**Chapter – 1**

# INTRODUCTION

## 1.1. Biodiversity – Concepts and Definition

The term ‘‘biodiversity’’ was first used in its long version (biological diversity) by Lovejoy (1980) and is most commonly used to describe the number of species (Swingland, 2001). The latter usage appears to have come into prominence around 1980, when Norse and Mc Manus (1980) first defined it. Its abbreviation into ‘biodiversity’ was apparently made by Walter G. Rosen in 1985 during the first planning meeting of the ‘National Forum on Biodiversity’ held at Washington D.C. in September 1986 (UNEP, 1995). The published proceedings of this meeting in a book entitled *Biodiversity* (Wilson and Peters, 1988) introduced the notion of biodiversity and popularized this word among the scientific community as well as the public. Since then, not only the numbers of publications on biodiversity, but also of people interested in the subject for one reason or the other has steadily increased (Harper and Hawksworth, 1994). The United Nations Conference on Environment and Development (UNCED) held in 1992 at Rio de Janeiro (Rio Summit or Earth Summit) has also substantially elevated the status of Biodiversity (Krishnamurthy, 2004).

According to UN Convention on Biological Diversity, 1992- Article 2, Biodiversity (or biological diversity) means the variability among living organisms from all sources including, *inter alia,* terrestrial, marine, and other aquatic ecosystems, and the ecological complexes of which they are a part; this includes diversity within species, between species and ecosystems (Agrawal, 2002). The India’s Biological Diversity Act 2002 defined it as, “the variability among living organisms

from all sources and the ecological complexes of which they are part and includes diversity within species or between species and of ecosystems" (BDA, 2002).

Delong (1996) has defined biodiversity as "an attribute of an area and specially refers to the variety within and among living organisms, assemblages of living organisms, biotic communities, and biotic processes, whether naturally occurring or modified by humans. Biodiversity can be measured in terms of gene, and the identity and the number of different types of species, assemblages of species, biotic communities, and biotic processes, and the amount of (*e.g.*, abundance, biomass, cover, and rate) and structure of each. It can be observed and measured at any spatial scale ranging from micro sites and habitat patches to the entire biosphere.

Biodiversity is generally considered an 'umbrella term' referring to organisms found within the living world, ***i.e.,*** the number, variety and variability of living organisms. It may thus be assumed to be a synonym for 'Life on Earth', variety of life and its processes' (Keystone Center, 1991), 'condition of being different' (Gove *et al.,* 1996), or what Darwin exclaimed as 'Life endless forms'. Taken in this general sense, biodiversity is indeed 'the essence of life' (Frankel, 1970). In reality, however, biodiversity is a very vast and complex concept and its ramifications extend deep into all spheres of human life and activity (Krishnamurthy, 2004).

In technical parlance biodiversity is the variety and variability of life on the earth. It includes diversity of forms right from the molecular unit to the individual organism, and then on to the population, community, ecosystem, landscape and biosphere levels. *In the simplest sense, biodiversity may be defined as the sum total of species richness,* ***i.e.,*** *the number of species of plants, animals*

*and microorganisms occurring in a given region, country, continent or the entire globe* (Agrawal, 2002).

Diversity addresses two distinct aspects ***i.e.,*** species richness and evenness. Richness refers to the number of species per unit area, and evenness refers to their abundance, dominance, or spatial distribution. The focus of biodiversity measurement is typically the species, because they are easily observed and mostly used in the studies of forest ecosystems (Barnes *et al.*, 1998).

The word Biodiversity is now very widely used not only by the scientific community, but also the general public, environmental groups, conservationists, industrialists and economists. It has also gained a very high profile in the national and international political arena (Krishnamurthy, 2004).

## 1.2. Types of Biodiversity

Various authors have proposed specific and detailed elaborations of biodiversity. Gaston and Spicer (1998) proposed a three-fold definition of "biodiversity"— ecological diversity, genetic diversity, and organismal diversity— while others documented as genetic diversity, species or taxonomic diversity and ecosystem diversity (Mc Allister, 1991, Solbrig, 1991, Groombridge, 1992, Heywood, 1994). Others conjoined the genetic and organismal components, leaving genetic diversity and ecological diversity as the principal components. These latter two elements can be linked to the two major ''practical'' value systems of direct use/genetics and indirect use/ecological described by Gaston and Spicer (1998). In the context of conservation strategies, Soule (1991) distinguishes five divisions: genes;

populations; species; assemblages (associations and communities) and whole system at the landscape or ecosystem level. Laverty *et al.* (2008) describe it based on a nested hierarchy, beginning at the subcellular scale and ending at the continental level. The smallest level of this hierarchy refers to the diversity of genes that can be found in individual cells. *Genetic* diversity is sometimes called the "fundamental currency of diversity," as ultimately it is responsible for the variation among individuals, populations, and species. The next level of the hierarchy is the *species* level: this is the level of the biodiversity hierarchy that most conservation legislation targets, where most conservation organizations focus their efforts, and what most people think of when they think of biodiversity. The interactions between the individual organisms that make up a *population* (competition, cooperation, etc.), and their specializations for their environment (including ways in which they might modify the environment itself) are important aspects of the next levels of the biodiversity hierarchy. Interactions between different species (**e.g.,** predator-prey relationships) and their environments form the next level of the hierarchy, focusing on *community* and *ecosystem* biodiversity. The largest scales of the biodiversity hierarchy are *landscapes* and *ecoregions*. However, Harper and Hawksworth (1994) favour the terms referred as genetic, organismal and ecological diversity. Another classification distinguishes three interdependent sets of attributes: compositional levels (the identity and variety of elements) and structural levels (ecological and evolutionary processes) (Noss, 1990).

Broadly speaking, the term biodiversity includes four different but closely related aspects:

*Genetic Diversity (Diversity within species):* It refers to the variation of genes within species. This constitutes distinct population of the same species or genetic

variation within population or varieties within a species (Agrawal, 2002). Genetic diversity, at its most elementary level, is represented by differences in the sequences of four nucleotides (adenine, cytosine, guanine, and thymine), which form the DNA within the chromosomes in the cells of organisms. Some cells have specific organelles that contain chromosomes (for example, mitochondria and chloroplasts have their own chromosomes, which are separate from a cell's nuclear chromosomes). Nucleotide variation is measured for discrete sections of chromosomes, called "genes." Each gene comprises a hereditary section of DNA that occupies a specific place on the chromosome, and controls a particular characteristic of an organism. DNA provides the instructions to create proteins and in turn all other parts of a cell (Laverty *et al.*, 2008).

In the living organisms where sexual reproduction takes place, a set of chromosomes each from the two parents is passed on to the offspring during the process of fertilization thus, the genetic differences from the two individuals (parents) are combined to form new combinations, as a result the new individuals with changed characters are formed adding to the diversity of the living world. The 'fine scale' level of biodiversity is measured in the variety of expressed genes or characters among organisms (Williams and Humphires, 1996). Genetic diversity is clearly an important component of biodiversity (Gaston, 1996; Mallet, 1996) as it provides *phenotypic* character which is an important measure of the organism for adaptation to changing environments and for the evolution of new life forms because it is these phenotypic characters that interact with the living and nonliving parts of the environment. Phenotypic diversity between individuals, populations, and species is usually described in terms of the variation in the external morphology or the outward

appearance of individuals. Variations in physiological and biochemical characteristics of the organism are also important indicators of phenotypic diversity. Behavioral characteristics represent the way in which an organism interacts with its environment, and are a product of the genes, which specify particular anatomical, physiological, or biochemical traits that might be adaptations for the environment. Genetic diversity exists:

- within a single individual,
- between different individuals of a single population,
- between different populations of a single species (population diversity), and
- between different species (species diversity) (Laverty *et al.*, 2008).

*Species diversity (Diversity between species):* Species diversity is one of the most fundamental aspects of biodiversity. It refers to the diversity between species within a region. Such biodiversity is most commonly measured at the species level. It can be defined as a group of inter-breeding or potentially inter breeding natural populations that are reproductively isolated from other such groups. It is also referred to as Taxonomic or Organismal Diversity (Agrawal, 2002).

There are three concepts which define species- The *morphological species concept* is the oldest of the approaches and also the most readily understandable. According to this concept, individuals that look alike and share the same identifying traits belong to the same species; the *biological species concept*, defines species as a group that interbreeds and is isolated from other groups. Basically, two individuals are the same species if they can breed and produce viable offspring—

that is offspring that can also breed; the *phylogenetic species concept*, a species is a group of individual organisms that share a common ancestor; and an "*evolutionary significant unit*" (ESU) is defined as a group of organisms that has undergone significant genetic divergence from other groups of the same species. Identifying ESUs requires natural history information, range and distribution data, and a suite of genetic analyses. This approach is more complex to apply than the morphological approach, and recognizes more species than the biological species concept. However, it is particularly helpful for testing scientific hypotheses (Laverty *et al.*, 2008).

Species diversity encompasses both species richness and evenness- the former deals with the number of different species in a particular area while the latter deals with the relative abundance of individuals within different species in the same area. The aspects of species diversity measurement can be classified into three groups: Species richness, species abundance and taxonomic or phylogenetic diversity (Magurran, 1988). The measures of species richness count the number of species in a defined area, while species abundance measures the sample of the relative numbers among species. A typical sample may contain several common species, a few less common species and numerous rare species. In effect, the measures of species diversity simplify information on species richness and relative abundance into a single index (Magurran, 1988; Spellerberg, 2008).

The relative abundance of species in various taxonomic groups like micro organisms, cryptogams, angiosperms etc. is only understood by taxic diversity. For example- habitats with equal species diversity (number of species) may not have the same taxic diversity (WRI, IUCN, UNEP, 1992).

Species diversity is the building block for the diversity of higher taxa and for the diversity of ecological associations such as communities and biomes (Kiester, 2001).

*Ecosystem diversity:* An *ecosystem* is a *community plus the physical environment* that it occupies at a given time (Laverty *et al.,* 2008). The ecosystem is the first unit in the molecule to ecosphere hierarchy that is complete, that is, it has all the components, biological and physical, necessary for survival. Accordingly, it is the basic unit around which to organize both theory and practice in ecology (*Encyclopedia of Biodiversity*, 2001). Ecosystems are the largest units generally considered in biodiversity, comprising some amalgam habitats, the species within them and importantly the processes occurring within and between the biotic and abiotic components (Wilcove and Blair, 1995; Christensen *et al.,* 1996; Noss, 1996). An ecosystem can exist at any scale, for example, from the size of a small tide pool up to the size of the entire biosphere (Laverty *et al.,* 2008). Thus, ecosystem can be defined as a square meter of grassland or of a forest, the edge of a pond, a tide pool, or any large area of nature that has living organisms and non-living substances interacting and exchanging between them. The ecosystem may be:

(a) Aquatic ecosystem – (i) Fresh water ecosystem and (ii) Marine ecosystem.

(b) Terrestrial ecosystem – Forest ecosystem (ii) Desert ecosystem (iii) man-made ecosystem.

Ecosystem refers to all the individuals, species, and populations in a spatially defined area, the interactions among them and those between them and the

abiotic environment (Likens, 1993). Ecosystem diversity encompasses the broad differences between ecosystem types, and the diversity of habitats and ecological processes occurring within each ecosystem type (Nagar, 2005). While it is possible to define what is in principle meant by genetic and species diversity, it is difficult to make a quantitative assessment of diversity at the ecosystem, habitat, or community level. There is no unique definition or classification of ecosystems at the global level, and it is difficult in practice to assess ecosystem diversity other than on a local or regional basis, and then only largely in terms of vegetation. Ecosystems are further divorced from genes and species in that they explicitly include abiotic components, being partly determined by soil/parent material and climate (*Encyclopedia of Biodiversity*, 2001). Ecosystems may be classified according to the dominant type of environment, or dominant type of species present; for example, a salt marsh ecosystem, a rocky shore intertidal ecosystem, a mangrove swamp ecosystem. Because temperature is an important aspect in shaping ecosystem diversity, it is also used in ecosystem classification (**e.g.,** cold winter deserts, versus warm deserts) (Udvardy, 1975).

Broadly speaking, the diversity of an ecosystem is dependent on the physical characteristics of the environment, the diversity of species present, and the interactions that the species have with each other and with the environment. Therefore, the functional complexity of an ecosystem can be expected to increase with the number and taxonomic diversity of the species present, and the vertical and horizontal complexity of the physical environment. However, one should note that some ecosystems (such as submarine black smokers, or hot springs) that do not appear to be physically complex, and that are not especially rich in species, may be considered to

be functional complex. This is because they include species that have remarkable biochemical specializations for surviving in the harsh environment and obtaining their energy from inorganic chemical sources (Rothschild and Mancinelli, 2001). While the physical characteristics of an area will significantly influence the diversity of the species within a community, the organisms can also modify the physical characteristics of the ecosystem (Butler, 1995).

The physical characteristics of an environment that affect ecosystem diversity are themselves quite complex. These characteristics include, for example, the temperature, precipitation, and topography of the ecosystem. There is a general trend for warm and moist tropical ecosystems to be richer in species than cold temperate ecosystems. Also, the energy flux in the environment significantly affects the ecosystem. An exposed coastline with high wave energy will have a considerably different type of ecosystem than a low-energy environment such as a sheltered salt marsh. Similarly, an exposed hilltop or mountainside is likely to have stunted vegetation and low species diversity compared to more prolific vegetation and high species, diversity found in sheltered valleys (Laverty *et al.,* 2008).

Ecosystem diversity is generally evaluated through measuring the diversity of the component species which may involve assessment of the relative abundance of different species as well as the types of species.

*Landscape (or regional) Diversity:* A *landscape* is made up of a collection of common land forms, vegetation types, and land uses. Therefore, *assemblages of different ecosystems* (the physical environments and the species that inhabit them, including humans) create *landscapes* on Earth (Laverty *et al.,* 2008). It involves more

than just the kinds of communities and species — it depends on the spatial arrangement of habitats across a large area and on the fluxes of energy, nutrients, disturbances, and organisms across the area (Agrawal, 2002). It is also defined as ‘a mosaic of heterogeneous land forms, vegetation types and land uses’ (Urban *et al.*, 1987).

Although there is no standard definition of the size of a landscape, they are usually on the order of hundreds or thousands of square kilometers (tens or hundreds of square miles, or tens to hundreds of thousand acres). The landscape level of biodiversity is a relatively new horizon for scientific research due to technological innovations in analyzing satellite images and geographic information systems (GIS) software. The study of landscapes is often closely tied to land use planning and human use of land (Laverty *et al.,* 2008). Species composition and population viability are often affected by the structure of the landscape; for example, the size, shape, and connectivity of individual patches of ecosystems within the landscape (Noss, 1990). Conservation management should be directed at whole landscapes to ensure the survival of species that range widely across different ecosystems (**e.g.,** jaguars, quetzals, species of plants that have widely dispersed pollen and seeds) (Hunter, 2002).

Diversity within and between landscapes depends on local and regional variations in environmental conditions, as well as the species supported by those environments. Landscape diversity is often incorporated into descriptions "ecoregions," (Laverty *et al.*, 2008).

## 1.3. Diversity at different scales

Whittaker (1972) created a system to describe biodiversity over different spatial scales. He recognized four levels of inventory diversity and three levels of differentiation diversity which are as follows:

*Inventory Diversity*: Inventory diversity, in other words the diversity of defined geographic unit, can be measured at different levels of resolution. Under this scheme-

(i). Point diversity : It is the diversity of a single sample

(ii). α (alpha) diversity : Alpha diversity refers to the diversity within a particular area or ecosystem, and it is usually expressed by the number of species in that ecosystem. This is equivalent to measuring the species richness of an area.

