **3**: 55-62.

Sagar, R. and Singh, J. S. (2005). Structure, diversity and regeneration of tropical dry deciduous forest of northern India. *Biodiversity and Conservation,* **14**: 935-959.

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

Sala, O.E., Chapin, F.S., Armesto, J.J., Berlow, E. and Bloomfield, J. (2000). Global biodiversity scenarios for the year 2100. *Science,* **287**: 1770-1774.

Samant, S, S., Dhar, U. and Rawal, R.S. (2000). Assessment of fuel resource diversity and utilization patterns in Askot Wildlife Sanctuary in Kumauan Himalaya, India for conservation and management. *Environment Conservation*, **27**: 5-13.

Samant, S. S. and Dhar U. (1997). Diversity, endemism and economic potential of wild edible plants of Indian Himalaya. *International Journal of Sustainable Development and World Ecology*, **4**: 179-191.

Samant, S. S., Dhar, U. and Palni, L. M. S. (1998a). *Medicinal plants of Indian Himalayas:* Diversity Distribution Potential Values. Gyanodaya Prakashan, Nainital.

Samant, S. S., Dhar, U. and Rawal, R.S. (1998b). Biodiversity status of a protected area of west Himalayas. 1- Askot Wildlife Sanctuary. *International Journal of Sustainable Development and World Ecology,* **5**: 194- 203

Sanchez-Azofeifa, G.A., Castro, K.L., Rivard, B., Kalascka, M.R., Harriss, R.C. (2003). Remote sensing research priorities in tropical dry forest environments. *Biotropica,* **35,** 134-142.

Santos, T., Telleria, J.L. and Virgos, E. (1999). Dispersal of Spanish Juniper Juniperus thurifera by birds and mammals in a fragmented landscape. *Ecography*, **22**: 193-204.

Sarma, K. (2002). *Coal mining and its impact on environment of Nokrek Biosphere Reserve, Meghalaya*. Ph.D. Thesis. North Eastern Hill University, Shillong, India.

Sarma, K. (2005). *Impact of coal mining on vegetation: a case study in Jaintia Hills district of Meghalaya, India*. Thesis for partial fulfilment of the requirements for the degree of Master of Science International Institute for Geo-Information Science and Earth Observation Enschede, The Netherlands.

Sausa, W. P. (1984). The role of disturbance in natural communities. *Annual Review of Ecology and Systematic*. **15**: 353-391.

Saxena, A.K. and Singh, J.S. (1982). A phytosociological analysis of woody species in forest communities of a part of Kumaun Himalaya. *Vegetatio*, **50**: 3-22.

Saxena, A.K. and Singh, J.S. (1984). Tree population structure of certain Himalayan forest associations and implications concerning their future composition. *Vegetatio*, **58**: 61–69.

Saxena, A.K., Singh, S.P. and Singh, J.S. (1984). Population structure of forest of Kumaun Himalaya: Implications for management. *Journal of Environment Management*, **19**: 307-324.

Schatz, G. E. (2001). *Generic Tree Flora of Madagascar.* St. Louis, MO: Kew, Royal Botanic Gardens & Missouri Botanical Garden.

Schulze, E.D. and Mooney, H.A. (1994). (Ed.) *Biodiversity and ecosystem function*. Springer-Verlag, berlin Heidelberg.

Schumann, M.E., White, A.S. and Witham, J.W. (2003). The effects of harvest created gaps on plant species diversity, composition and abundance in a Maine Oak-pine forest. *Forest Ecology and Management*, **176**: 543-561.

Scott, D.A., Proctor, J. and Thompson, J. (1992). Ecological studies on lowland evergreen rain forest on Maraca Island, Roraima, Brazil II. Litter fall and nutrient cycling. *Journal of Ecology*, **80**: 705-717.

Semwal, D.P. and Bhatt, A.B. (1994). Impact of biotic stress on composition and structure of some temperatre forests in Garhwal Himalaya. *Journal of Hill Research*, **7**(1): 17-22.

Semwal, D.P., Uniyal, P.L., Bahuguna, Y.M. and Bhatt, A.B. (2009). Soil nutrient storage under different forest types in a part of central Himalaya, India. *Annals of Forestry*, **17**(1): 43-52.

Shafroth, P.B., Stromberg, J.C. and Patten, D.T. (2002). Riparian vegetation response to altered disturbance and stress regimes. *Ecological Applications*, **12**: 107-123.

Shankar, U. (2001). A case of high tree diversity in a sal (Shorea robusta)-dominated lowland forest of Eastern Himalaya: floristic composition, regeneration and conservation. *Current Science*, **81**: 776-786.

Shannon, C. and Weaver W. (1963). *The Mathematical Theory of Communication*. Urbana: University of Illinois Press.

Sharma, C.M., Ghildyiyal, S.K., Gairola, S. and Suyal, S. (2009). Vegetation structure, composition and diversity in relation to soil characteristics of temperate mixed broad-leaved forest along an altitudinal gradient in Garhwal Himalaya. *Indian Journal of Science and Technology,* **2**(7): 39-45.

Sheil, D. (1999). Tropical forest diversity, environmental change and species augmentation: After the intermediate disturbance hypothesis. *Journal of Vegetation Science*, **10**: 851-860.

Shrikant, G., Rajeshwari, N. and Vasudeva, R. (2013). Tree diversity and disturbance of koan forests: Relics of a community protected climax vegetation in the Central Western Ghats. *Tropical Ecology,* **54**(1): 117-131.

Shugart, H.H. and West, D.C. (1980). Forest succession models. *BioScience,* **30**: 308-313.

Simberloff, D. (1991). Keystone species and community effects of biological introductions. In: Ginzberg LR, (Ed.). Assessing ecologica risk of biotechnology. Stoneham (MA): Butterworth-Heinemann. Pp. 1-19.

Simpson, E.H. (1949). Measurement of diversity. *Nature,* **163**: 688.

Simpson, G.G. (1964). Species diversity of North American recent mammals. *Systematic Zoology*, **13**: 57-73.

Singh, A., Reddy, V.S. and Singh, J.S. (1995). Analysis of woody vegetation of Corbett National Park, India. *Vegetatio,* **120**: 69-79.

Singh, J.S. (2002). The biodiversity crisis: a multifaceted review. *Current Science,* **82**: 638-647.

Singh, J.S. and Singh, S.P. (1987). Forest Vegetation of the Himalaya. *Botanical Reviews,* **53**: 80-192.

Singh, J.S. and Yadav, P.S. (1974). Seasonal variation in composition plant biomass and net primary productivity of tropical grassland at Kurukshetra. India. *Ecology Monograph*, **44**: 351-376.

Singh, J.S., Raghubanshi, A.S. and Varshney, C.K. (1994). Integrated biodiversity research for India. *Current Science*, **66**: 109-112.

Singh, J.S., Singh, K.P. and Agrawal, M. (1991). Environmental degradation of the Obra-Renukoot- Singrauli area, India and its impact on natural and derived ecosystems. *Environmentalist*, **11**: 171–180.

Singh, J.S., Singh, S.P., Saxena, A.K. and Rawat, Y.S. (1984). India's Silent valley and its threatened rain forest ecosystem. *Environmental Conservation*, **11**: 223-233.

Singh, K.P. and Singh, J.S. (1988). Certain structural and functional aspects of dry tropical forests and savanna. *International Journal of Ecology Environmental Science*, **14**: 31–45.

Singh, L. and Singh, J.S. (1991). Species structure, dry matter dynamics and carbon flus of a dry tropical forest in India. *Annual of Botany*, **68**: 263-273.

Singh, M.P., Singh, B.S. and Dey, S. (2002). Plant Biodiversity: *Plant Biodiversity and Taxonomy*. Daya Publishing House, Delhi.

Singh, S.P. and Singh, J.S. (1986). Structure and function of the forest ecosystems of Central Himalaya: Implications for management. *Proceeding of Indian National Academy Sciences,* **96**: 159-189.

Singhal, R.M., Soni, Sunita and Sharma, S.D. (1989). Study of the soils of Mussoorie area (Garhwal Himalayas). *Indian Forester,* **115** (12): 924- 933.

Sirajul Karim, A.J.M., Egashira, R., Yamada, Y., Haider, J. and Nahar, K. (1995). Long-term application of organic residues to improve soil properties and to increase crop yield in terrace soil of Bangladesh. *Journal of the Faculty of Agriculture Kyushu University,* **39**: 149-165.

Slik, J. W. F., Verburg, R. W. And Kebler, P. J. A. (2002). Effects of fire and selective logging on the tree species composition of lowland dipterocarp forest in east Kalimantan, Indonesia. *Biodiversity and Conservation*, **11**: 85–98.

Slik, J.W.F., Kebler, P.J.A. and Welzen, P.C. (2003). Macaranga and Mallotus species (Euphorbiaceae) as indicators for disturbance in the mixed lowland dipterocarp forest of East Kalimantan (Indonesia). *Ecological Indicators,* **2**: 311-324.

Smith, B. (1986). Evaluation of different similarity indices applied to data from the Rothamsted Insect survey. University of York, York.

Smith, M., Caswell, H. and Mettler-cherry, P. (2005). Stochastic flood and precipitation regimes and the population dynamics of a threatened flood plain plant. *Ecological Applications*, **15**:1036-1052.