(iii). γ (gamma) diversity : Gamma diversity represents the diversity of a large units such as landscape or island.

(iv). ε (epsilon) diversity : It is the diversity of a biogeographic province.

***Differentiation Diversity***: The levels of inventory diversity are matched by corresponding categories of differentiation diversity such as

(i). Pattern diversity : Pattern diversity describes the variation in the diversity of samples (point diversity) taken within a relatively homogenous habitats (or area of α -diversity).

(ii). β (Beta) diversity : Beta diversity is a measure of between-habitat diversity.

(iii). δ (Delta) diversity : Delta diversity is defined as change in species composition (and abundance) that occurs between units of gamma diversity within an area of epsilon diversity (Magurran, 2004).

Alpha (species) diversity is the diversity of species within a particular habitat or community. Beta diversity is a measure of the rate and extent of change in species along a gradient from one habitat to another (or expression of between-habitat diversity). Gamma (Landscape) diversity is dependent on both alpha diversity and beta diversity and is the diversity of species within a geographical area (Spellerberg 1991). To summarise all the above statements, the overall diversity of any given area will be a reflection of the range of habitat it includes and the diversity of the component habitats.

Halffter (1998) has advocated that the diversity be studied at the landscape level because the consequences of human activities (community modification and fragmentation) are most evident at this level. The components of diversity can be characterised by distinguishing them and quantifying the local distribution of species, similarity among local assemblages, and the rate of change in species composition with respect to ecological conditions.

(i) Alpha (α) diversity (***i.e.,*** diversity within communities) is measured as the number of species occurring within an area of a given size and the distribution of individuals among the species (Huston, 1994). It, therefore, measures the richness of a

potentially interactive assemblage of species. Alpha diversity has two important components: (a) Species richness, ***i.e.,*** the number of species per unit area, and (b) Species evenness, ***i.e.,*** the distribution of individuals among the species. Number of species is a function of the size of the area sampled, and may show different patterns at different spatial scales in grassland (Singh, 1996). The alpha diversity of any location is a balance between the actions of local biotic and abiotic elements and immigration from other locations (Halffter, 1998).

(ii) Beta (β) diversity (***i.e.,*** diversity between communities), on the other hand, measures the turnover of species between different types of communities or habitats (Whittaker, 1977). The species composition of biological communities often has important effects on ecosystem-level properties (Wardle *et al.,* 1997), and since beta diversity indicates the rate of species change along given habitat or physiognomic gradient, it measures the community responses to habitat heterogeneity.

(iii) Gamma (γ) diversity (***i.e.,*** total diversity of a region) refers to an overall diversity within a large area (Cornell, 1985) and corresponds to the species richness at landscape level (Franklin, 1993). It is the product of the alpha diversity of the communities of a landscape and the degree of beta differentiation among them.

### 1.4. Concept of Mega-diversity and Hotspots

***Mega-diversity:*** The concept of mega-diversity emphasizes on species richness, threaten species and endemic species, whereas hotspots concept relates to rich endemism and the degree of threat or habitat destruction. It involves an estimate of the total number of all the organisms in an ecosystem and means that a place has a larger

percentage of living species in its territory than what would correspond to it if that percentage were proportional to its surface. This concept stresses the importance of certain countries that have large biological diversity within their borders, many of which are endemic species. It is obvious that organisms are not at the disposal of frontiers but a megadiverse country is one in which a large number of species can be found (Myers *et al.,* 2000).

The notion of megadiversity countries was first suggested by a well-known conservation biologist Russell Mittermeier, who developed with an initial emphasis on tropical primates. Later it was extended to all types of ecosystem and several groups of organisms (Mittermeier and Mittermeier, 1997). The concept of megadiversity countries is close to that of centers of diversity, which refers to the existence of areas with high biodiversity, particularly large numbers of species and a high concentration of endemic organisms. However, there are important distinctions. Centers of diversity are natural spatial units and they may be recognized at several scales, such as local, regional and global. Megadiversity countries, on the other hand, are spatial entities restricted within geopolitical limits and the recognition of variation at different scales can only be made within countries' artificial boundaries or at the global scale (Cowling, 2001).

There are 17 identified megadiversity countries in the world which encompass 60 – 70% of all global biodiversity (Mittermeier and Mittermeier, 1997). India ranks 9$^{th}$ position in terms of plant diversity and endemism in these megadiversity countries (**Table 1)**.

**Table 1. Megadiversity Countries: Plant Diversity and Endemism**

| Sl. No. | Country | Area ($km^2$) | Total species | Endemics |
|---|---|---|---|---|
| 1 | Brazil | 8,511,965 | ~50,000 - 56,000 | 16,500 - 18,500 |
| 2 | Indonesia | 1,916,600 | ~ 37,000 | 14,800 - 18,500 |
| 3 | Columbia | 1,141,748 | 45,000 - 51,000 | 15,000 - 17,000 |
| 4 | Mexico | 1,972,544 | 18,000 - 30,000 | 10,000 - 15,000 |
| 5 | Australia | 7,686,810 | 15,638 | 14,458 |
| 6 | Madagascar | 587,045 | 11,000 - 12,000 | 8,800 - 9,600 |
| 7 | China | 9,561,000 | 27,100 - 30,000 | ~10,000 |
| 8 | Philippines | 300,780 | 8,000 - 12,000 | 3,800 - 6,000 |
| 9 | India | 3,287,782 | > 17,000 | 7,025 - 7,875 |
| 10 | Peru | 1,285,210 | 18,000 - 20,000 | 5,356 |
| 11 | Papua New Guinea | 475,369 | 15,000 - 21,000 | 10,500 - 16,000 |
| 12 | Ecuador | 283,561 | 17,600 - 21,100 | 4,000 - 5,000 |
| 13 | USA | 9,372,143 | 18,956 | 4,036 |
| 14 | Venezuela | 912,050 | 15,000 - 21,070 | 5,000 - 8,000 |
| 15 | Malaysia | 329,749 | 15,000 | 6,500 - 8,000 |
| 16 | South Africa | 1,221,037 | 23,420 | 16,500 |
| 17 | Dem. Rep. Congo/ Zaire | 2,344,000 | 11000 | 3,200 |
| | Total | 51,189,393 | | 155,475 - 183,025 |

Source: Mittermeier and Mittermeier, 1997 In *Encyclopedia of Biodiversity*, 2001 *Vol. 3.*

A separate organization known as Like-Minded Megadiverse Countries Group (LMMC Group) was set up on 18th February 2002 by the Ministers in charge of the Environment and the Delegates of Brazil, China, Colombia, Costa Rica, India, Indonesia, Kenya, Mexico, Peru, South Africa and Venezuela who assembled in the Mexican resort town of Cancun. These Group of Like-Minded Megadiverse Countries act as a mechanism for consultation and cooperation so that their interests and priorities related to the preservation and sustainable use of biological diversity could be promoted. They also declared that they would call on those countries that had not become Parties to the Convention on Biological Diversity, the Cartagena Protocol on Biosafety, and the Kyoto Protocol on climate change to become parties to these

agreements. At the same time, they agreed to meet periodically, at the ministerial and expert levels, and decided that upon the conclusion of each annual Ministerial Meeting, the next rotating host country would take on the role of Secretary of the group, to ensure its continuity, the further development of cooperation among these countries and to reach the agreements and objectives set forth herein.

This organization does not include all the megadiverse countries as identified by Conservation International. The current member countries of the Like-Minded Megadiverse Countries organization are Bolivia, Brazil, China, Colombia, Costa Rica, Democratic Republic of the Congo, Ecuador, India, Indonesia, Kenya, Madagascar, Malaysia, Mexico, Peru, Philippines, South Africa and Venezuela (Cancun Declaration of Like-Minded Megadiverse Countries, 2002).

***Biodiversity Hotspots:*** A biodiversity hotspot is a bio-geographic region with a significant reservoir of biodiversity that is threatened with destruction.

The concept of biodiversity hotspots was originated by Dr. Norman Myers in two articles in "The Environmentalist" (Myers, 1988; 1990). The hotspots idea was also promoted by Mittermeier *et al.* (2005) in the popular book "Hotspots Revisited: Earth's Biologically Richest And Most Endangered Terrestrial Ecoregions".

Norman Myers first identified ten tropical forest *hotspots* based on plant endemism and threat in 1988, and his method was later adopted by Conservation International (CI) in 1989. The method of selecting a hotspot has been refined since then. A *terrestrial biodiversity hotspot* is now defined quantitatively as an area that has at least 0.5 percent, or 1,500 of the world's 300,000 species of green plants, and that has lost at least 70 percent of its primary vegetation. *Marine biodiversity hotspots* are

quantitatively defined based on measurements of relative endemism of multiple taxa (***i.e.,*** species of corals, snails, lobsters, and fish) within a region and the relative level of threat to that region. According to this approach, the Philippine archipelago and the islands of Bioko, Sao Tome, Principe, and Annobon in the eastern Atlantic Gulf of Guinea are ranked as two of the most threatened marine biodiversity hotspots. The CI hotspot approach has continued to evolve, for example, boundaries have been updated and streamlined to conform to the WWF/TNC Ecoregion approach (Laverty *et al.,* 2008). Today, CI recognizes thirty-four hotspots (Mittermeier *et al.,* 2005) including nine new hotspots in the great range of the Himalayas and the island nation of Japan (Holsinger, 2005). These hotspots once covered 15.7 percent of the planet but already 86 percent of the hotspots have been destroyed and they now cover just 2.3 percent of the planet (Laverty *et al.,* 2008).

Between them, the hotspots hold at least 150,000 plant species as endemics, 50 percent of the world's total. The total number of terrestrial vertebrates endemic to the hotspots is 11,980, representing 42 percent of all terrestrial vertebrate species. Reptiles and amphibians, are more prone to hotspot endemism than are the more wide-ranging mammals and birds, but the overall similarity between taxonomic groups is remarkable. Overall, 22,022 terrestrial vertebrate species call the hotpots home, 77 percent of the world's total (Mittermeier *et. al,* 2005). Myers *et al.* (2000) considered eight 'hottest hotspots' based on five key factors: numbers of endemics and endemic species/area ratios for both plants and vertebrates, and habitat loss which are listed in **Table 2.**

**Table 2. The eight hottest hotspots in terms of five factors**

| Hotspot | Endemic plants | | Endemic vertebrates | | Endemic plants/ area ratio (species per 100km$^2$) | | Endemic vertebrate/ area ratio (species per 100km$^2$) | | Remaining primary vegetation as % of original extent | | Times appearing in top 10 for each of five factors |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Madagascar | 9,704 | 4 | 771 | 4 | 16.4 | 8 | 1.3 | 7 | 9.9 | 9 | 5 |
| Philippines | 5,832 | 8 | 518 | 9 | 64.7 | 2 | 5.7 | 2 | 3 | 1 | 5 |
| Sundaland | 15,000 | 2 | 701 | 5 | 12 | 10 | 0.6 | 10= | 7.8 | 7 | 5 |
| Brazil's Atlantic Forest | 8,000 | 5 | 664 | 6 | 8.7 | | 0.6 | 10= | 7.5 | 6 | 4 |
| Caribbean | 7,000 | 6= | 779 | 3 | 23.5 | 6 | 2.6 | 4 | 11.3 | | 4 |
| Indo-Burma | 7,000 | 6= | 528 | 8 | 7 | | 0.5 | | 4.9 | 3 | 3 |
| Western Ghats/Sri Lanka | 2,180 | | 355 | | 17.57 | | 2.9 | 3 | 6.8 | 5 | 3 |
| Eastern Arc and Coastal Forests of Tanzania/ Kenya | 1,500 | | 121 | | 6.7 | 1 | 6.1 | 1 | 6.7 | 4 | 3 |

(Source: Myers *et al.*, 2000)

Conservation biologists are also interested in areas that have relatively low biological diversity but also include threatened or rare species (sometimes called *biodiversity coldspots*). Just has hotspots do not imply that the ecosystem is physically "hot" (although most hotspots are coincidentally located in the hot tropics), coldspots similarly are not necessarily "cold." Although these areas are low in species richness, they can also be important to conserve, as an individual "coldspot" may be the only location where a rare species is found. Extreme physical environments (low or high temperatures or pressures, or unusual chemical composition) inhabited by just one or two specially adapted species are "coldspots" that warrant conservation because they represent unique environments that are biologically and physically interesting (Laverty *et al.*, 2008).

The biodiversity hotspots have been severely disturbed by various environmental factors, and five important determinants include (i) land use (conversion of 50% of land area to agriculture); (ii) climate change (4$^{o}$C or 30% change in precipitation); (iii) nitrogen deposition (20 kg/ha/yr); (iv) biotic change (arrival of 200 new species of plant/animal; and, (v) atmospheric $CO_2$ (2.5 fold increase) by the year 2100 (Sala *et al.,* 2000). Land use change has been the most severe driver of changes in global diversity.

## 1.5. THREATS TO BIODIVERSITY:

The principal direct threats to biodiversity are habitat loss and fragmentation, invasive species, overexploitation, pollution, and global climate change (Eldredge, 2002).

Habitat loss and fragmentation have been termed the greatest worldwide threats to wildlife and the primary causes of species extinction (Simberloff, 1986). Human settlement, resource extraction, and industrial development generally result in small, isolated areas or patches of natural habitat surrounded by developed land (Gascon *et al.,* 1999).

Invasive species are the second most important threat to biodiversity conservation globally, threatening individual species and even entire ecosystems. Invasive species can be exotic or native species whose populations have expanded dramatically and out-compete, displace, or extirpate native species, potentially threatening the structure and function of intact ecosystems (Hunter, 2002).

Natural resource consumption rates and human population size exert tremendous pressure on the world's plants and animals. Although direct use of wildlife is essential for human survival, overexploitation of resources (or using resources at an unsustainable rate) is a critical problem in conservation. Although habitat loss may be the greatest threat to most species, overharvesting, nonsustainable use, and the illegal trade in some species are threatening not only their continued survival but also that of ecosystems and the livelihoods of communities and local economics that depend upon them (Eldredge, 2002).

The loss of biological diversity is a global crisis. There is hardly any region on the Earth that is not facing ecological catastrophes. Of the 1.7 million species known to inhabit the Earth, one fourth to one third is likely to extinct within the next few decades (Spellerberg, 1991). According to Myers (1979), these exponential species extinction rates have increased dramatically in the last 50,000 years from one extinction per 1000 years to about 1000 extinctions per year and may reach 40,000 per year until the end of this century, so that one species will be lost every hour. Biological extinction has been a natural phenomenon in geological history. But man's intervention has speeded up extinction rates all the more. Between 1900 and 1950, the rate of extinction went up to one species every 10 years (Agrawal, 2002). Myers (1985) has argued that about 50 species are being driven to extinction everyday; bulk of them tropical forests. This is due to human interference (Agrawal, 2002). Extinction is thus a major problem because we lose genetic diversity, important links in a species, and community stability to interact and withstand stress. Thus, we lose important needs of future generations to control disease and human suffering, and to manage the environment and restore damaged habitat (Arora, 2004).

According to the report, “People and the Environment,” which has been released recently by the US based World Resources Institute, the current rate of biodiversity loss is the fastest ever known. The report based on the studies carried out by Food and Agriculture (1974) found that the tropical forest is shrinking at the rate of 0.8% each year. If the current rate of deforestation continues scientists estimated that roughly 5-10% of the tropical forest species may face extinction, within next 30 years.