Snyder, R.A. and Boss, C.L. (2002). Recovery and stability in Barrier Island plant communities. *Journal of Coastal Research,* **18**(3): 530-536.

Soave, R. de C.F. (2003). Phytosociological studies on natural established of vegetation in an unreclaimed limestone mining. *Brazilian Archives Biology and Technology,* **46**: 259-269.

Sood, V. and Bhatia, M. (1991). Population structure and regeneration status of tree species in forests around Shimla, Himachal Pradesh. *Van Vigyan*, **29**(4): 223–229.

Sorensen, L.H. (1972). Stabilization of newly formed amino acid metabolites in soil by clay minerals. *Soil Science*, **114**: 5-11.

Sousa, W. (1979). Disturbance in marine intertidal boulder fields: the non equilibrium maintenance of species diversity. *Ecology*, **60**: 1225-1239.

Sousa, W. P. (1984). The role of disturbance in natural communities. *Annual Review of Ecology and Systematics*, **15**: 353–391.

Southwood, T.R.E. and Henderson, P.A. (2000). *Ecological methods*. Blackwell Science, Oxford.

Spies, T.A. and Turner, M.G. (1999). Dynamic forest mosaics. *Maintaining Biodiversity in forest Ecosystems*. Malcolm, L. Hunter, Jr. (Ed.). Published by the Press syndicate of the University of Cambridge, U.K., 95-160.

Stein, B., Kutner, L.S. and Adams, J.S. (2000). Precious Heritage: *The Status of Biodiversity in the United States*. Oxford: Oxford University Press, pp 399.

Stevens, M.H. and Carson, W.P. (2002). Resource quality, not resource heterogeneity, maintains plant diversity. *Ecological Letter*, **5**:420-426.

Stoll, P. and Newbery, D. M. (2005). Evidence of species-specific neighbourhood effects in the Dipterocarpaceae of a Bornean rain forest. *Ecology*, **86**(11): 3048-3062.

Sundarpandian, S.M. and Swamy, P.S. (2000). Forest ecology structure and composition along an altituduninal gradient in the western ghats, South India. *Journal of Tropical Forest Science*, **12**(1): 104-123.

Sundriyal, R.C., Sharma, E., Rai, L.K. and Rai S.C. (1994). Tree structure regeneration and woody biomass removal in a subtropical forest of Mamlay watershed in Sikkim Himalaya. *Vegetatio*, **113**: 53–63.

Takyu., M., Aiba, S. and Kitayama, K. (2002). Effects of topography on tropical lower montane forest under different geological conditions on Mount Kinabalu, Borneo. *Plant Ecology*, **159**: 35-49.

Tamirat Tsegaye, (1992). *Vertisol of Central Highlands of Ethiopia: Characterization and Evaluation of Phosphorus Statues*. MSc Thesis, Alemaya University, Ethiopia.

Tansley, A.G. (1935). The use and abuse of vegetation concept and terms. *Ecology*, **16**: 284-307.

Tawnenga, Shankar, U. and Tripathi, R.S. (1997). Evaluating second year cropping on jhum fallows in Mizoram, Northeastern India: Soil fertility. *Journal Bioscience*, **22**(5): 615-625.

Taylor, A.H. and Zisheng, Q. (1988). Regeneration patterns in old growth *Abies-betula* forest in the Wolong natural reserve, Sichuan, China. *Journal of Ecology*, **76**: 1204–1218.

Thomas, S.C. and Bazzaz, F.A. (1999). Asymptotic height as a predictor of photosynthetic characteristics in Malaysian rain forest trees. *Ecology*, **80**: 1607–1622.

Thompson, L.H., Black, C.A. and Zoellner, J.A. (1954). Occurence and mineralization of organic phosphorus in soils with particular reference to assoiation with nitrogen, carbon and pH. *Soil Science*, **77**: 185-196.

Thorington, Jr. R.W., Tannenbaum, B., Tarak, A. and Rudran, R. (1982). Distribution of trees on Barro Colorado Island. A five hectare saple. In: Leigh, Jr. E.G., Rand, A.S. and Winddror, D.M. (Eds.). The Ecology of Tropical Forest seasonal Rhythms and Long Term Changes. Smithsoman Institute Press, Washinton, DC. Pp. 83-94.

Thukral, A.K., Chawla, A. and Samson, M.O. (2006). Measurement of Biodiversity. *Statistical Accounting of Land and Forestry Resources*, 244-256.

Tilman, D. (1982). Secondary succession and the pattern of plant dominance along experimental nitrogen gradients. *Ecological Monograph*, **57**: 189-214.

Tilman, D. (1984). Plant dominance along an experimental nutrient gradient. *Ecology*, **65**: 1445-1453.

Tilman, D. (2000). Causes, Consequences and Ethics of Biodiversity. *Nature*, **405**: 208-211.

Tilman, D., Knops, J., Wedin, D., Reich, P., Ritchie, M. and Siemann, E. (1997). The influence of functional diversity and composition on ecosystem processes. *Science*, **227**: 1300-1302.

Tilman, D., Wedin, D. and Knops, J. (1996). Productivity and sustainability influenced by biodiversity in grassland ecosystems. *Nature*, **379**: 718-720.

Tiwari, D.N. (1993). Conservation of biodiversity. Biodiversity conservation: Forest, wetlands and desert. Frame, B., Victor, J. and Joshi, Y. (Eds.) TERI, New Delhi.

Tiwari, S.C., Tiwari, B.K. and Mishra, R.R. (1992). Variation in some physic-chemical properties of pineapple orchard soils of north-east India. *Journal of Indian Soil Science Society*, **40**: 204-208.

Townsend, A. R., Asner, G. P. and Cleveland, C. C. (2008). The Biogeochemical Heterogeneity of Tropical Forests. *Trends in Ecology and Evolution*, **23**:(8) 424-431.

Townsend, A. R., Vitousek, P. M., Desmarais, D. J. and Tharpe, A. (1997). Soil carbon pool structure and temperature sensitivity inferred using CO2 and 13CO2 incubation fluxes from five Hawaiian soils. *Biogeochemistry*, **38**:1–17.

Tripathi, K.P., Tripathi, R. S., Selven, T., Kumar, K., Singh, K.K., Mehrotra, S. and Pushpangadan, P. (2004b). Community structure and species diversity of saddle Peak forests in Andaman Island. *Tropical Ecology*, **45**(20): 241-250.

Tripathi, O.P. (2002). *Study of distribution pattern and ecological analysis of major forest types of Meghalaya*. Ph.D. Thesis, North Eastern Hill University, Shillong, India.

Tripathi, O.P., Pandey, H.N. and Tripathi, R.S. (2004a). Distribution, community characteristics and tree population structure of subtropical pine forest of Meghalaya, Northeast India. *International Journal of Ecology and Environment Sciences*, **29**: 207-214.

Tripathi, O.P., Pandey, H.N. and Tripathi, R.S. (2009). Litter production and physic-chemical properties of soil in three developed agroforestry systems of Meghalaya, Northeast India. *African Journal of Plant Science*, **3**(8): 160-167.

Tripathi, O.P., Upadhaya, K., Tripathi, R.S. and Pandey, H.N. (2010). Diversity, dominance and population structure of tree species along fragment size gradient of a subtropical humid forest of Northeast India. *Research Journal of Environmental and Earth Sciences*, **2**(2): 97-105.

Tripathi, R.S. and Khan, M.L. (1990). Effects of seed weight an microsite characteristics on germination and seedling fitness in two species of *Quercus* in a subtropical wet hill forest. *Oikos*, **57**: 289-296.

Tripathi, R.S. and Khan, M.L. (2007). Regeneration dynamics of natural forests. *A review. Proceedings of the Indian National Science Academy,* **73**(3): 167-195.

Tripathi, R.S. and Law, P. (2006). Keystone species: The concept, their ecological significance and determining their keystone status. *International society of environmental botanist, Enviro News*, **12** (3).

Tripathi, S.K. and Singh, K.P. (1994). Productivity and nutrient cycling in recently harvested and mature bamboo savannas in the dry tropics. *Journal of Applied Ecology*, **31**: 109-124.

Tripathi, S.K., Kushwaha, C.P. and Basu, S.K. (2012). Application of fractal theory in assessing soil aggregates in Indian tropical ecosystems. *Journal of Forestry Research*, **23**(3): 355-364.

Tripathi, S.K., Kushwaha, C.P. and Singh, K.P. (2008). Tropical forest and savana ecosystems show differential impact of N and P additions on soil organic matter and aggregate structure. *Global change Biology*, **14**: 2572-2581.

Tripathi, S.K., Singh, R.S., Upadhyay, V.P. and Singh, R.P. (1989). Population structure of *Pinus roxburghii* and *Quercus leucotrichophora* forests of Almora Hills of Kumaun Himalaya. *Journal of Tree Sciences*, **8**: 78-80.

Tripathi, S.K., Upadhyay, V.P. and Verma, K.R. (1989a). A comparison of different indices of diversity in tree species at Kasar Devi forests in Kumaun Himalaya. *Vegetos*, **2**: 86-93.