According to the IUCN Red List of Threatened Species (2007) (**Table 3**) scientists have assessed conservation status for fewer than 10 percent of known species. Of the vertebrate species assessed about 23 percent are considered threatened. Examining individual vertebrate groups, 12 percent of birds are at risk, 22 percent of mammals, 30 percent of reptiles, 31 percent of amphibians, and 39 percent of fish as of 2007. Those species that rely on freshwater habitats are typically the most threatened.

Each area of the world has its own unique combination of living organisms. The living material interacts in such a way as to provide functional organization. If one species or a group of species are destroy the whole interacting system changes. If a number of species are lost, then the number of possible interactions is limited. The more species that are present, the more interaction occurs; therefore, it is necessary to preserve species diversity (Arora, 2004). The loss of biodiversity has immediate and long-term effects on human survival. The majority of the world's population still depends on wild plants and animals for their daily food, medicine, housing and household, material, agriculture, fodder, fuel wood, spiritual sustenance, and intellectual stimulation (Agrawal, 2002). Therefore, we must develop methods to manage for biological diversity. We must look beyond managing for an endangered species—a

deer, duck, or a trout—to consider all life as a global resource necessary for the well-being of all living things and sustaining life (Arora, 2004).

**Table 3. IUCN Red List of Threatened and Endangered Species**

| | Number of Described Species | Number of Species Evaluated By IUCN | Number Threatened in 2007 At % of Total Described Species | Number Threatened As % of Species Evaluated By IUCN |
|---|---|---|---|---|
| Mammals | 5,416 | 4,863 | 20% | 22% |
| Birds | 9,956 | 9,956 | 12% | 12% |
| Reptiles | 8,240 | 1,385 | 5% | 30% |
| Amphibians | 6,199 | 5,915 | 29% | 31% |
| Fishes | 30,000 | 3,119 | 4% | 39% |
| **Total Vertebrates** | 59,811 | 25,238 | 10% | 23% |
| Invertebrates | 1,203,375 | 4,116 | 0.18% | 51% |
| Plants | 297,326 | 12,043 | 3% | 70% |

*Note:* Note few invertebrates are evaluated for risk of endangerment compared to the total described species
*Source:* IUCN Red List 2007.

### 1.6. Soil

#### 1.6.1. Concepts and definition of Soil

The term *soil* is used in different ways in different disciplines and has many definitions. To engineers, soil is any loose material above solid bedrock, a usage equivalent to the term *regolith.* Soil scientists use the term for any material capable of growing plants. To a geologist, soil is produced by weathering and is the residual product of the chemical, physical, and biological breakdown of rock, whether bedrock or material that has been transported. Climate, topography, the composition of the material, and the length of time the processes have been working determine the type of

soil (Eldredge, 2002). According to Hilgard (1911), "Soil is the more or less loose and crumbly part of the outer earth crust in which, by means of their roots, plants may or do find a foot-hold and nourishment as well as all other conditions essential to their growth."

According to Raman, “soil is the upper weathering layer ***i.e.,*** layer subjected to physical and chemical changes of the soli earth crust.” Joffe and Marbut, have defined soil as natural body developed by natural forces acting on natural materials. It is usually differentiated into horizons of minerals and organic constituents of variable depths which differ from the parent materials in morphology, physical constitutions, chemical properties, composition and biological characterictics (Dutta, 2005).

According to Wadia (1949) "the soil is the topmost layer of the earth's outer crust capping the rocks exposed at the surface. It is a natural body of variable thickness, composed of disintegrated rock material together with variable proportion of organic matter, mostly unconsolidated, generally differentiated into zones or layers, the lowest of which passes imperceptibly into the parent rock below."

Soils are a mixture of weathered mineral rock particles, organic matter (***i.e.,*** both living, and dead and decaying), water, and air. Soils can be thought of as functional entities that are the resulting products of the interaction of physical, chemical, and biological processes (Pavao-Zuckerman, 2008).

The Soil Science Society of America defines soil as (i) The unconsolidated mineral or organic material on the immediate surface of the earth that serves as a natural medium for the growth of land plants. (ii) The unconsolidated

mineral or organic matter on the surface of the earth that has been subjected to and shows effects of genetic and environmental factors of: climate (including water and temperature effects), and macro- and microorganisms, conditioned by relief, acting on parent material over a period of time. A product-soil differs from the material from which it is derived in many physical, chemical, biological, and morphological properties and characteristics (SSSA, 1987).

### 1.6.2. Formation of Soil

The importance of soil formation, also termed ‘pedogenesis’, in shaping ecosystems, including human civilization, is hard to exaggerate. Soil formation determines the properties of soils, which determine the function and uses of this essential ecological and human resource (Harrison and Strahm, 2008).Soils are the resultant of the interactions of several factors-climate, organisms, parent material and topography (relief) - all acting through time (Jenny, 1941, 1980). These factors affect major ecosystem processes, such as primary production, decomposition, and nutrient cycling, which lead to the development of ecosystem properties unique to that soil type, as a result of its previous history (Coleman, 2001).

Soil formation takes place in two consecutives stages, starting with a simple weathering (disintegration and decomposition) of rocks and minerals giving rise to an unconsolidated regolith (from Gr. *rhegos*, covering, and *lithos*, stone), and followed by a soil profile development, whereby the regolith material is gradually modified and a horizon sequence develops under the combined action of climate, vegetation, topography and time.

Weathering which is the main process concerned in soil formation is due to active soil forming processes that may be physical, chemical or biological in nature ***i.e.,*** weathering can be physical, chemical and biological:

(a). Physical Weathering: Physical weathering means breaking up of rocks due to thermal expansion and contraction of particles (***i.e.,*** individual grains of different minerals in rock expand and contract at different rates in relation to each other), movement and abrasion, pressure from freezing of water, and root penetration and swelling (Harrison and Strahm, 2008). This is brought about by a number of climatic factors acting simultaneously but in varying degrees depending on local conditions.

(b). Chemical weathering: The general trend of chemical weathering is the breaking down of complex compounds, mainly through the agency of water containing dissolved carbonic acid and other acidic substances derived from organic matter in the soil. The acid solution contains hydrogen ions which displace the alkali (Sodium and Potassium) and alkaline earths (Calcium and Magnesium) in the silicate minerals. The chief end products are silica, clay, inorganic salts and hydrated oxides. Hydrolysis, hydration, oxidation and reduction are the other chemical processes which occur during weathering.

(c). Biological weathering: This includes biological activity of plants and animals. The processes of humification, nitrification and decay are of fundamental importance in the build up of soil fertility. Due to differences in their requirements, some species also colonise particular types of soil and hence affect the developmental processes in many ways. Animals play a great role as soil transporters, mixers, structure modifiers and occasionally as modifiers of textural and chemical composition.

### 1.6.3. Soil Profile

A vertical section of the soil consists of a succession of horizontal layers, which are either distinct or merging with each other in transitional zones. These are referred to as horizons and the section is termed as the soil profile. Morphology of a soil profile has a significant influence on the development of vegetation. According to Brady and Weil (2002), five master soil horizons are recognized and are designated using the capital letters O, A, E, B and C. Each horizon is further divisible into sub-horizons. A brief description of these horizons as given by Brady and Weil (2002) are below:

**O HORIZONS:** The O group is comprised of organic horizons that generally form above the mineral soil or occur in an organic soil profile. They derive from dead plant and animal residues. Generally absent in grassland regions, O horizons usually occur in forested areas and are commonly referred to as the forest floor. Often three subordinate O horizons can be distinguished.

The $O_i$ horizon is an organic horizon of flbric materials - recognizable plant and animal parts (leaves, twigs, and needles), only slightly decomposed. It is sometimes referred to as the *litter* or *L layer* by some foresters.

The $O_e$ horizon consists of hemic materials - finely fragmented residues intermediately decomposed, but still with much fiber evident when rubbed between the fingers. This layer corresponds to the *fermentation* or *F layer* described by some foresters.

The $O_a$ horizon contains sapric materials - highly decomposed, smooth, amorphous residues that do not retain much fiber or recognizable tissue structures. This is the humidified or H layer designated by some foresters.

**A HORIZONS:** The topmost mineral horizons, designated A horizons, generally contain enough partially decomposed (humified) organic matter to give the soil a color darker than that of the lower horizons. The A horizons are often coarser in texture, having lost some of the finer materials by translocation to lower horizons and by erosion.

**E HORIZONS:** These are zones of maximum leaching or eluviation (from Latin *ex* or *e*, out, and *lavere*, to wash) of clay, iron, and aluminum oxides, which leaves a concentration of resistant minerals, such as quartz, in the sand and silt sizes. An E horizon is usually found underneath the A horizon and is generally lighter in color than either the A horizon above it or the horizon below. Such E horizons are quite common in soils developed under forests, but they rarely occur in soils developed under grassland.

**B HORIZONS:** B horizons form below an O, A, or E horizon and have undergone sufficient changes during soil genesis so that the original parent material structure is no longer discernable. In many B horizons materials have accumulated, typically by **illuviation** (from the Latin *il*, in, and *lavere*, to wash) from the horizons above. In humid regions, B horizons are the layers of maximum accumulation of materials such as iron and aluminum oxides ($B_o$ or $B_s$ horizons) and silicate clays ($B_t$ horizons), some of which may have illuviated from upper horizons and some of which may have formed in place. In arid and semiarid regions, calcium carbonate or calcium sulfate may accumulate in the B horizon (giving $B_k$ and $B_y$ horizons, respectively).

The B horizons are sometimes referred to incorrectly as the subsoil, a term that lacks precision. In soils with shallow A horizons, part of the B horizon may become incorporated into the plow layer and thus become part of the topsoil. In other soils with deep A horizons, the plow layer or topsoil may include only the upper part of the A horizons, and the subsoil would include the lower part of the A horizon along with the B horizon. This emphasizes the need to differentiate between colloquial terms (topsoil and subsoil) and technical terms used by soil scientists to describe the soil profile.

**C HORIZONS:** The C horizon is the unconsolidated material underlying the solum (A and B horizons). It may or may not be the same as the parent material from which the solum formed. The C horizon is below the zones of greatest biological activity and has not been sufficiently altered by soil genesis to qualify as a B horizon. While loose enough to be dug with a shovel, C horizon material often retains some of the structural features of the parent rock or geologic deposits from which it formed. Its upper layers may in time become a part of the solum as weathering and erosion continue.

**R. LAYERS:** These are consolidated rock, with little evidence of weathering.

### 1.6.4. Physico-chemical properties of Soil

Soil constituents derived from parent materials and altered through pedogenesis determine the physico-chemical properties and related processes that influence soil suitability for various uses (Smith, 1999). The physical properties of soil are the production of continued interactions between soil biota and their abiotic milieu (Coleman *et al.,* 2004) whereas the chemistry of constituents determines the store of nutrients that are available to plant roots. It also determines whether concentrations of

particular chemicals will cause nutritional imbalances or toxicities (Smith, 1999). Soil physical properties play an important role in determining the physical conditions in soil where several biological processes take place (De Vos *et al.,* 1994) while its chemical properties determine the quality of a particular soil (Hassink, 1997).

Soil texture refers to the relative proportions of various mineral particles of various sizes by weight ***i.e.,*** Sand, silt and clay in a sample (Wild, 1996). According to Tan (1982), the soil texture is recognized from the feel of moist soil placed between the thumb and fore finger. The soil may be smooth and fine or it may be coarse or gritty. Soil texture has an extremely significant influence on the physical and mechanical behaviours of the soil, and on all the properties related to water content and the movement of water (Pansu and Gautheyrou, 2006). Moreover, it is negatively related to the mineralization of nitrogen (Cote *et al.,* 2000). The structure of soil influences organic matter turnover and fertility of soil and plays an important key role in the ability of soil to store organic matter (Balabane, 1996).

Soil particle density is defined as the mass per unit volume of soil solids. Particle density is essentially the same as the specific gravity of a solid substance. The chemical composition and crystal structure of a mineral determines its particle density. Particle density is not affected by pore space, and therefore is not related to particle size or to the arrangement of particles (soil structure) (Brady and Weil, 2005). Individual soil particles vary widely in any soil type. Similarly, as these particles are cemented together, a variety of aggregate shapes and sizes occur. For standard particle size measurement, the soil fraction that passes a 2-mm sieve is considered. Laboratory procedures normally estimate percentage of sand (0.05 - 2.0 mm), silt (0.002 - 0.05 mm), and clay (<0.002 mm) fractions in soils. Particle size distribution is an important

parameter in soil classification and has implications on soil water, aeration, and nutrient availability to plants (Ryan *et al.,* 2001).

Porosity is a measure of the amount of pore space in a soil, or the volume of the soil not occupied by solids. It is a critically important parameter of soil because it influences the movement of water and gases, which in turn determine the activity of roots and soil microorganisms. Soil pore may be small or large, thin or thick, capillary or non-capillary. The plant roots grow and exist in the pore spaces (Dutta, 2005). Pores are classified on the basis of their equivalent cylindrical diameters (ECD) although the boundaries of the size classes are somewhat arbitrary. Micro pores are defined as those pores sufficiently small (less than approximately 30 μm in diameter) to retain water by capillarity and these contrast with the larger macropores which do not (Lavelle and Spain, 2003). If all the space occurs as large pores, as it does in gravel or coarse sandy soil, then water will drain freely and the soil will be subject to drought. Conversely, if all the pores occur as minute spaces between clay particles, then the movement of gases and water will be extremely slow, and plants that grow in the soil will experience water logging and oxygen deficiency when the soil is wet and will have difficulty in taking up strongly held water as the clay-rich soil dries. The ideal pore distribution is that which retains sufficient water and yet permits adequate diffusion of oxygen and $CO_2$ and movement of water to satisfy the requirements of desired species of plants, soil animals, and soil microbes. Total pore space in a poorly structured soil may be as little as 35%, whereas a well-structured soil with the same texture may have as much as 65% pore space (Kimmins, 2005). Soil porosity may be divided into textural and structural components. Textural porosity is the minimal porosity resulting from the irregular distribution of the inorganic soil fragments; structural porosity is

that component of porosity due to the generally-larger interconnected pores (Lavelle and Spain, 2003).

Bulk density is defined as the mass of a unit volume (both solids and pores) of dry soil (Brady and Weil, 2005). The bulk density of a soil is generally smaller than its particle density (Dutta, 2005). The structure, texture, and porosity of soils, together with their organic matter content, combine to determine the *bulk density* of a soil. Expressed in units of mg $m^{-3}$ (mg/ $m^3$), the bulk density of clay, clay loam, and silt loam surface soils normally ranges from 1.00 to as high as 1.60, depending on their condition. Sands and sandy loams have values of 1.20 to 1.80. Very compact non soils may have bulk densities of 2.0 or even higher (Brady, 1984). Forest floor bulk densities also vary. For example, values of 0.12 to 0.16 g $cm^{-3}$ have been reported for yellow birch-red spruce stands in the Adirondack Mountains of New York (Phee and Stone, 1965). A 500-year-old subalpine forest in coastal British Columbia was found to have mean values of 0.14 to 0.18 (Kimmins, 2005). Much higher values (0.27) for a forest in New Hampshire (Hoyle, 1973) and much lower values (0.056) for undecomposed moss peat (Boelter, 1964) can also be found. One reason for this variation is the variation in biomass of live small and fine roots (<5 mm diameter) in forest floors and in the extent to which they were removed before bulk density was calculated (Kimmins, 2005). Changes in bulk density for a given soil are easily measured and can alert soil managers to changes in soil quality and ecosystem function. Increases in bulk density usually indicate a poorer environment for root growth, reduced aeration, and undesirable changes in hydrologic function, such as reduced water infiltration (Brady and Weil, 2002). One of the main reasons for measuring soil bulk density is that this value can be used to calculate pore space. For

soils with the same particle density, the lower the bulk density, the higher the percentage pore space (total porosity). Thus, bulk density and total porosity are inversely proportional to each other.

Soil temperature is one of the important aspects of soil productivity as it influences upon the rate and direction of many physical, chemical and biological processes in soil (Dutta, 2005). The temperature regimes that pertain in soils influence many processes that occur therein and play a part in controlling the rates and processes of soil development and the composition and activities of the biota (Lavelle and Spain, 2003). Soil temperature regimes are influenced by soil porosity and texture. Thermal conductivities generally increase with increasing particle size, so sands have higher conductivities, warm up faster in the spring, and cool down more rapidly in the fall than do clays. Denser materials have higher conductivities than those that have a lower bulk density (Kimmins, 2005).

The degree of soil acidity or alkalinity, expressed as soil pH, is a *master variable* that affects a wide range of soil properties—chemical, biological, and, indirectly, even physicals (Brady and Weil, 2005). The pH is the negative log of the hydrogen ion concentration in soil solution ($pH = -\log [H^+]$) (Barnes *et al.*, 1998). The pH range normally found in soils varies from 3 to 9. Various categories of soil pH may be arbitrarily describes as follows: *strongly acidic* (pH < 5.0), *moderately to slightly acidic* (5.0 – 6.5), *neutral* (6.5 – 7.5), *moderately alkaline* (7.5 – 8.5), and strongly alkaline (>8.5) (Ryan *et al.*, 2001). pH characterizes soil acidity and is strongly correlated with base saturation, organic carbon, total nitrogen and cation exchange capacity (CEC) that are important parameters to characterize soil fertility for plant production (Landon, 1984). Soil pH influences the solubility of nutrients, microbial

activity and physical conditions of the soil. It affects the activity of micro organisms responsible for breaking down organic matter and most chemical transformation in the soil. In natural systems, the pH of soil is affected by the mineralogy, climate and weathering (Nilsson, 2004).

Water is an essential nutrient for plant growth and it is needed in much larger quantities than any other nutrient. Almost all the mineral nutrients become available to plant only when certain amount of water is present in the soil. It is the medium in which most transport of elements and particles occur in the ecosystem (Scholes *et al.,* 1994). The major source of soil water or moisture is rain. Most of the water which falls during rainfall is lost as surface run-off while some of the water is retained in the soil. The forces responsible for water retention in the soil are surface tension and surface attraction. The water molecules get attached on the soil surface because of the forces of adsorption (attraction) exerted by the surface of soil molecules (Dutta, 2005). The water content of soil is related to its texture and structure along with the magnitude of such physical forces as capillary attraction, cohesion and adhesion. The size of the mineral particles and their shape and number of the pore spaces are important in the amount of water retained by the soil (Sharma, 1997). There are three physical classification of soil water such as *Gravitational water* which occupied the larger pores and goes downwards under the force of gravity. This type of water is of no use to plants. *Capillary water (available water)* is water found in the micropores which can be absorbed by plant roots. On the surface of soil colloidal particles, the water held tightly and this water is called *hydroscopic water*. This water is also not absorbed by plants (Dutta, 2005).

Soil organic carbon represents a major pool of carbon within the biosphere (Cerri *et al.,* 2000). It is the largest Carbon reservoir in many terrestrial ecosystems including grasslands, savannas, boreal forests, tundra, some temperate forests, and cultivated systems, comprising as much as 98% of ecosystem C stocks in some systems (Schlesinger, 1977). Globally, the amount of C stored in soil is equal to the amount stored in vegetation and in the atmosphere combined (Schimel, 1995). The standing stocks of soil carbon are twice as large as all of the standing crop biomass of all the terrestrial biomes combined (Post *et al.,* 1990; Anderson, 1992).

Nitrogen, phosphorus, and potassium are plant nutrients that are obtained from soil. They are so important for crop productivity that they are commonly added to soil as fertilizers. In most soils, over 90% of the nitrogen content is organic. This organic nitrogen is primarily the product of the biodegradation of lead plants and animals. It is eventually hydrolyzed to $NH_4^+$, which can be oxidised to $N0_3^-$ by the action of bacteria in the soil. Nitrogen bound to soil humus is especially important in maintaining soil fertility. Soil humus, however, serves as a reservoir of nitrogen required by plants (Bhatia, 2002). Nitrogen is an integral component of many essential plant compounds. It is a major part of all amino acids, which are the building blocks of all proteins—including the enzymes, which control virtually all biological processes. A good supply of nitrogen stimulates root growth and development, as well as the uptake of other nutrients soil (Brady and Weil, 2005).

Although the percentage of phosphorus in plant material is relatively low, it is an essential component of plants. Phosphorus, like nitrogen, must be present in a simple inorganic form before it can be taken up by plants (Bhatia, 2002). Phosphorus-deficient

plants are often severely stunted, since this element takes part in the synthesis of several essential compounds upon which all plant and animal life depends.

Of all the essential elements, potassium is the third most likely, after nitrogen and phosphorus, to limit plant productivity. For this reason it is commonly applied to soils as fertilizer and is a component of most mixed fertilizers (Brady and Weil, 2005). Potassium is one of the most abundant elements in the earth's crust, of which it makes up 2.6%; however, much of this potassium is not easily available to plants (Bhatia, 2002). Some 90 to 98% of all soil potassium in a mineral soil is in relatively unavailable forms. Only 1 to 2% of the total soil potassium is readily available. Available potassium exists in soils in two forms: (1) in the soil solution and (2) exchangeable potassium adsorbed on the soil colloidal surfaces. Although most of this available potassium (approximately 90%) is in the exchangeable form, soil solution potassium is most readily absorbed by higher plants (Brady and Weil, 2005).

The present study focused mainly on the physical properties such as soil temperature, porosity, bulk density, soil water or moisture content and water holding capacity, and chemical properties such as pH, total organic carbon, total nitrogen, available phosphorus and exchangeable potassium. These physico-chemical properties influence soil microbial population and their activities and uptake of water and nutrients by roots (Arunachalam *et al.*, 1997).

## 1.7. SCOPE AND OBJECTIVES

The documentation and proper assessment of biodiversity are essential and more valuable, which may provide base line information, facilitating formulation

or policies and programs for biodiversity conservation. The North- Eastern Region is considered as one of the rich biodiversity centers of the Indian sub-continent. In view of accelerated anthropogenic activities leading to loss of biodiversity, there is an urgent need to study the status of biological diversity in this region with main emphasis on the natural protected areas. The studies on the flora, vegetation and ecosystems in Wildlife Sanctuaries and National Parks are useful to bring about animal-plant relationships besides the floristic details.

The research work mainly focuses on the status of floristic diversity along habitat gradient and will contribute to the better understanding of the floristic and ecosystem diversity of the National Park. An attempt is also made to identify endemic, rare, endangered and threatened plant species. The taxonomic works of the area in the light of the revised taxonomic monographic work and the passed taxonomic nomenclature of our pioneer works will be the mirror of the vegetation of the area. Keeping the above fact as theme in objective, Phawngpui (Blue Mountain) National Park in Lawngtlai District of Mizoram has been selected to explore its status of plant diversity from ecological point of view. The vegetation of the national park has provided an ideal habitat for wild lives. As the wildlife entirely depends on the vegetation and floristic composition of the national park, the present study is hope to be helpful in providing necessary information for formulating policies and programs for effective management and conservation of valuable biodiversity including the other related benefits.

## OBJECTIVES OF THE STUDY

The research work focused on the following aims and objectives: -

1. To study plant diversity in relation to altitudinal gradient.
2. To study soil nutrient status by analyzing the physical and chemical properties of soil.
3. To identify and to assess stating endemic, rare and endangered plant species.

**Chapter – 2**

# REVIEW OF LITERATURE

## 2.1. PLANT DIVERSITY AT GLOBAL LEVEL

The total number of species for any taxonomic group can be estimated from the ratio of the number of new species described each year to the number of previously described species. Estimates can also be extrapolated from the number of species collected per unit area from field samples (Stork, 1997). Scientists estimated that the total number of species on earth could range from 3.6 million up to 111.7 million (Hammond, 1995). The range between the upper and lower figures is large because of the difficulty in estimating total species numbers for some taxonomically lesser known groups, such as bacteria, or groups not comprehensively collected from areas where their species richness is likely to be greatest—for example, insects in tropical rain forests (Eldredge, 2002). However, It is estimated that there exists 5 - 50 million species of living organisms on the earth (Agrawal, 2002) and only 1.7 million have been identified so far (Groombridge and Jenkins, 2000). According to Mc Neely *et al.* (1990), about 5% of the biological diversity of the rain forest is known to science. Scientists are of the opinion that more than half of the species on the earth occur in moist tropical forests which is about 7% of the total land surface. Tropical forests are assumed to support 50-90% of the world's biodiversity (Agrawal, 2002). The estimated numbers of described species according to Lecointre and Guyader, 2001 (*In:* Eldredge (ed), 2002) is: Bacteria - 9,021; Archaea - 259, Bryophyta (mosses) - 15,000, Lycophyta (clubmosses)-1,275, Filicophyta (ferns) - 9,500; Coniferophyta

(conifers) - 601, Magnoliophyta (flowering plants) - 233,885, Fungi - 100,800, Porifera (sponges) - 10,000, Cnidaria - 9,000, Rotifers - 1,800, Platyhelminthes (flatworms) - 13,780, Mollusca (mollusks) - 117,495, Annelida (annelid worms) - 14,360, Nematoda (nematode worms) - 20,000, Arachnida - 74,445, Crustacea - 38,839, Insecta - 827,875, Echinodermata - 6,000, Chondrichthyes (cartilaginous fishes) – 846, Actinopterygii (ray-finned bony fish) - 23,712, Lissamphibia (living amphibians) - 4,975, Mammalia (mammals) - 4,496, Chelonia (living turtles) - 290, Squamata (lizards and snakes) - 6,850, Aves (birds) - 9,672, Others - 1, 93, 075. The total number of described species is assumed to be 1,747,851. This provides a measure of the evolutionary or taxonomic diversity of the species present in any given region. These studies correct common misconceptions about global biodiversity. For example, most public attention is focused on the biology and ecology of large, charismatic species such as mammals, birds, and certain species of trees (for example, mahogany and sequoia). Far less public concern is paid to groups such as molluscs, insects, and, to some extent, flowering plants. However, this indicates that mammals and birds represent only a small portion of the total number of species (0.3 percent and 0.6 percent, respectively). Molluscs, on the other hand, represent about 7 percent of the total number of known species, and flowering plants 13 percent. Insects represent 47 percent of the total number of species; there are approximately 300,000 species of beetles alone, representing 17 percent of all species on earth. The greater part of earth's species diversity is often overlooked (*Ibid*).

## 2.2. PLANT DIVERSITY AT COUNTRY LEVEL

India is the seventh largest country in the world, with a total land area

of 3,287,263 sq. km. It measures 3,214 km. from North to South and 2,993 km. from East to West. It has a land frontier of 15,200 km. and a coastline of 7,517 km. (SoE Report, 2009). The forest and tree cover in India is 78.37 million ha in 2007 which is 23.84% of its geographical area and includes 2.82 tree cover (SFR, 2009). Over forty per cent of the total land area of the country is under cultivation, which is fairly high by world standards (Agarwal, 2002).

India occupies a dominant position in South Asia. Young folded mountains lie along the country's north-western, northern and north-eastern borders. Its southern coast is washed by the Indian Ocean whereas the Bay of Bengal and Arabian see lie to its south east and south-west respectively. The country is quite rich in biodiversity with a sizable percentage of endemic flora and fauna. This richness in biodiversity is due to immense variety of climatic and altitudinal conditions coupled with varied ecological habitats. These vary from the humid tropical Western Ghats to the hot desert of Rajasthan, from the cold desert of Ladakh and the icy mountain of Himalayas to the warm costs of peninsular India (Agarwal, 2002).

India, with a varied terrain, topography, land use, geographic and climatic factors, can be divided into ten recognizable bio-geographic zones (Rodgers *et al.,* 2000). These zones encompass a variety of ecosystems such as mountains, plateaus, rivers, forests, deserts, wetlands, lakes, mangroves, coral reefs, coasts and islands (SoE Report, 2009). Champion and Seth (1968) classified the forests of India in six major groups which are further divided into sixteen type groups and finally into two hundred types including subtypes and variations of forests based on climate, soil, vegetation and the past treatment. Recently, FSI has mapped about 170 forest types of

India on 1:50,000 scale using remote sensing and GIS (SFR, 2009). Nayar (1996) listed three mega centers of endemic plants in India which are (i) Eastern Himalaya harboring 9,000 species of plants with 3500 endemic species; (ii) Western Ghats possessing 5800 plant species with about 2000 endemics; and (iii) Western Himalayas with 1195 endemic species of plants. The Andaman and Nicobar Islands harbor about 83% endemic species.

Under the Wildlife (Protection) Act, 1972, the state Govt. is empowered to declare any area as a Sanctuary or National Park for the purpose of protecting, propagating or developing wildlife there in or its environment. The Biological Diversity Act, 2002 provides directives of the CBD's main objectives owing to the sovereignty of the state to use its own biological resources to regulate its bioresources for equitable sustainable use of biodiversity, respect local knowledge, development of biological heritage sites, involvement of local institutions and NGO's About 4.9 percent of the country's area is protected under IUCN categories I-V. At present, there are 15-Biosphere Reserves, 99 National Parks and 523 Wildlife Sanctuaries in the country (SoE Report, 2009).

India with 2.45% of the world's area is one of the most significant in the world of biodiversity. It is one of the 17 megadiversity countries and one of the 34 biodiversity hotspots in the world (SoE Report, 2009). India has four global biodiversity hot spots - Eastern Himalaya, Indo-Burma, Western Ghats and Sri Lanka, and Sundaland (Goyal and Arora, 2009) which posses 60-70% of the world's biodiversity (SoE Report, 2009). In terms of plant diversity, India ranks tenth in the world and fourth in Asia. With over 45,500 plant species, India represents nearly 11% of the world's known floral diversity. Some of the important floral groups found in

India are-Angiosperms -17,527 species of flowering plants (more than 7% of the world's known flowering plants); Gymnosperms - 67 species ; Pteridophytes - 1200 species; Bryophytes - 2500 species; Lichens (representing symbiotic association of fungi and Algae) - 2,223 species; Fungi - 14,500 species; Algae - 7,175 (Goyal and Arora, 2009).

India is also a storehouse of primitive flowering plants, confined mainly in the North Eastern region of the country. Diversity of such plants led Takhtajan (1969) to designate this region as the ''Cradle of Flowering Plants". The Indian flora also shows a rich diversity in aquatic flowering plants. Some important families of aquatic plants include Hydrocharitaceae (13 species), Pontederiaceae (13 species), Alismataceae (8 species), Aponogetonaceae (6 species), Potamogetonaceae (6 species), Typhaceae (4 species), Salviniaceae (3 species), etc. The insectivorous plant families are represented by Lentibulariaceae (36 species), Droseraceae (3 species), and Nepenthaceae (1 species) (Goyal and Arora, 2009).

About 11,058 species are endemic to Indian region, of which 6,200 belong to flowering plants alone (Goyal and Arora, 2009). In terms of crop diversity, India is recognized as one of the eight Vavilovian centres of origin and diversity of crop plants, having more than 800 crop species and 320 wild ancestors and close relatives of cultivated plants, which are still evolving under natural conditions (*Ibid.* 2009). Nearly 6,500 native plants are still used prominently in the indigenous healthcare systems (SoE Report, 2009).