Tripathi, S.K., Upadhyay, V.P. and Verma, K.R. (1989b). Diversity of shrub species at Kasar Devi forests in Kumaun Himalaya. *Environment and Ecology*, **7**: 537-542.

Tripathi, S.K., Verma, K.R. and Upadhyay, V.P. (1987). Analysis of forest vegetation at Kasar Devi hill of north-west Almora division in Kumaun Himalaya. *Proceedings of National Academy Sciences, (Plant Science)*, **97**: 265-276.

Troumbis, A.Y., Galanidis, A. and Kokkoris, G.D. (2002). Components of short-term invisibility in experimental Mediterranean grasslands. *Oikos*, **98**: 239-250.

Tuomisto, H., Ruokolainen, K., Aguilar, M. and Sarmiento, A. (2003). Floristic patterns along a 43 km long transect in and Amazonian rain forest. *Journal of Ecology*, **91**: 743-756.

Tuomisto, H., Ruokolainen, K., Kalliola, R., Linna, A., Danjoy, W. and Rodriguez, Z. (1995). Dissecting Amaznian biodiversity. *Science*, **269**: 63-66.

Turner, G.M., Romme, W.H., Gardener, R.H., O.Neill, R.V. and Kraz, T.K. (1993). A revised concept of landscape equilibrium, disturbance and stability on scaled landscapes. *Landscape Ecology*, **8**: 213- 227.

Tynsong, H. and Tiwari, B.K. (2010). Plant diversity in the homegardens and their significance in the livelihoods of war khasi community of Meghalaya, Northeast India. *Journal Biodiversity*, **1**(1): 1-11.

Tynsong, H. and Tiwari, B.K. (2011). Diversity and population characteristics of woody species in natural forests and arecanut agroforestry of south Meghalaya, Northeast India. *Tropical Ecology*, **52**(3): 243-252.

UNEP. (2001). *India: State of the Environment-2001*. United Nations Environment Programme. Nairobi.

UNEP. (1992). Convention on Biological Diversity, NA 92-7801, June 5, 1992, New York.

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 Science*, **34**(3): 245-257.

Uriarte, M., Canham, C.D., Condit, R. and Hubbel, S.P. (2004b). A spatially explicit model of sapling growth in a tropical forest: does the identity of neighbours matter. *Journal of Ecology*, **92**: 348-360.

Uriarte, M., Canham, C.D., Thompson, J. and Zimmerman, J.K. (2004a). A neighbourhood analysis of tree growth and survival in a hurricane driven tropical forest. *Ecological Monographs*, **74**(4): 591-614.

Uriate, M., Canham, C.D., Thompson, J., Zimmerman, J.K. and Brokaw, N. (2005). Seedling recruitment in a hurricane-driven tropical forest: light limitation, density dependence and the spatial distribution of parent trees. *Journal of Ecology*, **93**: 291-304.

Valencia, R., Foster, R.B., Villa, G., Condit, R., Svennings, J., Hernandez, C., Romoleroux, K., Losos, E., Magard, E. and Balslev, H. (2004). Tree species distributions and local habitat variation in the Amazon: large forest plot in Eastern Ecuador. *Journal of Ecology*, **92**: 214-229.

Van der Maarel, E. (1996). Vegetation dynamics and dynamic vegetation science. *Acta Botanica Neer- landica*, **45**: 421- 442.

Van derKrift, T.J. and Berendse, F. (2001). The effects of plant species on soil nitrogen mineralization. *Journal of Ecology*, **89**: 555-561.

Verghese, A.O. and Menon, A.R.R. (1998). Vegetation characteristicis of southern secondary moist mixed deciduous forests of Agasthyamalai region of Kerela. *Indian Journal of Forestry*, **21**(4): 639-644.

Vazquezg, J.A. and Givnish, T.J. (1998). Altitudinal gradients in tropical forests composition, structure and diversity in the Sierra de Manantan. *Journal of Ecology*, **86**: 999-1020.

Veblen, T.T. (1992). Regeneration dyanamic. Glenn-Lewin, D.G., Peet, R.K. and Beblen, T.T. (Ed.), *Plant succession*: Chapman and Hall, London, U.K. pp. 152-187.

Veblen, T.T., Ashton, D.H. and Schlegel, F.J. (1979). Tree regeneration strategies in lowland Nothofagus dominated forest in South Central Chile. *Journal of Biogeography*, **6**: 329–340.

Vetaas, O.R. (1992). Micro-site effects of tree and shrubs in a dry savanna. *Journal of Vegetation Science*, **3**: 337-344.

Visalakshi, N. (1995). Vegetation analysis of two tropical dry evergreen forest in southern India. *Tropical Ecology*, **36**: 117-142.

Vitousek, P.M., Aber, J., Howarth, R.W., Likens, G.E., Matson, P.A., Schindler, D.W., Schlesinger, W.H. and Tilman, G.D. (1997). Human alteration of the global nitrogen cycle: Cause and consequences, Issue in Ecology No.1.

Walkley, A. and Black, I.A. (1934). An examination of the Degtjareff method for determining organic carbon in soils: Effect of variations in digestion conditions and of inorganic soil constituents. *Soil Science*, **63**: 251-263.

Walters, C. (1986). *Adaptive management of renewable resources*, New York: MacMillan.

Wangda, P. and Ohsawa, M. (2006). Structure and regeneration dynamics of dominant tree species along altitudinal gradient in a dry valley slopes of the Bhutan Himalayas. *Forest Ecology and Management*, **230**: 136-150.

Wardle, D.A., Zackrisson, O., Hornberg, G. and Gallet, C. (1997). The influence of island area on ecosystem properties. *Science*, **277**: 1296-1299.

WCMC, (1992). World Conservation Monitoring Centre. *Global Biodiversity: Status of Earth's Living Resources*. Chapman and Hall, London, UK

Webb, C.J., Tracey, J.G., Williams, W.T. and Lance, G.N. (1967). Studies in the numerical analysis of complex rain forest communities. A comparison of methods, applicable to site/species data. *Journal of Ecology*, **55**: 171-191.

Webb, C.O. and Peart, D.R. (2000). Habitat associations of trees and seedling in a Bornean rain forest. *Journal of Ecology,* **88**: 464-478.

Wedin, D., and D. Tilman. (1990). Species effects on nitrogen cycling: a test with perennial grasses. *Oecologia*, **84**:433– 441.

Weltzin, J.F. and Coughenour, M.B. (1990). Savanna tree influence on understorey vegetation and soil nutrients in north-western Kenya. *Journal of Vegetation Science,* **1**: 325-334.

White, P. S. (1979). Pattern, process and natural of disturbance in vegetation. *Botanical Reviews,* **45**: 229-299.

White, P. S. and Jentsch, A. (2001). The search for generality in studies of disturbance and ecosystem dynamic. *Progress in Botany,* **62**: 399- 450.

White, P.S. and Pickett, S.T.A. (1985). Natural disturbances and patch dynamics. In: Pickett, S.T.A. and White, P.S. (Eds.) *The ecology of natural disturbance and patch dynamics,* Academic Press, San Diego, CA, US. pp. 3-13.

Whitemore, T.C. and Burslem, D.F.R. (1996). Major disturbances in tropical rain forests. pp. 549-565. *In*: D.M. New Berry, H.H.T. Pains & N.D. Brown (eds.) *Dynamics of Tropical Communities.* Blackwell, Cambridge

Whitmore, T.C. (1984). Tropical Rain Forest of Far East. 2nd edition. Claredon Press, London.

Whitmore, T.C. (1989). Canopy gaps and the two major groups of forest trees. *Ecology*, **70**: 536-538.

Whittaker, R.H. (1956). Vegetation of the great Smoky Mountains. *Ecological Monographs*, **26**: 1-80.

Whittaker, R.H. (1965). Dominance and diversity in land plant communities. *Science,* **14**: 250-259.

Whittaker, R.H. (1972). Evolution and measurement of species diversity. *Taxon*, **21**: 213-251.

Whittaker, R.H. (1975). Communities and Ecosystems. Mac Milans publishing Co. Inc. New York.

Whitton, J. and Rajakaruna, N. (2001). Plant Biodiversity overview. *Encyclopedia of Biodiversity,* **4**: 621-630.

Wikipedia, (2010). Biodiversity. *http:/en.wikipedia.org/wiki/biodiversity*.

Wilkinson, D. M. (1999). The disturbing history of intermediate disturbance. *Oikos*, **84**, 145–148.

Wilson, E.O. (1988). (Ed.) Biodiversity, Washington, DC. National Acadamy press.

Wilson, M.V. and Mohler, C.L. (1983). Measuring composition change along gradients. *Vegetation*, **54**: 129-141.

Wright, S.J., and Muller-Landau, H.C., Calderon, O. and Hernandez, A. (2005). Annual and spatial variation in seedfall and seedling recruitment in a Neotropical forest. *Ecology*, **86**: 848-860.

Xu, K., Ye, W., Cao, H., Deng, X., Yang, Q. and Z. (2004). The role of diversity and functional traits of species in community invisibility. *Botanical Bulletin of Academia Sinica*, **45**: 149-157.

Yadav, A.S. and Gupta, S.K. (2009). Natural regeneration of tree species in a tropical dry deciduous thorn forest in Rajasthan, India. *Bulletin of the National Institute of Ecology*, **20**: 5-14.