However, this rich biodiversity of India is under severe threat owing to habitat destruction and over-exploitation (Agrawal, 2002). As per the IUCN

Red List (2008), India has 246 globally threatened floral species, which constitute approximately 2.9% of the world's total number of threatened floral species (8457) (Goyal and Arora, 2009). From the biodiversity standpoint, India has some 59,353 insect species, 2,546 fish species, 240 amphibian species, 460 reptile species, 1,232 bird species and 397 mammal species, of which 18.4 per cent are endemic and 10.8 per cent are threatened. The country is home to at least 18,664 species of vascular plants, of which 26.8 per cent are endemic (SoE Report, 2009).

## 2.3. PLANT DIVERSITY AT THE NORTH –EAST INDIA LEVEL

The North-East region of India comprising seven States of the country namely, Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland and Tripura is endowed with rich forest resources. The region, which is only 7.76% of the geographical area of the country, accounts for nearly one fourth of the forest cover. The total forest cover in the region is 170,423 $km^2$, which is 66.81% of the geographical area (SFR, 2009). This region is also rich in biodiversity and has been identified as one of the 34 'global hotspot centers of biodiversity representing Indo-Myanmar biodiversity hotspot. It is also one of the 10 distinct biogeographic regions of the country. The ecosystem varies from tropical wet evergreen, moist deciduous sub-alpine, alpine forests and grasslands to the numerous freshwater lakes, rivers, swamps and marshy wetlands. A number of sacred groves have been reported from Meghalaya and Manipur States (SFR, 2009).

The flora of this region is remarkably rich and diverse and is known as the "The *cradle of ancient angiosperms"* due to the presence of a large number of primitive and ancient flowering plant in the region (Takhtajan, 1969). About 8000

species of flowering plants (approximately 45% of an estimated 17, 527 flowering plants reported in India) occur in this zone. The region is the habitat of many botanical curiosities and rarities. *Sapria himalayana* of the family Rafflesiaceae, discovered in Arunachal Pradesh, is one of the largest root parasites, with crimson flowers measuring 35 centimeters across (Deb, 1957 *In:* Chatterjee *et al.,* 2006). Among insectivorous plants *Nepenthes khasiana,* endemic to Meghalaya and listed in Appendix I of CITES and placed in Schedule VI of the Wildlife (Protection) Act, 1972, and two species of *Drosera peltata* Sm. and *D. burmanii* are important (Chatterjee *et al.,* 2006).

Orchidaceae, the most fascinating and highly evolved group of plants, has 1,229 species belonging to 184 genera in India (Shukla *et al.,* 1999). About 700 species have been reported from the Northeastern Region of India. Of these, 545 species belonging to 122 genera are reported from only Arunachal Pradesh of which 12 species are in the endangered category, 16 species are vulnerable, and 31 species are threatened (Choudhery, 1998).

The genus *Rhododendron* of Ericaceae is another remarkable group of showy plants with more than 90 percent of the total rhododendrons reported from India confined to the Himalayan region (Singh *et al.,* 2003). In total 72 species, 20 subspecies, and 19 varieties are listed from India, with the eastern Himalaya region harboring 71 species. Of 12 species, 2 subspecies, and 5 varieties of *Rhododendron* endemic to India, in the Northeastern Region Arunachal Pradesh has most endemic species, with 9 species and 1 subspecies, followed by Manipur and Sikkim with 3 species and 1 subspecies, and Mizoram with 2 species (Mao *et al.,* 2001).

The region is considered as the primary and secondary centers of origin and diversity of about 50 crop plants and about 190 wild relatives. Important crop plants originated in this zone include Citrus, banana and plantain, mango, rice and several species of legumes, cucurbits, orchids, bamboos and medicinal an aromatic plants (SFR, 2009).

The number of National Parks and Wildlife Sanctuaries (in parenthesis) present in the region is: Arunachal Pradesh-2, (11); Assam-5, (18); Meghalaya-2, (3); Mizoram-2, (8); Manipur-1, (1); Nagaland-1, (3) and Tripura-2, (4). There is also one Biosphere Reserve each in Arunachal Pradesh, Assam and Meghalaya, respectively (*Ibid.* 2009).

## 2.4. PLANT DIVERSITY AT THE LOCAL LEVEL

Mizoram is rich in flora and fauna and has the highest forest cover. It is one of the biodiversity hotspots in the Eastern Himalayan region (North east India) with about 94% tribal people living in the State. The forest cover, based on interpretation of satellite data of Nov 2006 –Jan 2007, is 19,240 $km^2$, which is 91.27 % of State's total geographic area. In terms of forest canopy density classes, Mizoram has 134 $km^2$ very dense forests, 6,251 $km^2$ moderately dense forests and 12,855 $km^2$ open forest The State has 2 National Parks and 8 Wildlife Sanctuaries covering an area of about 1241 $km^2$ which is 5.89% of its geographical area (SFR, 2009) which are as follows:

I. **Wildlife Sanctuaries**

(1). Dampa Tiger Reserve 500.00 sq. km

| | | |
|---|---|---|
| (2). | Khawnglung Wildlife Sanctuary | 35.00 sq. km |
| (3). | Lengteng Wildlife Sanctuary | 60.00 sq. km |
| (4). | Tawi Wildlife Sanctuary | 35.75 sq. km |
| (5). | Palak Wildlife Sanctuary | 5 sq. km |
| (6). | Thorang Wildlife Sanctuary | 50.00 sq. km |
| (7). | Pualreng Wildlife Sanctuary | 50.00 sq. km |
| (8). | Ngengpui Wildlife Sanctuary | 110.00 sq. km |

II. **National Parks**

| | | |
|---|---|---|
| (1). | Phawngpui National Park | 50.00 sq. km |
| (2). | Murlen National Park | 100.00 sq. km |

Little is known about the plant diversity of Mizoram and no adequate scientific research has been carried out so far. According to IIRS (Indian Institute of Remote Sensing) Dehra Dun report 2002, maximum number of species occurs in the tropical wet evergreen forests followed by sub-tropical broad-leaved hill forests. The evergreen trees form the main part of multi-storied canopy. Dipterocarpus tree species and similar group of trees may project above the general level. Deciduous species are few and never form separate type of forest in Mizoram. Canes, climbers and bamboos are abundant, while herbaceous vegetation and grasses are scarce. Undisturbed patches of tropical evergreen forests occur in Dampa Tiger Reserve and Ngengpui Wildlife Sanctuary.A few patches of pines confined to the eastern higher altitude in Champhai District. Large tracts of bamboo cover almost all the lower valleys and river banks *Arundinaria callosa*, *Sinarundinaria* intermedia etc occur above 1800 m. *Melocana baccifera* dominates the bamboo forests and occurs associated with jhumlands. They

occur as pure patches along the river valleys and also form under storey in Semi-evergreen forests. Pure pockets of *Bambusa tulda* occur sporadically along riverbanks and clumps of *Dendrocalamus hamiltonii* occur here and there between the elevations of 900 m-1500 m (Anon. 2002).

The first exploration and documentation of plant diversity in the State was first made by Col. A. T. Gage, based on his own collections made from a very small area in Lunglei district during March – April 1899. He recorded 317 species, including 26 species of cryptogams (Gage, 1899). J. E. Leslie also made some collections in December 1902 and sent them to Calcutta. Some valuable collections made by Mrs. N.E. Parry from 1924 to 1928 were sent to Royal Botanic Garden, Calcutta (now India Botanic Garden, Howrah). She contributed some plants in her book 'The Lakhers' (Parry, 1932). Rev. W.G.L. Wenger (1926 and 1932), Rev. R.A. Lorrain and his daughter Lorrain Foxall (1940) also made some collections from Lunglei, and sent most of them to Kew and some to Calcutta. Based on these collections, Fisher (1938) published "The Flora of Lushai Hills" enumerating 1360 species including 6 gymnosperms and 155 species of cryptogams. The plant collections of the state have also been made by Kanjilal *et al.,* 1934-1940. Deb and Dutta (1987) have thrown some light on the vegetation of Mizoram based on the observation made in Mamit subdivision and west Aizawl. Lalramnghinglova in the year 1997 published "Handbook of Common Trees of Mizoram" and later in the year 2003, he published "Ethnobotanical Plants of Mizoram" (Lalramnghinglova, 2003). Jha (1997) has published "Natural Resources of Mizoram". Singh *et al.* (1990) recorded 244 species of orchids under 74 genera from the state (Singh *et al.,* 2002). Flora of Mizoram has been published by Singh *et al.* (2002). Sawmliana (2003) has published "Plants of

Mizoram" enumerating 966 plant species of Mizoram. Some species of sedges and grasses were worked out for the state by some workers (Rao & Verma 1982; Shukla 1995). So far, Lalnunmawia (2003) identified 20 species of bamboos and Environment & Forest Department, Govt. of Mizoram, Aizawl (2010) published 35 species of bamboos (Anon. 2010). Lalnuntluanga (2007) identified 12 species of canes from Mizoram. Saithantluangi (2010) recorded 233 species of orchids from Mizoram.

The reported floral resources of Mizoram are: Flowering plants-2141 species; genera-905; Family-176; Gymnosperms-6, Pteridophyte-211, Quercus-18; Desmodium-17; Ficus-34; Polygonum-20; Begonia-18; Piper-126; Endemics-30spp (Chaudhuri & Sarkar, 2003).

## 2.5. PLANT DIVERSITY ALONG HABITAT GRADIENT

Changes in animals or plants communities along habitat gradient have attracted attention since Alexander von Humboldt's investigations on altitudinal patterns in plant diversity in the Andes (von Humboldt and Bonpland, 1807). Whittaker (1972) coined the term beta diversity (inter-habitat diversity) for the change of organismic diversity along habitat gradient (Brehm and Fiedler, 2004). Beta (β) diversity is by far the most studied scale of differentiation diversity and indeed the term is often applied to any investigation which looks at the degree to which the species compositions of samples, habitats or communities differ (Southwood, 1978). Taken together with measures of within habitats diversity, β diversity can be used to give the overall diversity of an area (Routledge, 1977).

The latitudinal decrease in species richness has been known for over a century (Wallace, 1878; Pianka, 1966; Brown and Lomolino, 1998). This latitudinal pattern is commonly explained by monotonic relationship with climatic factors such as primary productivity or other energy-related factors. (Richerson and Lum, 1980; Turner *et al.,* 1987; Currie, 1991; Rohde, 1992; Wright *et al.,* 1993; Austin *et al.,* 1996; Grytnes *et al.,* 1999). Altitudinal trends in species richness are generally thought to mimic latitudinal trends in species richness, and the same factors are often used to explain this altitudinal pattern (Mac Arthur, 1969, 1972; Begon *et al.,* 1990; Rohde, 1992; Rahbek, 1997; Brown and Lomolino, 1998; Givnish, 1999; Grytnes and Vetaas, 2002).

Several studies have found a decreasing trend in species richness with altitude (**e.g.,** Yoda, 1967; Alexander and Hilliard, 1969; Kikkawa and Williams, 1971; Hamilton, 1975; Wolda, 1987; Gentry, 1988; Kitayama, 1992; Navarro, 1992; Stevens, 1992; Patterson *et al.,* 1998; Vazquez and Givnish, 1998; Odland and Birks, 1999). On the contrary, Mishra and Laloo (2006) have reported more species at high altitude than low altitude forests situated in vicinity. They argued that this could be due to varied topography and changed edapho climatic conditions in the forests of an area located at different altitudes. However, separating the influences of altitude, area, and isolation is difficult because of the conical shape of mountains. Altitude and/or surface area are better predictors of species richness than any measure of water chemistry (Jones *et al.,* 2003).

Rahbek (1995) presented a critical literature review on species richness patterns in relation to altitude and showed that approximately half of the studies detected a mid-altitude peak in species richness. Studies reported a humped

relationship between species richness and altitude includes Whittaker (1960), Janzen (1973), Whittaker and Niering (1975), Tilman (1982), Shmida and Wilson (1985), McCoy (1990), Tilman and Pacala (1993), Lieberman *et al.* (1996), Rahbek (1997), Gutierrez (1997), Fleishman *et al.* (1998), Grytnes and Vetaas (2002), Oommen and Shanker (2005), Kharkwal *et al*. (2005), Jiang *et al.* (2007), Gairola *et al.* (2008) and Aynekulu, (2008).

Species density, for example the number of species per $m^2$, is the most commonly used measure of species richness, and is especially favored by botanists (Bunce and Shawn, 1973; Kershaw and Looney, 1985). High species richness per unit area is largely due to presence of synuisae in the forest (Mishra *et.al.* 2005). Species richness as a measure of diversity, has been used successfully in many studies, for example those of Abbott (1974), Corror and Simberloff (1978). Kempton (1979) observed that the distribution of species abundance is often a more sensitive measure of environmental disturbance than the species richness alone. A number of simple indices have been derived using some combination of 'S' (the number of species richness recorded) and 'N' (the total number of individuals summed over all 'S' species). These include Margalef's species richness index ($D_{mg}$) (Clifford and Stephenson, 1975). The undisturbed forests in north-east India are stable and more complex; however, species richness is highly supported by mild disturbance (Mishra *et. al.* 2004, 2005). The gaps in the forests as created by mild disturbance support seedling recruitment as well as their survival and growth, resulting in more number of young individuals indicating better natural regeneration (Mishra *et. al*. 2003, 2005).

One of the most enduring of all diversity measures is the Shannon index. Shannon and Wiener independently derived the function that is now known as

the Shannon index or Shannon information index (Shannon and Weiner 1963), though sometimes mistakenly referred to as the Shannon – Weaver index – a misunderstanding that arouse because the original formula was published in a book by Shannon and Weaver in 1949 (Magurran, 2004). Although as heterogeneity measures, Shannon's index takes into account the evenness of abundance of species; it is possible to calculate a separate additional measure of evenness. The Maximum diversity ($H_{max}$) which could possibly occur would be found in a situation where all species are equally abundant, in other words if $H' = H_{max} = \ln S$. The ratio can therefore be taken as a measure of evenness (J') (Pielou, 1969).

One of the best-known measurements of dominance is Simpson's index of Dominance (D), Simpson (1949) whose measurements are weighted towards the abundances of the commonest species rather than providing a measure of species richness. It is occasionally called the Yule index since it resembles the measure of G. U. Yule devised to characterize the vocabulary used by different authors (Southwood, 1978). Simpson's index is heavily weighted towards the most abundant species in the sample while being less sensitive to species richness.

Harper (1977) has suggested that the largest tree in the canopy is likely to be the oldest. Typically, the size-class distribution of Dipterocarps is in the reversed 'J' shaped with the abundance of established seedlings, poles and mature trees but relatively few in small saplings (Richards, 1996).

The distance methods yield three quantitative parameters- density, basal area, and frequency. Any one of the three parameters may be interpreted as 'importance value' (Phillips, 1959). The importance value index (I.V.I) is defined as

the sum of relative dominance, relative frequency, and relative density. The importance value of a species may be converted into the so called "importance percentage" by dividing the importance value by three (Muller-Dombois and Ellenberg, 1974).