Yadav, A.S. and Yadav, R.K. (2005). Plant community structure of Bala-fort forest in Alwar, Rajasthan. *International Journal of Ecology and Environmental Sciences* **31**: 109-117.

Yadava, P.S., Singh, E.J. and Soreishang, K.A.S. (1991). Tree population structure of sub-tropical forests of Manipur, North Eastern India and implications for their regeneration. In: Rajwar G.S. (Ed.), Advances in Himalayan ecology. Today and Tomorrows Printers & Publishers, New Delhi, pp. 13–23.

Yamada, T., Ngakan, O.P. and Suzuki, E. (2006). Differences in growth and light requirement of two sympatric congeneric tree species in an Indonesian floodplain forest. *Journal of Tropical Ecology*, **22**: 349-352.

Yamada, T., Zuidema, P.A., Itoh, A., Yamakura, T., Ohkubo, T., Kanzaki, M., Tan, S. and Ashton, P.S. (2007). Strong habitat preference of a tropical rain forest tree does not imply large differences in population dynamics across habitats. *Journal of Ecology*, **95**: 332-342.

Yuan, J.G., Fang, W., Fan, L., Chen, Y., Wang, D.Q. and Yang, Z. (2006). Soil formation and vegetation established on the cliff face of abandoned quarries in the early stages of natural colonization. *Restoration Ecology*, **14**(3):349-356.

Zhang, K., Dang, H., Tans, S., Wang, Z. and Zhang, Q. (2010). Vegetation community and soil characteristic of abandoned agricultural land and pine plantation in the Qinling mountains, China. *Forest Ecology and Management*, **259**: 2036-2047.

Zhu, J.J., Mao, Z.H., Hu, L. and Zhang, J.X. (2007). Plant diversity of secondary forests in response to anthropogenic disturbance levels in montane regions of northeastern China. *Journal of Forest Research*, **12**: 403–416.

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Status of ethnomedicinally important plants sampled from different forest patches of Mizoram University campus

Sh. Bidyasagar Singh, B. P. Mishra[1*], S. K. Tripathi
Department of Forestry, Mizoram University, Aizawl – 796004, Mizoram
[1*]Department of Environment Science, Mizoram University, Aizawl – 796004, Mizoram

ABSTRACT

The present study deals with documentation of medicinally important plants within Mizoram University campus at Tanhril, Aizawl. The field data was collected during 2009-2010 from various points (>200) located within the campus and specimens were identified. A total of 64 medicinally important plant species belonging to 36 families of angiosperms were recorded. In most plant species, leaves were commonly used components for the treatment of various diseases by tribal communities followed by roots, barks and seeds. Anthropogenic activities especially developmental activities like construction of buildings and roads within the University campus, adversely affected medicinal plant diversity, and resulted in more number of mono-specific families. Integrated management measures are needed as a basic tool to conserve medicinally important plant species so as to overcome the developmental activities.

Keywords: Conservation, restoration of ethnomedicinal plants, traditional health care system.

In India, the significance of plants for their immense and valued services rendered to the society in the form of food, fiber and medicines has been recognized since time immortal. Since ancient times, plants have been categorized as religious and/or spiritual for their conservation based on important services they provided to the society. Natural plant resources were directly used as medicines by the villagers from ancient times because of our advanced traditional knowledge of the plants and our tribal communities are using these plant products for their day to day medicinal uses even today. Dates back to the Vedic period, the first mention of diseases and drugs, found in the Rig-Veda and Yajurveda (around 2000 BC) and the earliest comprehensive description of Ayurveda is available in the Atharvaveda (1600-1000 BC) which contains inter alia description of human anatomy, rudiments of classification of diseases and reference to herbal medicine. Ayurveda, a discipline of medical science, is still on the way to find out the traditional Indian knowledge system of medicine and involves in dispensing of herbal and plant products for number of medicinal uses in various forms (i.e. powders, extracts).

Traditional medicine system is the synthesis of therapeutic experience of generations of practicing physicians of indigenous systems of medicine. Traditional preparation is mainly based on medicinal plants, minerals and organic matters. Herbal drugs constitute only those traditional medicines that primarily based on medicinal plant preparations for therapy. The ancient record is evidencing their use by Indian, Chinese, Egyptian, Greek, Roman and Syrian dates back to about 5000 years. About 500 medicinally important plants are mentioned in ancient texts, however, about 800 plants have been used in indigenous traditional health care systems. Indian subcontinent is a vast repository of medicinal plants used in traditional herbal treatments. In India, about 20,000 medicinal plant species have been recorded so far (Dev, 1997), but more than 500 traditional communities using 800 plant species for curing different diseases (Kamboj, 2000). The available literature depicts that about 80% of the

Author for correspondence
B. P. Mishra
Email: mishrabp111@yahoo.com

world population depends on plant-derived medicines for the first line of primary health care for human alleviation because it has no side effects.

Medicinal plants play a significant role in our national economy. Plant derived drugs are used to cure mental illness, skin diseases, tuberculosis, diabetes, jaundice, hypertension, cancer and other kind of diseases. Plant based drugs also came into use in the modern medicine through the uses of plant material as indigenous cure in folklore or traditional systems of medicine. About 64 plants have been recognized for their antibacterial properties and 24 plants species having antidiabetic properties (Perumal & Ignacimuthu, 1998). Root extract of Indian sarsaparilla *Hemidesmus indicus* R.Br. antidote effectively neutralized Daboia russellii venom (Chatterjee *et al*. 2006; Alam *et al*. 1994).

Description of study area and study site

Mizoram (21°56`-24°31` N and 92°16`-93°26`E) is one of the 8 states of northeast India, and it covers an area of 21,081 km². The tropic of cancer divides the state into almost two parts. The state is bordered by Myanmar to the east and south, Bangladesh to the west, and by the states of Assam, Manipur and Tripura to the north. Aizawl (21°58`-21°85`N and 90°30`-90°60` E), the capital of the state is 1132 (metre above sea level). The altitude in Aizawl district varies from 800 to 1200 metre asl. The climate of the area is typically monsoonic with three distinct seasons namely rainy, winter and summer seasons. The wet-humid rainy season is long for about 6 months (i.e. from April to September) followed by 3 months cool-dry winter season (i.e. from November to January) and a short hot-dry summer season (spring) that persists for about two months (i.e. from February-March). October is a transition month between rainy and winter season. The annual average rainfall is amounting to 1694 mm, of which rainy season receives about 90%. During rainy season, heavy storms come from the north-west sweep over the hills in the entire state. Mean minimum and maximum temperature varies from 12°C in winter and 30°C in summer. The forest vegetation falls under three major categories i.e., tropical wet evergreen forest, tropical semi-evergreen forest and sub-tropical pine forest (Champion & Seth, 1968). The forests are very rich in medicinal plants diversity. The medicinally important species are protected on priority basis by the indigenous local tribal community traditionally. Thus, ethno-medicinal knowledge inherent among elderly aged rural people adds new dimensional towards conservation of biodiversity especially medicinally important species.

In view of the above, the present study has been carried out in the forest within Mizoram University campus, Aizawl. The main aim of the study focus documentation of medicinally important species as recognized locally.

Method

The study was conducted during 2009-2010. The field study was carried out following (Misra, 1968; Kershaw, 1973; Mueller-Dombois & Ellenberg, 1974). The specimens were processed as per routine herbarium techniques as recommended (Jain & Rao, 1977), and identified on the basis of morphological characters, and counter checked with the help of local and regional floras. For documentation of medicinal importance of plant species, the information was collected from the local people having ethnomedicinal knowledge through questionnaire.

Results and Discussion

During present study, a total of 64 medicinal plant species belonging to 36 families were recorded, of which 44% were tree, 23% shrubs, 31% herbs and 2% climbers (Fig.1). The plant used to cure different types of disease is presented in Table-1. Euphorbiaceae was the most dominant family (5 species) followed by Caesalpiniaceae, Compositae, Mimosaceae and Papilionaceae (4 species each), Solanaceae (three species), Amaranthaceae, Anacardiaceae, Asteraceae, Gramineae, Malvaceae, Moraceae, Myrtaceae, Rubiaceae, Verbenaceae and Zingiberaceae (2 species each) whereas, the remaining twenty families were represented by single species each. The disturbance led to thiny of vegetation and leading to increase in the number of monospecific families. The result depicts that leaves are used to a maximum extent (30%) and it is followed by roots (23%), barks (20%), seeds (15%), whole plants (7%) and rhizome (5%) to cure various disease (Fig. 2).

Tribal healers in most of the countries, where ethnomedical treatment is way common to treat cut wounds, skin infection, swelling, aging, mental illness, cancer, asthma, diabetes, jaundice, scabies, eczema, venereal diseases, snakebite and gastric ulcer, provide instructions to local people as how to prepare medicine from herbs (Perumal & Ignaci-

Table: 1, Ethnomedicinal plants species found in study area.