The idea that in tropical forests the crowns of the trees form several superposed strata or stories (the words tier, layer and canopy are also used) has been current in the literature for a very long time; it may be originated in Von Humboldt's (1808) description of the South American hylaea as 'a forest above the forest'. The term stratification as applied to rain forests has been variously interpreted; its meaning is often misunderstood. Sometimes it is stated categorically that there are three strata (according to a few authorities, more than three). Brown (1919) described the stratification of Philippine *Dipterocarp* forest in these words ''the trees are arranged in three rather definite stories- the first, or dominant storey form complete canopy; under this there is another storey of large trees, which also form a complete canopy. Still lower there is a storey of small scattered trees". Study of forest structure by using profile diagram was first applied in the forest of Guyana (Davis and Richards, 1934), has now been widely used in many parts of the world. Detailed analysis of forest structure using profile diagram was also done in Mora associations of Trinidad, dominated by *Mora excelsa* (Beard, 1946). Though somewhat laborious, profile diagram has proved a valuable method of recording and comparing the structure of tropical forest communities.

The demand of species-rich natural communities such as rain forest is variable and complex as there are inter-specific differences in the quantities, proportions, spatial placement, and timing of nutrient requirements (Jordan, 1977).

Successful establishment of seedlings and their growth rate are determined by different microclimate like light, moisture level in the soil, chemical composition of soil and temperature (Fox, 1976, Mishra *et al.,* 2003).

## 2.6. SOIL AND VEGETATION RELATIONSHIP

Soil physico-chemical properties and vegetation has a complex interrelationship. Soil properties influence the vegetation and *vice versa.* Selective absorption of nutrients by different tree species and their capacity to return these to the soil brings about changes in the soil properties (Rawat, 2005).

Temperature is an important parameter of soil because it influences the activity of roots and soil organisms, rates of decomposition, and nutrient and water uptake (Kimmins, 2005). It is one of the most important factors for the growth of plant particularly that of the surface layers by its effect during germination (Richardson, 1958). Soil temperature may affect microbial activity both directly and indirectly, through its impact on other factors such as soil moisture and litter quantity. Higher temperatures are associated with higher rates of microbial activity. Moreover, changes in soil temperature also affect the microbial community composition (Wang and D'Odorico, 2008). High soil temperatures will reduce the germination and establishment of seedlings while low soil temperatures frequently limit growth rates in cool climates. Soil temperatures are effectively reduced by the presence of a living canopy or a layer of dead vegetation, either standing or as a surface mulch (Lavelle and Spain, 2003). Soil temperature also influences the growth and composition of forest ecosystems, for example, forest ecosystems of the Chena River floodplain in interior Alaska (Viereck, 1970). Bonneau, 1979 (In: Lavelle and Spain, 2003)

considered that a forest canopy in a temperate climate may increase winter soil temperatures by 1-2 °C and reduce those during summer by as much as 7-8 °C, compared with soils outside the forest. Soil temperature also affects root growth of plants. Root-growth of ponderosa pine is more dependent on soil temperature and shoot-growth more dependent upon air temperature (Larson, 1967). Optimum root growth occurred in $15^0$C air and $23^0$C soil. Optimum root growth for northern red oak, basswood and white ash also occurs at relatively high soil temperatures (Larson, 1970). Low soil temperatures tend to reduce metabolic activity and reduce membrane permeability so that uptake of water and nutrients is limited (Barnes *et al.,* 1998).

The physical properties of water greatly influence its availability to plants and control the global, regional and local distribution of vegetation on the Earth. It is the interaction of water molecules with soil particles that largely influence the amount of water that can be used by an individual plant for growth (Barnes *et al.,* 1998). The single most powerful control on the rate of chemical and biological processes in the soil is the soil water content. It is the medium in which most transport of elements and particles occurs within the ecosystem **e.g.,** to the root surface and across its boundaries (Scholes *et al.,* 1994). A sufficient amount of soil moisture is necessary for efficient growth of plant, excessive irrigation or flooding diminishes the growth, as it destroys the soil texture (Howard and Hole, 1918). The amount of moisture in the soil influences transpiration from foliage of plants (Singh and Singh, 1937). The moisture content in soils is influenced by the nature of the soil (Bhide, 1921). Medium black soils have higher amounts of soil moisture than light grey coarse soil. Sandy soils have the lowest amount of soil moisture (Dighton, 1997).

pH characterizes soil acidity and is strongly correlated with base saturation, organic carbon, total nitrogen and cation exchange capacity (CEC) that are important parameters to characterize soil fertility for plant production (Landon, 1984). Most forest soils range from extremely acid (pH 4.0) to slightly acid (pH 6.5) (Barnes *et al.,* 1998). According to Singh and Datta (1987) the hill soils of Mizoram are acidic and conformed with several other works (Toky and Ramakrishnan, 1981; Andresse and Koopmans, 1984; Okigbo, 1984; Kumada *et al.,* 1985). A particular forest soil is substantially influenced by organic matter additions (**e.g.,** leaves, roots, twigs, reproductive structures) from overstory trees and the acids produced during microbial decomposition. The general trend is for conifers such as pine, spruces, hemlock and Douglas-fir to increase surface soil acidity (***i.e.,*** decrease pH) to a greater extent than hardwoods or northern white-cedar (Barnes *et al.,* 1998). An example of how individual trees influence soil acidity is provided by tuliptree and eastern hemlock in eastern Kentucky (Boettcher and Kalisz, 1990). Although these trees co-occur on the same parent material, the soil pH under tuliptree (pH 4.7) is consistently greater than that beneath eastern hemlock (pH 4.0). In eastern Washington, organic matter additions from western hemlock (pH 4.0) lower surface pH to a much greater extent than western red cedar (pH 5.9) when both species occur on the same soil parent material (Alban, 1969). Comparison of species distributions in France (Bouché, 1972) with those at a number of tropical sites (Lavelle *et al.,* 1995) - including soils with a wide pH range showed that modal species diversity occurred at pH values of 6 to 7 in France and at 5 to 6 in the humid tropics, respectively (Lavelle and Spain, 2003).

The first ever comprehensive study of organic carbon (OC) status in Indian soils was conducted by Raychaudhuri in 1960. They studied 500 soil samples

collected from different cultivated fields and forests with variable rainfall and temperature pattern and confirmed the effects of climate on carbon reserves on both virgin and cultivated soils (Velayutham, *et al.,* 2000). The amount of organic carbon in soils at a particular time is a function of C decomposition rate, annual C input, soil temperature, soil moisture content, soil type and microbial biomass characteristics. As a result, soil carbon has a high correlation with climate. Soil carbon generally increases with increasing rainfall and for any particular level of precipitation decreases with increasing temperature (Resck *et al.,* 2000). A substantial portion of C fixed by vegetation is transferred to the soil annually (Raich and Nadelhoffer, 1989), a portion of which is refractory material with long turnover times (Paul *et al.,* 1997; Falloon and Smith, 2000); the rest decomposes relatively rapidly and is returned to the atmosphere as $CO_2$. Thus soil C is a large, relatively dynamic component of terrestrial C stocks.

The determination of total organic carbon by oxidation with potassium dichromate in a strong acid open medium, was proposed first by Schollenberger (1972) then by Walkley and Black (1934) from which it takes its name (Pansu and Gautheyrou, 2006). The Walkley and Black method for soil organic carbon estimation (Walkley and Black, 1934) is probably the most widely used wet oxidation method for carbon characterization because of its ease of operation (Cheng and Kimble, 2000). The Walkley and Black (1934) method of estimating soil organic carbon has been employed by various scientists (Nelson and Sommers, 1982; Kitayama and Aiba, 2002; Pansu and Gautheyrou, 2006).

After carbon, hydrogen and oxygen, nitrogen is the most abundant element in living tissue. It plays a major role in agriculture, nitrogen being an essential

element for plant growth (Pansu and Gautheyrou, 2006). Nitrogen occurs in both organic and inorganic forms in the soil. Except in carbon -rich sedimentary rocks, sources of soil nitrogen are exclusively from the atmosphere (Kimmins, 2005). In the soil, the organic forms can reach approximately 90% of total nitrogen (Pansu and Gautheyrou, 2006). Total soil N (mainly organic) is generally measured after wet digestion using the well known Kjeldahl procedure (Ryan, *et al.,* 2001). The plant demand for nitrogen is met by the N uptake from soil after the restoring of positive carbon balance of the whole plant (Clement *et al.,* 1978). Vegetative storage proteins may also serve as a mobilizable nitrogen reserve. Convincing evidence for their importance has recently been summarised by Stephen *et al.* (1994) on woody plants and by Staswick (1994) on herbaceous species. Tanner *et al.* (1998) found that reported foliar and litter fall nutrients – particularly nitrogen (N) and to a lesser degree phosphorus (P) and potassium (K) – decreased with increasing elevation and suggested that upland tropical rain forests were constrained by low nutrient supply (Kitayama and Aiba, 2002).

The main source of soil phosphorus is weathering of soil nutrients, there being very little phosphorus in the atmosphere (Kimmins, 2005). Phosphorus (P) is one of the key elements necessary for the growth of plants and animals. Phosphorus exists in soils and minerals, living organisms, and in the water column of lakes and wetlands (Mitsch and Gosselink, 1993). It is available over a narrower range of pH than nitrogen, availability declining above pH 7.5 and below pH 6.5. In acid soils (pH less than 5), phosphorus in the $H_2PO^{4-}$ form reacts with iron and aluminum to form insoluble compounds. Above pH 6, phosphorus reacts with calcium to form insoluble calcium phosphate, although there is generally not a great amount of free calcium in

the soil until the pH rises to pH 7 or above. Maximum availability occurs at approximately pH 6.5. As a result of these processes, phosphorus is found only at very low levels in the soil solution (and is therefore not subject to leaching) and many forest plants must depend on mycorrhizal fungi to obtain the phosphorus that they need. Phosphorus can exist in a number of organic forms, including chelates of iron and aluminum phosphate, and these may increase its availability to plants. It is also held on anion exchange sites (Kimmins, 2005).

A soil tests for routine use should be simple, quick, easy to execute, and inexpensive. The sodium bicarbonate procedure of Olsen *et al.* (1954) meets these criteria and is generally accepted as a suitable index of P "availability" for alkaline soils, where the solubility of calcium phosphate is increased because of the precipitation of $Ca^{++}$ as $CaCO_3$. Field research has confirmed its usefulness in the CWANA region since the region's soils are mainly calcareous (Ryan and Matar, 1990; 1992). Consequently, this soil test has been adapted for routine use almost in all laboratories of the region. The original sodium bicarbonate method, developed and described by Olsen *et al.* (1954), involved the use of carbon black in the extraction reagent to eliminate the color (because of soil organic matter) in the extract. The procedure was, however, modified later, eliminating the use of carbon black (Murphy and Riley, 1962; Watanabe and Olsen, 1965; Olsen and Sommers, 1982). In the modified method, a single solution reagent containing ammonium molybdate, ascorbic acid and a small amount of antimony is used, for color development in the soil extracts (Ryan, *et al.,* 2001).

Of all the essential elements, potassium is the third most likely, after nitrogen and phosphorus, to limit plant productivity. For this reason it is commonly

applied to soils as fertilizer and is a component of most mixed fertilizers (Brady and Weil, 2005). Potassium is one of the most abundant elements in the earth's crust, of which it makes up 2.6%; however, much of this potassium is not easily available to plants (Bhatia, 2002). Some 90 to 98% of all soil potassium in a mineral soil is in relatively unavailable forms. Only 1 to 2% of the total soil potassium is readily available. Available potassium exists in soils in two forms: (1) in the soil solution and (2) exchangeable potassium adsorbed on the soil colloidal surfaces. Although most of this available potassium (approximately 90%) is in the exchangeable form, soil solution potassium is most readily absorbed by higher plants (Brady and Weil, 2005). The readily exchangeable plus water soluble potassium is determined in the neutral normal ammonium acetate (1N $NH_4OAc$) extract of soil (Maiti, 2003). Potassium is taken up by plants from the soil solution, and the concentration in solution will be replenished by the exchangeable fraction. Some of non-exchangeable K can also be released into the soil solution and may thus be taken up by plants (McLean, 1961; Blanchet and Bosh, 1967; Prasad and Power, 1997; Havlin *et al.*, 1999; Brady and Weil, 1999). The capacity of soils to supply plants with K does not depend only on the amount of K reserve in soil, but also on the rate of availability of plants. The latter can be estimated only with suitable experiments in pots (Grimme and Nemeth, 1978). Some soils can provide enough for many years, but the release of K is slow to meet the need of crops (Arnold and Close, 1958; Mc Lean and Watson, 1985; Johnston and Goulding, 1990).

**Chapter – 3**

# STUDY AREA

## 3.1. General Description of Mizoram

Mizoram, which is located in northeastern part of India, is one of the biodiversity hotspots in the Eastern Himalayan region with about 94% tribal people living in the State. The state is characterized by hills with sparse to dense forest throughout. It has a geographical area of 21,081 sq.km and lies between 21° 58' & 24° 35' N Latitude, and 92° 15' & 93° 20' E Longitude, with the tropic of cancer passing through the middle of the state at 23° 30' N latitude (just south of Aizawl city). The length of the state from North to South is about 277 km, while East - West width extends over 121 km.-It has a long inter- state boundary with Assam (123 km), Tripura (66 km), and Manipur (95 km). Besides, Mizoram shares international borders on three sides, with Myanmar in the East and South *(ca* 404 km) and Bangladesh in the West *(ca* 306 km). It is surrounded in the North by the Cachar district of Assam, in the East by the state of Manipur, in the East-south and South-west by the Chin and Arakan hills of Myanmar and the western side by the state of Tripura and Chittagong hill tracts of Bangladesh.

The State comprises eight districts, namely- Aizawl, Champhai, Kolasib, Lawngtlai Lunglei, Mamit, Saiha and Serchhip. In terms of geographical area Lunglei District covers the largest area with 4,536 sq. km. while Kolasib District is the smallest with an area of 1,382 sq. km. Aizawl, the capital City of Mizoram has an area of 3,575 Sq. km. Lawngtlai District and Saiha District differs from the rest of the other districts in their administrative setup. There are two Autonomous District Councils

within Lawngtlai District namely the Lai Autonomous District Council (LADC) and the Chakma Autonomous District Council (CADC) with their headquarters at Lawngtlai and Chawngte (Kamalanagar) respectively. One autonomous district council resides within Saiha district, ***i.e.,*** Mara Autonomous District Council (MADC) with it administrative seat located at Saiha town. These autonomous regions are administered in accordance with the provisions of the Sixth Schedule of the Constitution of India. The total population of Mizoram according to 2011 census is 1,091,014 out of which 5,52,339 are male and 5,38,675 are female. The literacy rate is 91.58% as per 2011 population census and statistics collected by Economics & Statistics Dept, Govt. of Mizoram. The main occupation of the people is agriculture.

**(a). Physiography**

The state is a mountainous region and consists of seven, long, North-South traversing parallel ranges with intervening valleys. These valleys are broken into innumerable small hills, locally called "Tlang" with sharp and pointed hill tops. These look like hundreds of pyramids grouped together (Singh *et al.*, 2002). The hilly terrains (High hills) are undulating with average altitude above 1300 m (msl), Medium hills with altitudes ranging between 500 m and 1300 m and Low hills with altitudes below 500 m above msl with the maximum reaching 2,200 m in Blue Mountains (Phawngpui). Dissected hills and hillocks are dominantiy found in most of the river valleys in the western part of the state. The terrain has, perhaps, the most variegated topography among all hilly areas in this part of the country. The hills are extremely rugged and sleep and the ranges and leaving some plains scattered occasionally here and there.