Botanical name	Local name (Mizo)	Family	Part use	Therapeutic use	Specimen collection no.
Abelmoschus moschatus Linn.	Uichhuhlo	Malvaceae	Roots, seeds & bark	Stimulant, antispasmodic, glycyrrhizin useful in coughs, emmenagogue.	H- 1
Achyranthes aspera Linn.	Buchhawl	Amaranthaceae	Whole plant	Pungent, purgative, astringent, hydrophobia.	H- 2
Ageratum conyzoides Linn.	Vailenhlo	Asteraceae	Root and leave	Tuberculosis. Leave and inflorescences are used for hair wash by women.	H- 3
Albizia chinense (Osb.) Merr.	Vang	Mimosaceae	Bark	Piscicidal	T- 1
Albizia procera (Roxb.)	Kangtek	Mimosaceae	Bark & leaves	Stomach, intestinal disease, anti cancer activity.	T- 2
Albizia lebbek Benth.	Thing-chawk-e	Mimosaceae	Leave, bark & seeds	Antiseptic, antidysenteric and antitubercular properties.	T- 3
Aporusa octandra (Buch.-Ham. Ex D.Don	Chhawntual	Euphorbiaceae	Bark	Stomach ulcer, diarrhoea and dysentery.	T- 4
Artocarpus heterophyyllus Lamk	Lamkhuang	Moraceae	Root & fruit	Ddiarrhoea. Unripe fruit is astringent and the ripe is laxative.	T- 5
Amaranthus spinosus Linn.	Len-hling	Amaranthaceae	Root & leave	Menorrharia, eczema and colic pain.	H- 4
Bombax ceiba Linn	Phunchawng	Bombacaceae	Root, bark, leave & gum	Demulcent, haemostatic, astringent, roots are stimulant,tonic.	T- 6
Bridelia stipularis(Linn.) Bl.	Phaktel	Euphorbiaceae	Roots, leaves & seed	Seeds possess hemagglutinating properties.	S- 1
Biden pilosa Linn.	Vawk-pui-thai	Compositae	Flower, seed & roots	Diarrhoea.	H- 5
Barleria cristata Linn.	Ui-te-ke	Acanthaceae	Roots & leave	Swelling and snake bite.	H- 6
Bauhinia purpurea Linn.	Vau-fa-vang	Caesalpiniaceae	Bark & roots	Bark extract in leucorrhoea, leprosy.	T- 7
Callicarpa arborea Roxb.	Hnahkiah	Verbenaceae	Bark	Cutaneous disease	T- 8
Cassia fitula Linn	Ngaingaw	Caesalpiniaceae	Root, bark	Chronic fever, purgative, ringworms	T- 9
Cassia hirsuta Linn		Caesalpiniaceae	Leaves	Ringworms and pustules	S- 2
Cassia occidentalis Linn.	Rengan	Caesalpiniaceae	Roots & seed	Laxative, arphrodisiac	S- 3
Centella asiatica Linn	Lambak	Apiaceae	Whole plant	Diabetes, stomach-ache, dysentery, high blood pressure	H- 7
Castanopsis tribuloides (Sm.) DC.	Thingsia	Fagaceae	Bark & leaves	Contain tannin.	T- 10
Chromolaena odorata Linn.	Tlangsam	Asteraceae	Leaves	Fish poison	S- 4
Costus speciosus (Koenig) Smith.	Sumbul	Zingiberaceae	Rhizome & seeds	Dysuria, fever, bronchitis, rheumatism	H- 8
Cynodon dactylon Pers.	Phaitaulhlo	Gramineae	Rhizome	Genito-urinary troubles	H- 9
Desmodium gyroides DC.	Hmeithaisarawhtui	Papilionaceae	Leaves	Lumbago	S- 5
Debregeasia velutina Gaud.	Lehngo	Urticaceae	Leave	Applied on burns	T- 11
Derris robusta Benth.	Thingkha	Papilionaceae	Roots	Fish poison	T- 12
Emblica officinalis Gaertn	Sunhlu	Euphorbiaceae	Fruit	Vitamin C, astringent, diuretic and laxative	T- 13
Engelhardtia spicata Lindl.	Hnum	Juglandaceae	Bark	Fish poison	T- 14
Erythrina stricta Roxb.	Fartuah	Papilionaceae	Bark	Stomach trouble	T- 15
Eucalyptus globulus Labill.	Nawalhthing	Myrtaceae	Leaves	Expectorant, stimulant, insect repellant	T- 16
Ficus hirta Linn.f	Sazutheipui	Moraceae	Leaves	Ringworms, dysentery	T- 17
Flemingia stricta Roxb.	Uifawmaring	Papilionaceae	Root	Swelling and pain	S- 6
Gynura nepalensis Benth.	Buar	Compositae	Leave	Stopping bleeding, headache	H- 10
Hedychium spicatum Buch-Ham	Aithur	Zingiberaceae	Rhizomes	Stomachic, carminative, stimulant	H- 11
Impatiens chinensis Linn.	Hawilo	Balsaminaceae	Whole plant	Burns and taken internally with milk in gonorrhoea.	H- 12
Imperata cylindrica Wall.	Di	Gramineae	Root	Restrorative, haemostatic, antifebrile properties	H- 13
Inula cappa DC.	Hmeithaisatui	Compositae	Root	Adulterant of Kuth.	S- 7
Largerstroemia speciosa Pers	Thlado	Lythraceae	Seed, bark, leave & roots	Narcotic, purgative, astringent	T- 18
Lantana camara Linn	Tilduhpar	Verbenaceae	Leaves	Antispasmodic, diaphoretic, abdominal viscera	S- 8
Macaranga denticulata Muell.-Arg	Zawngtenawhlung	Euphorbiaceae	Gum	Antiseptic	T- 19
Mangifera indica Linn.	Theihai	Anacardiaceae	Fruit,bark & gum	Riboflavin, haemorrhoids, tonic	T- 20
Melastoma nepalensis Lodd.	Builukhamnu	Melastomaceae	Fruit	Dysentery, constipation	S- 9
Meliosma pinnata (Roxb) Walp.	Buangthei	Sabiaceae	Leave	Vitamin A and C	S- 10
Michelia champaca Linn.	Ngaiuhnahhlai	Magnoliaceae	Flower & bark	Insect repellant, tonic, stomachic	T- 21
Mimosa pudica Linn.	Hlonuar	Mimosaceae	Root	Urinary complaints, pile	H- 14
Murraya koenigii (Linn.) Spreng.	Arpatil	Rutaceae	Leaves	Diarrhoea, dysentery, digestive	S- 11
Mussaenda glabra Vahl.	Vakep	Rubiaceae	Root & leaves	Snake bite, leucoderma	S- 12
Phyllanthus glaucus Wall.ex Muell-Arg	Saisiakte	Euphorbiaceae	Whole plant	Astringent, deobstruent, febrifuge.	S- 13
Physalis minima Linn.	Chalpangpuak	Solanaceae	Shoot	Urinary disorder, jaundice	H- 15
Plantago major Linn.	Kelbaan	Plantaginaceae	Leave & root	Fever, genito-urinary tract complaints	H- 16
Oroxylum indicum Vent.	Archangkawm	Bignoniaceae	Leave & root bark	Epilepsy, tonic and astringent.	T- 22
Psidium guajava Linn.	Kawlthei	Myrtaceae	Young leave & bark	Dysentery, anthelmintic,tonic	T- 23
Rhus succedanea Linn.	Chhimhruk	Anacardiaceae	Leave & fruit	Kidney and urinary complaints due to stones	T- 24
Rubus rugosus Sm.	Sailinuchhu	Rosaceae	Leave & fruit	Astringent, abortifacient	S- 14
Schima wallichii (DC.) Korthals.	Khiang	Theaceae	Bark	Expelling worm from intestine, gonorrhoea	T- 25
Scoparia dulcis Linn.	Perhpawngchaw	Scorphulariaceae	Whole plant	Emetic, antidiabetic, anaemia	H- 17
Solanum nigrum Linn.	Anhling	Solanaceae	Whole plant	Dysentery, pile, heart disease	H- 18
Solanum torvum Swartz	Tawkpui	Solanaceae	Fruit	Sedative, diuretic	S- 15
Spilanthes acmella Murr.	Ansapui	Compositae	Flower & root	Relieve toothache, mosquito larvicide, purgative	H- 19
Stephania rotunda Hoof. F. & Thoms	Chaihchun	Menispermaceae	Tuber	Intestinal complaints, asthma.	C- 1
Sterculia villosa Roxb.	Khaupui	Sterculiaceae	Gum	Antiseptic, veterinary medicine	T- 26
Toona ciliata M.Roem	Tuipui	Meliaceae	Leave & bark	Vomiting, chronic infantile dysentery	T- 27
Urena lobata Linn.	Sehnap	Malvaceae	Leave & root	Fever, cough, headache, diuretic	H- 20
Wendlandia tinctoria DC.	Batling	Rubiaceae	Bark	Cholera patients	T- 28

T- Tree, **S**- Shrub, **H**- Herb, **C**- Climber.

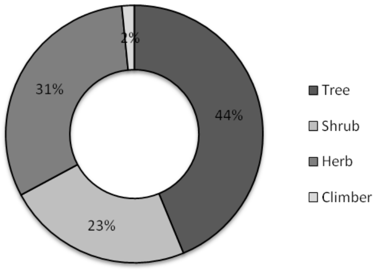

Figure 1. Habit wise distribution of plant species.

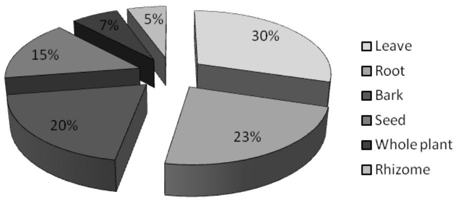

Figure 2. Plant parts used as herbal medicine.

muthu, 1998; Puspangadan & Atal, 1984) . The ethnomedicinal knowledge is normally transmitted from generation to generation and there are limited records on documentation of medicinal plants used in traditional system (Dhar *et al*. 1968; Sofowora, 1982). World Health Organization (WHO) has shown great interest in documenting medicinal plants used by tribal communities Worldwide (Kaido *et al*. 1997). Recently many developing countries have made significant efforts in documenting the ethnomedical data on medicinal plants and researches to find out scientific evidence for claim by tribal healers on Indian herbs have been intensified. Once these local ethnomedical preparations are scientifically evaluated and disseminated properly, people will be better informed regarding efficacious drug treatment and improved health status (Manandhar, 1987).

Further traditional herbal medicines are easily available and economically viable. Hence, there is an urgent need of detailed investigation and documentation of indigenous knowledge on medicinally important plant that inherent among local indigenous tribal community. Moreover, integrated approach involving Scientists, NGOs and indigenous community will be an effective strategy for the conservation and documentation of medicinal plants. To encourage local community towards traditional healthcare systems, there is ample scope of the credit should be given to the persons having such knowledge development of reward system will add a new dimension for protection of medicinal plant as well as restoration of land.

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References

Alam, M.I., Auddy, B. and Gomes, A. 1994. Isolation and partial characterization of viper venom inhibiting factor from the root extract of the Indian medicinal plant sarsaparilla (*Hemidesmus indicus* RBr). *Toxicon* 32:1551–1557.

Champion, H. and S.K. Seth. 1968. A revised survey of forest types of India. *Government of India* Press, Delhi.

Chatterjee, I., Chakravarty, A.K. and Gomesa, A. 2006. *Daboia russellii* and *Naja kaouthia* venom neutralization by lupeol acetate isolated from the root extract of Indian sarsaparilla *Hemidesmus indicus* RBr. *Journal of Ethnopharmacology* 106 (1):38-43.

Dev, S. 1997. Ethno-therapeutic and modern drug development: The potential of Ayurveda. *Current Science* 73(11): 909-928.

Dhar, M.L., Dhar, M.M., Dhawan, B.N., Mehrotra, B.N. and Ray, C. 1968. Screening of Indian plants for biological activity: Part I. *Indian Journal of Experimental Biolpgy* 7: 232-247.

Jain, S.K. and R.R. Rao 1977. *A Handbook of Field and Herbarium Methods*. Today and Tomorrow's Printers, New Delhi.

Kaido, T.L., Veale, D.J.H., Havlik, I and Rama, D.B.K. 1997. Preliminary screening of plants used in South Africa as traditional herbal remedies during pregnancy and labour. *Journal of Ethnopharmacology* 55:185-191.

Kamboj, V.P. 2000. Herbal medicine, *Current Science*, 78(1):35-39.

Kershaw, K.A. 1973. *Quantitative and Dynamic plants Ecology*, Edward Arnold Ltd, London.

Manandhar, N.P. 1987. Traditional medicinal plants used by tribals of Lamjung District, Nepal *Int J Crude Drug Research* 25 (4): 236-240.

Misra, R. 1968. *Ecology Work Book*, Oxford Publishing Company, Calcutta.

Mueller-Dombois, D. and H. Ellenberg 1974. *Aims and Methods of Vegetation Ecology*, John Willey and Sons, USA.

Perumal Samy, R. and Ignacimuthu, S. 1998. Screening of 34 Indian medicinal plants for antibacterial properties. *Journal of Ethno-pharmacology* 62:173-182.

Puspangadan, P. and Atal, C.K. 1984. Ethnomedico-botanical investigation in Kerala. Some primitive tribals of Western Ghats and their herbal medicine. *Journal of Ethnopharmacology* 11:59-77.

Sinha, S.C. 1996. *Medicinal Plants of Manipur*. Manipur Assocaition for *Science* & Society, Manipur Cultural Integration Conference, Palace Compound, Imphal.

Sofowora 1982. *A Medicinal Plants and Traditional Medicine in Africa*. Wiley and Sons, Chichester, 75-76.

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Changes in phytosociological attributes and plant species diversity in secondary successional forests following stone mining in Aizawl district of Mizoram, India

Sh. Bidyasagar Singh, B.P. Mishra[1*] and S.K. Tripathi
Department of Forestry, Mizoram University, Aizawl – 796004, Mizoram
[1]Department of Environmental Science, Mizoram University, Aizawl – 796004, Mizoram

ABSTRACT

Habitat degradation is one of the major factors responsible for many changes plant community attributes and finally resulted in decrease in plant diversity. After the removal of causal factor (e.g. stone mining) for degradation, the community starts to rebound its original state during the course of time that varies from the site to site depending on the factors responsible for the recovery. Thus, it is important to understand the pattern of rehabilitation of disturbed ecosystems and to speed up the process to conserve the plant species diversity to maintain land productivity at ecosystem scale. The present ecological study was carried out in the forests situated in unmined area (undisturbed), and stone mining affected area (disturbed), and to assess impact of stone mining on vegetation composition, plant community attributes and plant diversity. The findings of the study depicts that there was shift in position of a species and family from undisturbed to disturbed forests. Moreover, tree species were replaced by shrubs and herbs in the disturbed stand. Reduced vegetation in degraded land use due to stone mining was mainly due to removal of top soil that contains soil seed bank. The important tree species were *Schima wallichii, Sterculia villosa, Callicarpa arborea, Emblica officinalis, Albizzia chinensis, Castonopsis tribuloide, Rhus succedanea, Toona ciliatea, Wendlandia tinctoria* in stone mining area, whereas, *Schima wallichii, Callicarpa arborea, Castonopsis tribuloide, Emblica officinalis, Antidesma diandrum, Wendlandia peniculata, Sterculia villosa* in unmined area.

Keywords: Biodiversity, disturbance, microclimate, plant community attribute, and stone mining.

Biodiversity is the product of billion years of evolutionary development on the Earth, which is mainly concentrated in the natural ecosystems with a mosaic formation of communities and ecosystems (WCMC, 1992). During last few decades, biodiversity issues related to conservation and restoration are the important concerns of research throughout the world because of rapid loss of biological resources and immense significance in human life. Recently, Sala *et al*. (2000) have identified major drivers of biodiversity change of the World in the 21st century in decreasing order of their importance as landuse change, climate change, nitrogen deposition, increase in atmospheric CO_2 concentration and biotic exchange. The authors have also emphasized that the order of importance of these drivers changes with respect to the ecosystem and biome. Tremendous increase in the human population may lead to change in the landuse pattern as a result of greater resource exploitation that may lead to further loss in biodiversity at an alarming rate. Thus, to conserve the biodiversity over the world, important conservation efforts are being made, for example, identification of biodiversity hotspots based on the number of endemic species and the degree of threat to biodiversity in a region (Myers *et al*. 2000). As result of this, 34 biodiversity hotspots have been identified throughout the world, of which 4 occurs in

Author for correspondence
B.P. Mishra
Email: mishrabp111@yahoo.com

India namely, Western Himalaya, Western Ghats, Indo-Burma and small part of Sunderland covered by Nicobar Island.

India is one of the mega biodiversity countries and supports enormous biological wealth, along with its huge population, encompassing a wide spectrum of habitats from tropical rainforests to alpine vegetation. The country is known for the unique floral and faunal heritage with varying climatic and topographic realms of the country that causes backbone of the biodiversity richness. Quantitatively about 30% flora and fauna found in the country's hotspots region are endemic in nature and northeast India showing very high endemism due to rainfall though out the year and favorable edapho climatic conditions, supporting a variety of vegetation that However, the complete biodiversity estimation of the region is still incomplete because of the problems related to extensive field investigation and availability of expertise for plant identification. In some areas of the country work on biodiversity inventory has been carried out at desired pace and few diversity indices have been calculated mainly based on the number of species and proportion of individuals of a species in an ecosystem. Some recent studies are reflecting a gap between the existing indices of diversity (Simpson, 1949; Shannon & Weaver, 1963; Rao, 1982) and the newer notions of biological diversity (Chapin III *et al.* 2000; Tilman, 2001; Norberg *et al.* 2001; Roy *et al.* 2004). However, this needs a holistic and integrated approach of biodiversity that is to be planned for future investigation.

Over a period of time, due to use and abuse of forests and also with wrong or in appropriate property rights and institutional arrangements, majority of forests are facing different degree of distribution leading to loss of biodiversity, and thereby decreasing their ability to fulfill human needs. In north-east India shifting cultivation is a major cause of forest degradation and biodiversity loss followed by the practice namely stone mining which is prevalent in the state of Mizoram. The anthropogenic disturbances play an important role in changes, loss or maintenance of plant diversity of the region. Trees are lopped for fuel wood and timber for house construction, building and industrial raw material. Various other factors produce like removal of forest floor biomass, over exploitation of edible plants and medicinal plant cause massive loss of biodiversity. The anthropogenic disturbances not only influence the soil, nutrient and water conditions but also alter climatic conditions. Therefore, conservation and management of forest biodiversity is mainly aimed for sustainability leading to improvement of soil nutrient condition and moisture content. On the account of the above fact, the present study was carried out that deals with the change in the various aspects of plant species diversity in numerical forms in secondary successional forests following the stone mining in Aizawl district of Mizoram.