**(b). Geology**

The geology of Mizoram is represented in general by repetitive succession of Neogene (40-20 million years), arenaceous (sandy) and argillaceous (clayey) sediments, subsequently folded into a series of North-South trending, longitudinal plunging, anticlines and synclines. The Mizo hills are part of the folded belt of Tripura -Gachar-Mizoram and adjoining areas which in turn constitute a part of major Assam-Arakan basin (Singh *et al.*, 2002). Geologically, two broad groups - Barail and Surma are eminent, where geological formation may be broadly classified under Bokabil, Bhuban and Barail formation.

*Barail: These are m*ainly argillaceous and have monotonous sequence of shales within interband of siltstone and localised Micaceous sandstone. Oligocene in age, the rocks have low (3° - 15°) rolling dipsand (Singh *et al.*, 2002), which are exposed in the eastern part of the state; showing dendritic drainage pattern and denuded hills oriented in different directions. In the north eastern corner along border with Myanmar, rocks show north-linear trend and sub – parallel mountain ranges and valley type of topography. This is due to the alteration of hard stone and soft shale beds, grouped under the Barail group.

*Surma Group:* The rocks of the Surma group are exposed in the western part of the state and exhibit ridge and valley features and trellis drainage pattern. This group, Mio - Pliocene in age, is represented by the Bhuban and the Boka Bill Formations. The Bhuban formations, which are predominantly arenaceous, have been further sub-divided, based on lithology and order of superposition, into three units, ***viz***., the lower, middle arid the upper Bhubans, The Boka bill Formation remained undivided.

*Lower Bhuban* : It is predominantly arenaceous and includes fine to very fine grained, compact, bluish ash, greyish coloured massive to well bedded lethic greywacke sandstones, full of turbidits features. Besides, well laminated siltstone, silty shale/shale (olive green) interlaminations are found to occur within this. The Bhuban is found to occur in the anticlinal cores of the high ranges and in most cases crop out along the faulted contacts.

*Middle Bhuban:* It shows dominance of shales and mud stone with interbands of sandstone.

*Upper Bhuban:* This unit overlies the Middle Bhuban conformably and their contact is gradational to transitional to the underlying rocks. It is predominantly arenaceous and comprises mostly hard, compact, massive to well-laminated, bluish grey to grey coloured sandy greywacke with siltstone/shale interlamination. The shales are olive green in colour. At places, silty shales are dominant. Sometimes sandstone bands have calcareous matrix and often contain narrow bands of calcareous pebbly conglomeratic sandstones with lamellae branch fossils. Besides, sandstone bands contain large calcareous boulders of various shapes and sizes. They exhibit typical turbidite structures with much ridge structures and ripple-drift-cross laminations.

*Bokabil formation:* The rocks belonging to this formation occur conformably over the Upper Bhuban and their contacts with the lower units are transitional. It is represented by soft, grey coloured, friable loosely packed medium to fine grained feldsp.atb.ic sandy greywacke sandy shale with interiaminated silt/shale alternations. Occasionally, brownish yellow ferruginous sandstones are also present. The rocks of this formation exhibit typical turbidite features, with multiple grading, and ripple-drift-cross laminations etc.

At places, rough cross beddings and large current bedding are also present (Singh *et al.,* 2002).

**(c). Drainage**

The drainage pattern of Mizoram is virtually shaped by its physiography and the geological structures. Mizoram is drained by a number of rivers, streams and rivulets of various patterns and lengths. The drainage follows the synclinal valleys between the parallel ranges. The rivers, tributaries and streamlets at various places form deep gorges, and cut across the striking ridges forming water gaps. The upper courses of the rivers are often intervened by waterfalls. As the drainage course is controlled by parallel ranges, the drainage of ephemeral and consequent types show trellis, dendretic as well as parallel drainage patterns. Most of the drainage lines originate in the central part of the state and flow either towards north or south directed by the north-south trending ridges. The valleys are narrow and have been carved out in softer formations.

There are number of rivers in Mizoram. The longest river is Tlawng (Dhaleshwari) which is 185.15 km in length. It is followed by Tiak (159.39 km in length), Chimtuipui or Kolodyne (130.46 km), Khawthlangtuipui or Karnaphuli (128.08 km), Tuichang (120.75 km), Tuirial or Sonai (117.53 km), Tuichawng (107.87 km), Mat (90. 16 km), Tuipui or Khawchhak (86.94 km), Tuivawl (72.45 km), Teirei (70.84 km), Tuirini (59. 57 km), Serlui (56.35 km) etc.

The northern part is drained by large rivers like Tlawng (with its tributaries - Teirei and Tut), Tuivawl, Tuirial, Langkaih and Tuivai which eventually falls into the Tuiruang River in Cachar plains of Assam. The southern part is drained

by many prominent rivers like Chhimtuipui (also known as Kolodyne, which originates in Myanmar) with its tributaries - Mat, Tuichang, Tiau and Tuipui whereas river Khawthlangtuipui with its tributaries Kawrpui, Tuichawng, Kau and De drains the south-western part of the state eventually flowing into Bangladesh. These and a few more rivers, forms their respective watersheds in the path they flow giving rise to 25 watersheds in total for the whole of Mizoram. Rainfall is the only source of water supply to the rivers of Mizoram and is well spread throughout the year except November, December and January.

**(d). Climate**

Mizoram enjoys a moderate climate owing to its tropical location. It is neither very hot nor too cold throughout the year. The region falls under the direct influence of the south-west monsoon. As such, the region receives an adequate amount of rainfall. The climate is humid tropical, characterized by long summer with heavy rainfall.

Temperature in the state varies from about 6 $^0$C in winter to about 30 $^0$C in summer or spring. Spring starts from March till May and the temperature is usually between 18 $^0$C to 25 $^0$C and occasional rainfall sometimes occurs during this season. Summer/ Monsoon season starts from Late May/June till September. The onset of monsoon brings down the temperature to about 18 $^0$C to 31 $^0$C. The North-westerly thunderstorms, sweeping over-the hills in the entire state brought heavy downpour during monsoon. Late September and October are the autumn months when rains cease and temperature is usually between 19° C and 25° C. The temperature continues to fall

with the break of the winter season from November to February with temperature ranges normally between 6 $^0$C to 20 $^0$C.

It rains heavily from Late May to September. The average rainfall is 2000 mm to 3600 mm per annum. The north western portion of the state receives highest rainfall ***i.e.,*** more than 3500 mm per annum. The rainfall also increases southward with increase in humidity. While Aizawl located at 23$^0$44'N and 92$^0$43'E receives about 2080 mm rainfall, Lunglei (22$^0$ 53'N and 92$^0$45'E) records as high as 3500 mm. of rainfall.

**(e). Soil**

The soils of Mizoram have developed from shale, sandstones and mudstone and are dominated mainly by loose sedimentary formations. They are generally young, immature and sandy. The lateritic soil with high percentage of acidity is the common characteristic of the soil of Mizoram. The soil acidity is high with pH value varies from 4.1 to 5.8. Due to heavy rainfall the soil is weathered and leached and as a result is poor in potash, phosphorus and organic carbon contents. But in an un-eroded soil, the content of Nitrogen is quite high fostered by accumulation of organic matters. The water holding capacity of the soil is low because of its clayey nature. The soils in the valleys are heavier as they were brought down by rain water from the high altitudes. The soils of Mizoram can be classified into three orders of soil taxonomy, ***viz***., Entisols, Inceptisols and Ultisols.

**(f). Forest Types / Vegetation cover**

The forest or vegetation cover of North-east India has been dicussed by many eminent botanists and forest officers such as Hooker (1872-1897), Kanjilal *et al.*

(1934 - 40), Champion and Seth (1968), Rao and Panigrahi (1961). However, studies pertaining to forest types of Mizoram (Deb and Dutta, 1987; Singh, 1997; Lalramnghinglova and Jha, 1997) are scanty. Based on these fragmentary studies as well as from the observations and collections made in the field, Singh *et al.* (2002) classified the forests of Mizoram into following types, based mainly on the altitude, rainfall and dominant species composition.

**1. Tropical wet evergreen and semi evergreen forests:**

These forests are usually met below an altitude of 900 m and form one of the major forest types in Mizoram with rich species diversity. Patches of these forests can be seen usually on the steep slopes, rocky and steady river banks and areas not suitable for shifting cultivation. The exact distinction between the evergreen and semievergreen forests is difficult as they occur in the areas of similar characteristics where rainfall averages between 2000 - 2500 mm annually and temperature varies between 20° C and 22° C. Tropical wet evergreen forests are met usually in southern and western part of Mizoram, while semi-evergreen forests occur in northern, North-western, western and central part of the Mizoram.

The top canopy is composed of mighty trees, *like Dipterocarpus turbinaius, D. retusus, Michelia champaca, Artocarpus chama, Aphanamixis wallichii, Mesua ferrea, Toona ciliata, Duabanga grandiflora, Bischofia javanica, Schima wallichii. Haldina cordifolia, Firmiana colorata, Syzygium cumini, Actinodaphne angustifolia, A. obovata, Sapium baccmum, Phoebe attenuata, Chukrasia tabularis, Anogeissus latifolia, Calophyllum polyanthum, Cryptocarya amygdalina, Cinnamomum bejolghota, C. pauciflorum, Lindera pulcherrima, Persea villosa, Castanopsis indica, Beilschmiedia assamica, Pterospermum acerifoliurn, Elaeocarpus*

*aristatus, E. fioribundus,* etc. Buttressed trunks are characteristic of the majority of the trees of this storey.

In exposed and drier areas, where there is only a thin layer of soil, deciduous elements along with some evergreen trees etc are found. Sometimes these are grouped as a distinct type, referred as tropical moist deciduous forests (Lalramnghinglova & Jha, 1997). The distinction between the tropical evergreen forests and tropical moist deciduous forests is difficult as they are found in the same hill ranges. Some common deciduous trees are *Bombax ceiba, Juglans regia, Emblica officinalis, Erythrina arborescens, Albizia lebbek, A. procera, Lagerstroemia speciosa, Firmiana colorata, Sterculia villosa, Bischofia javanica, Podocarpus neriifolia, Gmelina arborea, Bursera serrata, Garuga plnnata, Macaranga denticulata,* etc.

The second canopy is composed of trees, like *Garcinia cowa, G. lanceaefolia, Dysoxylum binecteriferum, Aphanamixis chittagonga, Litsea glutinosa, L. laeta, L. lancifolia, Pterospermum semisagittatum, Syzygium cerasoides, Symplocos javanica, S. lucida, Oxyceros longiflora, Stereospermum colais, Elaeocarpus lanceaefolius, Ardisia colorata, A. paniculata, Turpinia pomifera, Hydnocarpus kurzii, Heritiera papilio, Mangifera sylvatica* etc. Many of these trees are tall but thin boled. Smaller trees of top canopy are also found in second storey.

The third storey or canopy consists of smaller trees and shrubs, like *Ficus subincisa, Leea indica, Meliosma simplicifolia, Litsea meissneri, Saurauia napaulensis, Garcinia sopsopia, Euria cerasifolia, Maesa paniculata, Clausena heterophylla, Mycetia longifolia, Pandanus foetidus, Tournefortia monhana,* etc.

Ground cover comprises species, like *Curculigo latifolia, Phrynium capitatum, Globba clarkei, G. multiflora, Cosius speciosus, Begonia annulata, B. hatacoa, B. lushaiensis, Impatiens chinensis, L. balsamina, Viola betonicifolia, Euphorbia spp, Sonerila maculata, etc. Aeginetia indica,* a saprophyte is also found in moist places.

Climbers and liana, like *Pericampylus glaucus, Pycnarrhena pleniflora, Stephania glandulifera, Tinospora cordifolia, Entada rheedei, Dioscorea pentaphylla, Passiflora foetida, Hoya parasitica, Rhaphidophara eximia, Pathos scandens, Mucuna pruriens, Sarcostemma secamone, Thladianiha calcarata, Thunbergia grandiflora, Piper nigrum, P. clarkii, Combrelurn squamosum, Smilax lanceaefolia, Gnetum gnemon,* etc. are common. Many epiphytic ferns also grow over these giant lianas.

The evergreen forests are also rich in both epiphytic as well as terrestrial orchids. Species, like *Coelogyne nitida, C. flaccida, Cymbidium aloifolium, C. longifolium, Bulbophyllum viridiflorum, B. reptans, Dendrobium aphyllum, D. chrysanthum, D. densiflorum, D. falconeri, D. fimbriatum, Eria pannea, Paphiopedilum villosum, Renanthera imschootiana, Phaius flavus, Pholidota imbricata, Pleione preaecox, etc.* are of common occurrence in Lunglei, Champhui, Sairep areas. *Among the parasites Scurrula pulverulenta, Helixanthera parasitica, Cuscuta reflexa, Viscum monoicum, Balanophora dioica* (root parasite), *Loranthus spp*., etc are seen.

In exposed places or abandoned jhumland, the canopies are not distinct. In these places the species, like *Aponisa oblonga, Mallotus philipp'ensis, Maesa ramentacea, Cordia fragrantissima, Macaranga denticulata, Aritidesma*

*bunius, Dysoxylurn binectariferum, Sterculia villosa, Callicarpa arborea, Meliosma simplicifolia, Dalbergia stipulacea, Duabanga grandiflora, Gmelina arborea, Bauhinia variegata, Syzygium fruticosum, etc. are common. Similarly climbers like Dalhousiea bracteata, Butea parviflora, Combrctum roxburghii, Mucuna nigricans, Thunbergta grandiflora,* members of *Cucurbitaceae, Dioscoreaceae,* etc, are also abundant.

The ground flora of these forests consists of herbs and undershrubs, like *Clerodendrum viscosutn, Melastoma malabathricum, Triumfetta rhomboidea, Desmodium heterocarpon, D. caudatum, Uraria clarkei, Ageratum conyzoides, Blumea fistulosa, Crotalaria ferruginea, Urena lobata, Hedychium coronarium, Ipomoea hederifolia, Peperomia pellucida, Galinsoga parviflora, Vernonia albicans, Solanum nigrum, Polygonum chinense, Torenia diffusa,* members of Scrophulariaceae, Acanthaceae, Lamiaceae, etc. The three species of 'Dancing girl', ***viz***., *Mantisia sanatoria, M. spathulata,* and *M. wengeri,* the later- being endemic to the state are also found in shade on rocks in Theiriat near Lunglei and Blue Mountain areas. Other than these the common species of grasses, ***viz.***., *Imperata cylindrica, Chimonobambusa callosa, Panicum incomtum, Cynodon dactylon, Digitaria ciliaris, Pogonatherum crinitum, Saccharum arundinaceum, S. longisetosum, Thysanolaena maxima,* etc., are also abundant.

Several species of canes such as *Calamus latifolius, C. erectus, C. tennis, C. leptospadix, C. acanthospathus,* etc. are found in Mizoram.

Swamp flora as reported by Deb and Dutta (1987) consists of many herbaceous species, some shrubs and few trees. The common tree species are *Barringtonia acutangula, Lagerstroemia parviflora, Ficus spp., Bischofia javanica,* etc.

The dominant herbaceous species are *Phragmites karka, Alpinia nigra, Saccharum arundinaceum, S. spontaneum, Polygonum microcephalum, P. donii, P. glabrum, Schoenoplectus lateriflorus, Cyperus laxus, C. difformis, Fimbristylis dichotoma, Utricularia aurea, U. exoleta, Eichhornia crassipes*, etc. In marshy places along the river courses especially in Demagiri area, *Alpinia nigra, A. bracteata, A. galanga, Imperata cylindrica, Phragmites karka, Saccharum arundinaceum* and *S. spontaneum*, etc. are found.