Materials and Methods

Study site and the climate

The study was conducted within the campus of the Mizoram University which is located in the Tanhril area of the Aizawl (21°56'-24°31' N lat and 92°16'-93°26' E long). For detailed ecological investigation two sites - one pure stand of forest where no stone mining activity was done in the past that is referred to as undisturbed forest stand or unmined site, and the other site where the stone mining activity was done recently (about 4 years back) which is referred to as disturbed stand where the forest vegetation develops naturally on abandoned land following the stone mining. Detailed description of the forest vegetation of the region was reported by Champion & Seth (1968). The climate of the area is typically monsoonic with three distinct seasons namely rainy, winter and summer seasons. The wet-humid rainy season is long for about 6 months (i.e. from April to September) followed by 3 months cool-dry winter season (i.e. from November to January) and a short hot-dry summer season (spring) that persists for about two months (i.e from February-March). October is a transition month between rainy and winter season. The annual average rainfall is amounting to 1694 mm, of which rainy season receives about 90% that is almost evenly distributed from April to September (2009). During rainy season, heavy storms come from the north-west sweep over the hills in the entire state. Mean minimum and maximum temperature varies between 12^{o}C in winter and 30^{o}C in summer. There is very limited rainfall during the winter months.

Vegetation analysis

To determine floristic diversity in the selected sites, random quadrats of different sizes were laid. For sampling trees 40 quadrats of 10 × 10 m size were placed on the forest floor and all the trees with ≥15 cm girth at breast height (GBH at 1.3 m above ground) were recorded. Shrubs were enumerated in two plots of 5 × 5 m size laid diagonally inside 10 x 10 m quadrats used for trees. Herbs were recorded in each shrub plot using quadrats of size 1 × 1 m laid diagonally in the same way as in case of shrubs. All the plant species occurred in the quadrats were brought to the laboratory for herbaria. The species were identified with the help of herbarium of the BSI, Eastern circle, Shillong and counter checked with the help of Flora of Assam (Kanjilal *et al.* 1934-40), Flora of Meghalaya (Haridasan & Rao, 1985-1987), and other regional and local floras. The field data on vegetation was quantitatively analyzed for density, frequency and abundance as proposed by Curtis & Mclntosh (1950). The Importance value index (IVI) was determined as the sum total of relative values of density, frequency and dominance as per Philips (1959). Species diversity and dominance indices were determined following the methods as outlined in Misra (1968); Mueller-Dombois & Ellenberg (1974).

Calculations of species diversity

The species diversity was calculated adopting Shannon–Wiener index based on the information theory proposed by Shannon and Weaver (1963) by using the following formula:

$$H' = \sum_{i=1}^{s} (pi \ln pi)$$

where p_i is the proportion of the total sample belonging to the *i* th species, $1 \le i \le s$.

The concentration of dominance was calculated (Simpson, 1949) with the help of following formula:

$$CD = \sum (pi)^2$$

Where p_i is the proportion of the total sample belonging to the *i* th species.

Margalef's index of species richness index (Margalef's, 1958):

$$D_{mg} = \frac{S - 1}{In\ (N)}$$

Where, S = Number of species, N= Number of the individuals.

Pielou's Evenness index (Pielou, 1966):

The equation is given as follows:

$$E = \frac{H'}{H'max}$$

Where, H' = Shannon's index value, H'max = InS, S = Total number of species.

Sorensen Similarity index (Sorensen, 1949):

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

Where, C = Species common in both the stands.
A= Species present in stand A.
B= Species present in stand B.

Results and Discussion

The finding of the present study revealed that there was a marked variation in the canopy cover, light interception and tree density between undisturbed and disturbed forest stands (Table 1). Marked difference in the above mentioned parameters due to reduced values in disturbed stand has been reported as accelerated rate of vegetation degradation in the disturbed stand (Mishra *et al.* 2004). The floristic composition of the present study showed that a total of 70 species belonging to 39 families of angiosperms were recorded in the undisturbed stand, however, 51 species belonging to 33 families in the disturbed stand. Margelef's species richness index was very high in the undisturbed stand 29.8, however, it decreased to 11.8 in the disturbed stand. The total tree basal area and density in the disturbed stand were 19.1 % and 36.1% of undisturbed stand, respectively (Table 1 & 2). This depicted that the prevailing condition at disturbed site is not supporting proper growth and survival of the individuals for attaining tree stage. The findings of the present study are in conformity with the work (Mishra *et al.* 2003; 2004; 2005). The Shannon diversity index was higher in undisturbed stand (2.9) than the disturbed stand (2.1). On the contrary, the Simpson index of dominance was higher in the disturbed stand. The evenness index exhibited a similar trend as Shannon diversity index.

Table 1. Canopy cover, light interception and tree density in the undisturbed and disturbed forest stands.

Parameter	Forest stands	
	Undisturbed stand	Disturbed stand
Canopy (%)	>40	<40
Light interception (%)	>50	<50
Tree density (ind. ha^{-1}	885	323

Schima wallichii was the dominant tree species in both the stands, however, there was shift in position co-dominant species *Callicarpa arborea* was replaced by *Sterculia villosa* in the disturbed stand. The family dominance was also changed from undisturbed to disturbed stand. In stone mine affected area (disturbed stand) Compositae (5 species) was the most speciose and dominant family followed by Mimosaceae and papilionaceae (4 species each). On other hand, Euphorbiaceae was the most dominant family (7 species) in the undisturbed stand followed by Compositae (5 species) and Fagaceae (3 species). The dominant growth form in the community also varied from undisturbed to the disturbed stand. The tree species were the dominant form of vegetation in undisturbed stand whereas, in the disturbed stand herbs and shrubs were the dominant form of vegetation. This followed a normal successional pattern that the herbs and shrubs are occupying the open space followed by the trees which then suppresses the species during the course of development. A similar trend in result was reported by Mishra *et al.* (2004).

Table 2. Plant diversity and phytosociological attribute in the undisturbed and in disturbed forest stands.

Parameter	Undisturbed stand	Disturbed stand
Number of family (T,S,H,C)	39	33
Number of genera (T,S,H,C)	59	49
Number of species (T,S,H,C)	70	51
Tree basal area (m^2ha^{-1})	20.82	3.78
Shannon diversity index	2.9	2.1
Simpson dominance index	0.11	0.2
Margalef's index (Species richness index) of trees	29. 82	11.79
Evenness index	0.6	0.6

T= Tree, S= Shrub, H= Herb, C= Climber.

The shift in position of the species and family from undisturbed to disturbed stand was reported to be linked with the levels of anthropogenic disturbance (Mishra *et al*. 2004; 2005; Mishra & Laloo, 2006). The species tolerant to the stress was showing better growth and survival and as a result expressing greater IVI in the disturbed stand. On the contrary, the species sensitive to the disturbance either eliminated or showing poor growth and resulting into low value of IVI.

Table 3. Importance value index (IVI) and tree density (individual ha^{-1}) in the undisturbed and disturbed stands.

	Undisturbed forest		Disturbed forest	
Species	Density	IVI	Density	IVI
Albizzia chinensis (Osb.) Merr.	-	-	17	15.6
Albizzia lebbeck L Benth	10	3.6	-	-
Albizzia procera (Roxb.) Benth.	13	5.2	3	2.8
Antidesma diandrum Roxb.	25	9.5	-	-
Artocarpus heterophyllus Lamk.	3	1.3	-	-
Brassiopsis hainla Seem.	17	5.7	-	-
Bridelia spp. Bt.	30	9.5	-	-
Callicarpa arboria Roxb.	57	20.8	28	26.9
Cassia fistula Linn.	8	2.9	-	-
Castanopsis Hystrix DC.	37	13.7	-	-
Castanopsis tribuloides DC.	53	20.4	25	22.6
Crotalaria humifusa Gareton.	20	5.7	-	-
Debregeasia velutina Gaud.	12	4.9	-	-
Emblica officinalis Gaertn.	33	10.6	23	18.9
Erythrina stricta Roxb.	15	6.3	-	-
Eugenia macrocarpa Roxb.	22	7.2	-	-
Glochidion helfari Hk.f.	25	8.5	-	-
Lagerstroemia parviflora Roxb.	3	1.2	5	6.2
Litsea citrata Bl.	27	8.9	-	-
Meliosma pinnata Roxb.	23	7.6	-	-
Micromelum integerrimum Roxb.	10	3.9	-	-
Murraya koenigii (L.) Spreng.	12	3.9	-	-
Phoebe cooperiana U.N. Kanjilal	20	7.2	-	-
Quercus semiserrata Roxb.	12	4.8	-	-
Rhus succedanea Linn.	23	9.1	15	13.5
Schima wallichi (DC.) Korthals.	265	79.3	103	93.6
Sterculia villosa Roxb. ex Smith	50	17.1	57	49.4
Tapiria hirsuta Hk.f	15	6.4	-	-
Terminalia arjuna Roxb.ex DC.	3	1.6	-	-
Toona ciliata M. Roemer	-	-	10	13.5
Turpinia nepalensis Wall.	12	3.6	-	-
Wendlandia peniculata DC.	30	9.6	17	16.5
Wendlandia tinctoria (Roxb.) DC.	-	-	20	20.5
	885		323	

-, Absent.

This result was in conformity with work of Mishra *et al.* (2003; 2004). Thorington *et al.* (1982); Parthsarathy & Sethi, (1997) have also reported a similar result. Girth class distribution indicated reduced number of individuals in higher girth classes and girth size was shortened under the disturbed condition. This could be linked with poor nutrient status of soil because of extensive mining operation in the past, leading to retarded growth (Mishra *et al.* 2004). The tree species common in undisturbed and disturbed stand namely *Schima wallichi*, *Emblica officinalis*, *Callicarpa arboria*, *Albizia procera*, *Albizia chinensis and Castanopsis tribuloide* showing

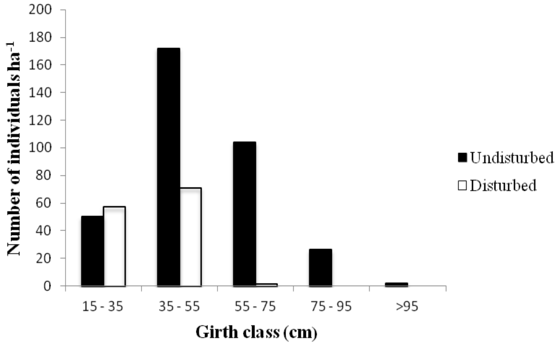

Figure 1. Girth class distribution of trees in the undisturbed and disturbed stands.

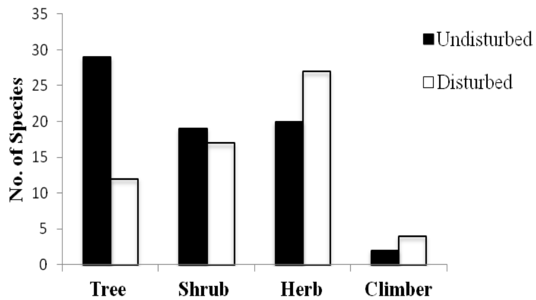

Figure 2. Plant habits in the undisturbed and disturbed stands.

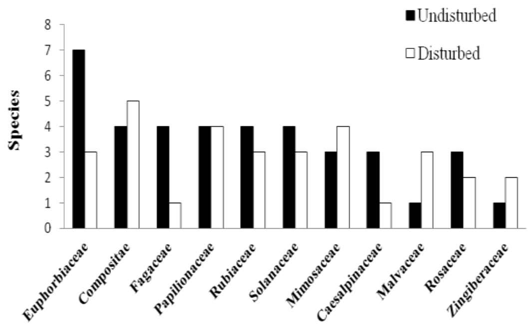

Figure 3. Dominance distributions of families in the undisturbed and disturbed stands

greater ecological amplitude with respect to disturbance. These species appears to quickly rebound during the course of development of stand after the stone mining and maintained their existence after forest developed to maturity because of their strong competitive ability. Species namely *Wendlandia tinctoria, Toona ciliate, Albizzia chinensis* are restricted to the disturbed stand indicating that such species are either shade intolerant species or cannot complete with the primary tree species growing in undisturbed condition. The tree species namely *Albizzia lebbeck, Antidesma diandrum, Artocarpus heterophyllus, Brassipsis hainla, Cassia fistula, Castanopsis hystrix, Erythrina stricta, Eugenia macrocarpa, Glochidion helfari, Meliosma pinnata, Micromelum integerrimum, Murraya koenigii, Phoebe cooperiana, Quercus semiserrata, Tapiria hirsuta, Terminalia arjuna* were absent in disturbed stand. Thus, these species are categorized as the species vulnerable to disturbance stone mining in this region. This indicates that such species are appearing in the early stages of the development after the stone mining and performed growth in a particular set environmental conditions but could not compete well with the other successional species for the resource utilization and getting disappear during the course of time. The similarity index computed for tree was accounted as 33.1, indicating accelerated loss of tree diversity due mining operation.

The findings of the present study depicts that there is an ample scope of extensive ecological study along disturbance gradient selecting stone mining areas of different ages to ascertain changes in vegetation composition, community attributes and diversity of plants. In addition to this, study on natural regeneration status and regeneration behavior may provide a needful dimension toward developing appropriate strategy for biodiversity conservation.

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References
Champion, H. and Seth, S.K. 1968. *A revised survey of forest types of India*. Government of India Press, New Delhi.

Chapin III, F.S., Zaualeta, E.S., Eviner, V.T., Naylor, R.L., Vitousek, P.M.,Reynolds, H.L., Hooper, D.V., Lavorel, S.,Sala, O.E., Hobbie, S.E., Mack, M.C. and

Diaz, S. 2000. Consequences of changing biodiversity. *Nature* 405: 234-242

Curtis, J.T. and R.P. McIntosh 1950. The interrelations of certain analytic and Synthetic phytosociological characters. Ecology 31: 434-455.

Haridasan, K. and Rao, P.R. 1985-1987. Forest Flora of Meghalaya. Vol. 1 & 2. ((Bishen Singh Mahendra Pal Singh, Dehra Dun).

Kanjilal, U.N., P.C. Kanjilal, A. Das, R.N. De and N.L. Bor. 1934-40. Flora of Assam. 5 vols., Government Press, Shillong.

Margalef, R. 1958. *Information theory in Ecology*. General systems 3:36-71.

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

Mishra, B.P., O.P. Tripathi and R. C. Laloo 2005. Community characteristics of a climax subtropical humid forest of Meghalaya and population structure of ten important tree species. *Tropical Ecology* 46(2): 239-249.

Mishra, B.P., O.P. Tripathi, R.S. Tripathi and H.N. Pandey 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.

Mishra, B.P., R.S. Tripathi, O.P. Tripathi and H.N. Pandey 2003. Effect of disturbance on the regeneration of four dominant and economically important woody species in a broad-leaved subtropical humid forest of Meghalaya, northeast India. *Current Science* 84(11): 1449-1453.

Misra, R. 1968. Ecology, *Work Book*, Oxford Publishing Company, Calcutta.

Mueller-Dombois, D. and H. Ellenberg 1974. Aims and Methods of vegetation Ecology. John Wiley and Sons, USA.

Myers, N., Mittermiler, R.A., Mittermiler, C.G., Gustava, A.B., Da. Foseca, and Kent, J. 2000. Biodiversity hotspots for conservation priorities. *Nature* 403, 853 – 858.

Norberg, J., Swaney, D.P., Dushoff, J., Lin, J., Casagrandi, R. and Levin, S.A. 2001. Phenotopic diversity and ecosystem functioning in changing environments; a theoretical framework. PNAS 98 (20): 11376-11381.

Parthasarathy, N. and P. Sethi 1997. Tree and liana species diversity and population structure in a tropical dry evergreen forest in South India. *Tropical Ecology* 38: 19-30.

Philips, E.A. 1959. Methods of Vegetation study. Henry Holt and Co., London. pp.105.

Pielou, E.C. 1966. The measurement of diversity in different types of biological collections. *Journal of Theoretical Biology* 13: 131- 141.

Rao, C.R. 1982. Diversity and dissimilarity coefficients: a unified approach. *Theoretical Population Biology* 21: 24-43.

Roy, A., Tripathi, S.K., and Basu, S.K. 2004. Formulating diversity vector for ecosystem comparison. *Ecological Modelling* 179: 499-513.

Sala, O.E., Chapin III, F.S., Armesto, J.J., Berlow, E., Bloomfield, J., Dirzo, R., Huber-sanwald, E., Hunneke, L.F., Jackson, R.B., Kinzig, A., Leemans, R., Lodge, D.M., Mooney, H.A., Oesterheld, M., Poff, N.L., Sykes, M.T., Walker, B.H., Walker, M. and Wall, D.H. 2000. Global biodiversity scenario for the year 2100. *Science* 287: 1770-1774.

Shannon, C.E. and Weaver, W. 1963. *The mathematical theory of communication.* Urbana, University of Illinois Press. pp 1-117.

Simpson, E.H. 1949. Measurement of diversity. *Nature* 163: 688.

Sørensen, T. 1949. A method of establishing group of equal amplitude in plant sociology based on similarity of species content. Det Kong Danske Videnskabernes Selskab Biologiske Skrifter (Copenhagen) 5: 1-34.

Thorington R.W. Jr., Tannenbaum B., Tarak A. and Rudran R. 1982. Distribution of trees in Barro Colorado Island: a five hectare sample. In: Leigh E.G Jr., Rand A. S. and Windsor D. M. (eds). *The Ecology of a Tropical Forest-seasonal Rythms and Long Term Changes.* Smithsonian Tropical Research Institute, Washington, D.C. pp 83-94.

Tilman, D. 2001. An evolutionary approach to ecosystem functioning in changing environments: *a theoretical framework.* PNAS 98(20): 11376-11381.

World Conservation Monitoring Centre (WCMC) 1992. Global biodiversity: Status of the Earth's Living Resources. Chapman & Hall, London.