Rooted in the mud at edges are found *Osbeckia chinensis, Ludwigia octovalvis, L. prostrata*, etc. Aquatic species either floating or submerged are few in Mizoram. Some such species are *Trapa natans* var. *bispinosa, Pistia stratiotes, Spirodela polyrrhiza, Hydrilla verticillata, Limnophila repens, Rotala indica, Leersia hexandra, Polygonum spp.*, etc.

**2. Montane subtropical forests:**

These forests are usually found on high hills between 900 and 1500 m altitude in the eastern fringes bordering Chin Hills of Myanmar, and places which are cooler and have less precipitation. Subtropical vegetation shows mixed pine forests. The common species of these forests are *Pinus kesiya, Quercus leucotrichophora, Q. acutissima, Q. semiserrata, Castanopsis purpurella, Podocarpus neriifolia, Schima wallichii, Prunus cerasoides, Myristica spp., Phoebe goalparensis, Duabanga grandiflora,* etc. In Ngur - Zote, close to Myanmar border, there is a small patch of *Pinus kesiya,* associated with *Schima, wallichii, Myrica esculenta* and *Quercus spp.* The other species of subtropical forests belong to the genera *Acacia, Albizia, Bridelia, Castanopsis, Cinnamomwn, Engelhardtia, Erythrina, Ficus, Garcinia, Michelia,*

*Terminalia,* etc. In some places palms such as *Calamus erectus, Caryota urens, Didymosperma nana, Licuala peltata, Phoenix humilis,* etc. are also found and form part of subtropical forests. The species of *Lyonia, Gaultheria, Rhus,* etc., are some of the common shrubs in the forests, whereas the herbaceous elements are represented by *Potentilla fulgens, Ranunculus sceleratus, Artemisia spp., Elsholtzia fruticosa,* etc.

**3. Temperate forests:**

These forests usually occur above the elevation of 1600 m in the areas, like Lengteng, Naunuarzo, Farpak, Phawngpui. These forests are not typical temperate forests as found elsewhere in eastern Himalaya. In appearance they look like somewhat subtropical type. Here subtropical elements are mixed with some temperate elements. The predominent arboreal elements in the forests are *Pinus kesiya, Actinodaphne microptera, Betula alnoides, Exbucklandia populnea, Elaeocarpus serratus, Dillenia pentagyna, Michelia doltsopa, M. champaca, Garcinia anornala, Photinia integrifolia, Litsea salicifolia, Querus floribunda. Liihocarpus. dealbata, Rhododendron arboreutn, R. vetchianum, R. watti, R. johnstoneanum, etc.* The prominent shrubs occuring in these forests are *Pittosporum podocarpum, Xylosma controversum, Camellia caudata, Mahonia pycnophylla, Rubus ellipiicus, R. birmanicus, Clerodendrum viscosum, Rosa brunonii, Baliospennum spp., Osbeckia spp., Mussaendra spp.*, etc. The common herbaceous species of these forests are *Hypericum elodeoides, Plantago major, Potentilla fulgens, Impatiens spp., Centella asiatica, Cyanotis cristata, Chirits spp., members of* Asteraceae, Commelinaceae and grasses, like *Arundinaria callosa, Coix lacryma - jobi, Cynodon dactylon, Saccharum longisetosum, Eragrostis unioloides, E. nigra*, etc. Besides, the common climbers in these forests are *Brachystemma calycinum, Illigera khasiana, Millettia pachycarpa, M. pulchra, Rosa brunonii, Smilax*

*spp., Vitis spp.,* etc. Pteridophytes are also abundant in these forests and are represented by *Selagineila chrysocaulos, Cyclasorus perakensis, Dryopteris elongata, Lycopodium hamiltonii, L. setaceum, Tectaria macrodonta, Davallodes membranulosum, Arthromeris wallichiana, Pyrrosia stenophylla, Polypodium spp., Dryopteris spp.,* etc. The epiphytic components are dominated mostly by Lichens, Bryophytes, Pteridophytes, various species of orchids, *Aeschynanthus spp., Agapetes spp., Hoya spp., Vaccinium spp., Viscum spp*., etc.

**4. Bamboo forests:**

Bamboos usually grow as an understorey to the tree species in tropical evergreen and subtropical mixed-deciduous forests, whereas *Melocanna baccifera* forms dense or pure forests in certain areas in the state. Large tracts of bamboos are seen throughout Mizoram but their distribution is somewhat restricted to about 1600 m and below. They occur mostly between 40 m and 1520 m in tropical and Subtropical areas. However, few species, like *Chimonobambusa callosa, Drepanostachyum jainianum, Melocalamus mastersii* occur in temperate areas in Blue Mountain and Mount Chalfilh. Bamboos are more concentrated along the Tripura border. They are abundant in the western and eastern fringes than in the eastern region. In the eastern region bamboos are usually confined along the river banks up to a kilometer or so. The commom species of bamboos found in Mizoram are *Melocanna baccifera, Bambusa tulda, Dendrocalamus hamiltonii, Schizostachyum polymorphum.*

Some important associates found growing along with bamboos are *Emblica officinalis, Litsea monopetala, Pterospermum acerifolium, Terminalia myriocarpa, Dipterocarpus turbinalus, Caryota mitis, Artocarpus chama, Duabanga grandiflora, Albizia procera, Haldina cordifoia, Gmelina arborea, Syzygium spp.,* etc.

**5. *Quercus* forests:**

Quercus forests are mostly found intermingled in subtropical and temperate areas. Pure patches or predominant Quercus species are present near Champhai - Baite hill ranges and its distribution is restricted to other small areas in the eastern part of Mizoram. *Lithocarpus dealbata* is other main species.

**6. Jhumland:**

Jhumland are very common in Mizoram. They are classified variously as current Jhumland, old Jhumland and abandoned Jhumland. Jhumlands are more prevalent in eastern Mizoram where extensive and intensive jhumming is practiced. Similarly, the areas in western side in Lunglei district towards Bangladesh have also'jhumlands. Chimtuipui district is most effected district, as far as jhum cultivation is concerned. The vegetation of these Jhumlands has also been described above. The bamboos, grasses, members of Asteraceae, Melastommaceae are most abundant in Jhumlands.

## 3.2. Phawngpui National Park

### (a) Location

Phawngpui (Blue Mountain) National Park is situated 330 km. away from Aizawl in Lawngtlai District, the south-eastern corner of Mizoram **(Fig. 1)**. It was notified following the provisions under Wildlife (P) Act, 1972. Final Gazette notification was issues vide No. B. 12011/5/91-FST, the 22$^{nd}$ July (Vol-XXVI Aizawl, 1$^{st}$ August, 1997 Issue no. 257). The Park is managed by Range Officer with

headquarter at Sangau village and Beet Officers under the control of District Forest Officer (DFO), Lawngtlai.

The area of Phawngpui (Blue Mountain) National Park is about 50 sq. km. with a Geographic Location of 93° 00' 41" E to 93° 04' 57" E and 22° 36' 37" N to 22° 41' 33" N. It is accessible from Sangau via Thaltlang village in the north by light vehicle during fair weather but difficult to go during rainy seasons. Phawngpui National Park lies under the Sub-tropical Hill forest (Lalramnghinglova, 1996) and consists of a series of parallel hills running from North to South direction and includes the highest peak (2,200 m asl) in the State called "Blue Mountain"(**Photo 1**). It has a pleasant and equable warm climate throughout the year. The climate is humid-sub tropical and characterized by long winter. In summer, the temperature ranges from $18^0$C to $24^0$ C and in winter $6^0$C to $15^0$C. Winter starts in November and ends in February. The area is under direct influence of Monsoon. The area receives maximum rainfall between May and September, and the annual rainfall is about 2300mm. A small extent of grassland plateau known as "Far Pak" is situated towards top of the hill and the sylvan of temperate oak trees and *Rhododendron* abound with orchids (**Photo 2**). Commanding a majestic view over the hills and the valleys, this peak presents the most enchanting scenic beauty in Mizoram. There is a semi-circular beautiful cliff in the western side called 'Thlazuang Kham' which has a sharp and deep fall (**Photo 3**). This is the habitat of the wild mountain goats. This cliff was believed to be haunted by spirits. There is Rest House at "Far Pak" maintained and owned by the Department of Environment and Forest, Government of Mizoram. Phawngpui National Park is surrounded by the villages of Sangau, Sentetfiang, Thaltlang, Vawmbuk, Bualpui (NG), Pangkhua, Cheural, Tialdawngi lung, Rawlbuk, Pangrang, Archhuang and

Lungpher. The Park is managed by Range Officer with headquarter at Sangau village and Beet Officers under the control of District Forest Officer (DFO), Lawngtlai.

**(b) Description of the boundary**

**NORTH:** The northern boundary of Phawngpui National Park starts from the point where Khamkhuaiva meeting Cheu Lui. It thence follows Cheu Lui downwards upto the meeting point of Hrangchal Samhriahva. The boundary thence goes $10^0$ E upto Khuairawlva. It thence follows Khuairawlva, east-ward encircling hillock where it meets tri-junction point.

**EAST:** The eastern boundary starts from tri-junction point. It thence follows $120^0$ E upto LADC development roads. It thence follows the said development road upto Hnarriat from Hnarriat, the boundary goes downwards following Mangchem khuaikham where all Hnarriat meet. It thence follows south-east direction crossing Khawhalh tlang and Vawmkhaw tlang. From Vawmkhaw tlang the boundary goes south-west direction upto the 3rd saddle of Sabual/Tisun tlang. It thence goes southern direction upto Pangrava just below Pangrang kham. The boundary thence goes straight south-west upto Khumtawipu kham. It thence goes the same direction upto Sangauva/Hrangerhva. The boundary thence follows the said stream upward upto Archhuang peng/ Paduh lungphun kawn.

**SOUTH:** The southern boundary starts from Archhuang peng/ Paduh lungphun kawn. The boundary thence goes South-west direction till it meets Limhmuhva just below Limhmuh kham. It thence goes south-west direction upto Hnaktlawl mual. It thence follows western direction below Hnaktlawl kham till it meets Siachang Lui. It thence follows Siachang Lui upstream uptothe meeting point of streamlet. It thence

goes north-west direction upto Thothek tlang. From Thothek tlang, the boundary thence goes at $254^0$ W till it meets Ailian Lui.

**WEST:** Western boundary starts from Ailian Lui. It thence follows one streamlet upto 200 mts crossing a saddle and thence goes towards northern direction just above Lungpher jhumland till it meets Luilaklawh. From Luilaklawh the boundary goes north direction just above Jhumland of Lungpher village till the last Luilaklawh. The boundary thence goes northern direction till it meets Tisi source crossing Tisi ral Mual. It thence goes north direction till it meets Vawmrawh Lui. It thence goes north-east direction till it meets Sakuhva at its source crossing a saddle till it meets Saza Kah-Lui. It thence follows Saza-Kah-Lui downstream till it meets Cheu Lui. It thence follows Cheu Lui down-stream till it meets the starting point where Khamkhuaiva meets Cheu Lui.

The highest peak is accessible by foot from Archhuang and Vawmbuk villages from the East and is about 4 km. It is also accessible by foot from Lungpher from the West which is about 3.5 km. From Sangau in the North which is the Headquarters of Range Officer, and the Forest Rest House which is located at the grassy 'Far Pak' is accessible by light vehicle during fair weather conditions *via* Thaltlang village and is about 14 km. From 'Far Pak', the highest peak is accessible only through patrolling path which is about 7 km. From the South the highest peak is accessible by foot from Lungpher, Siachangkawn and Vawmbuk villages which are about 7 - 8 km.

The topographical, landuse/landcover and sketch map of Phawngpui National Park is given in **Fig. 2, Fig. 3** and **Fig. 4** respectively as follows:

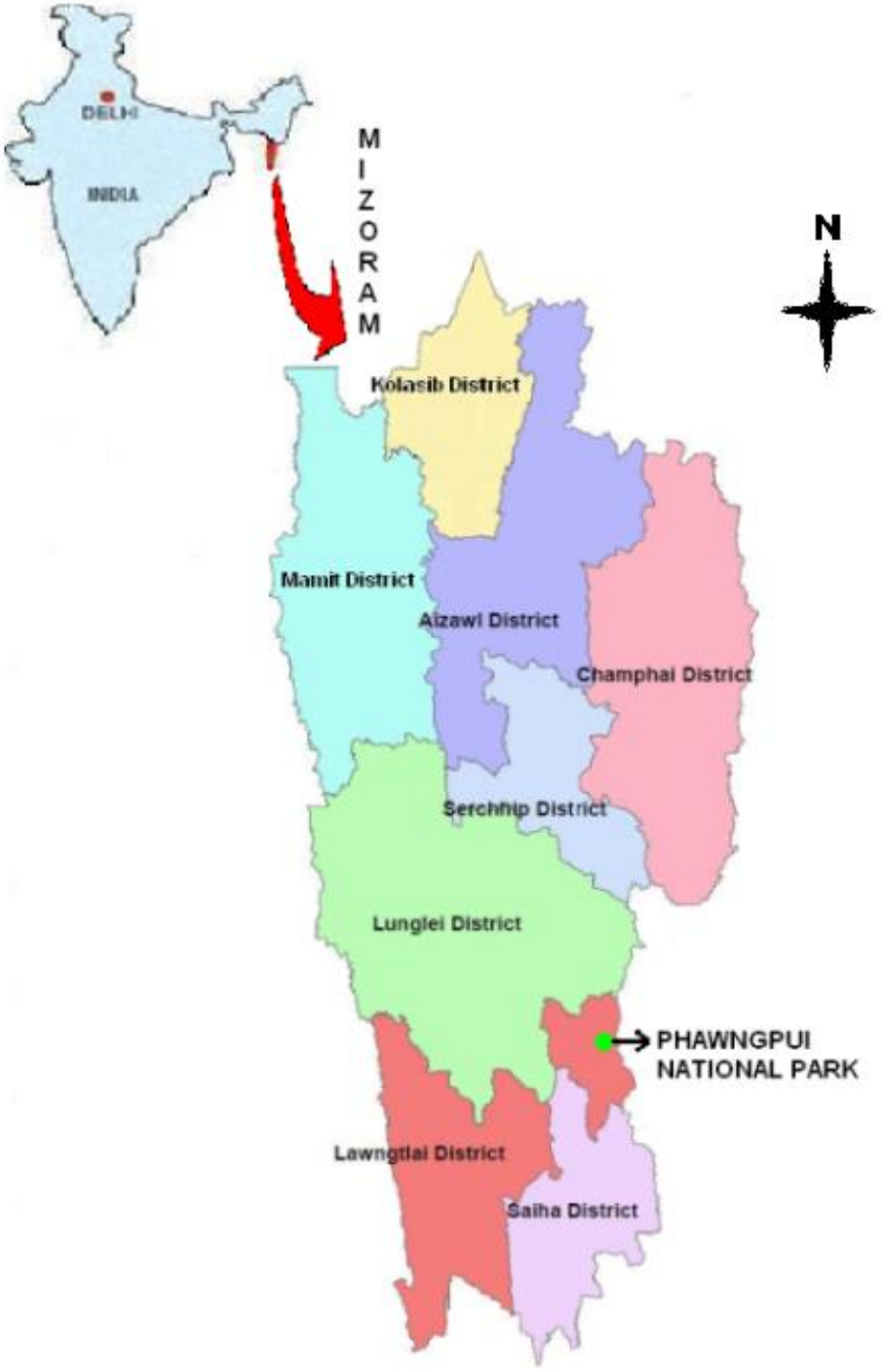



**Fig. 1.** Map of Mizoram showing location of Phawngpui National Park.


**Fig. 2.** Topographical map of Phawngpui National Park.

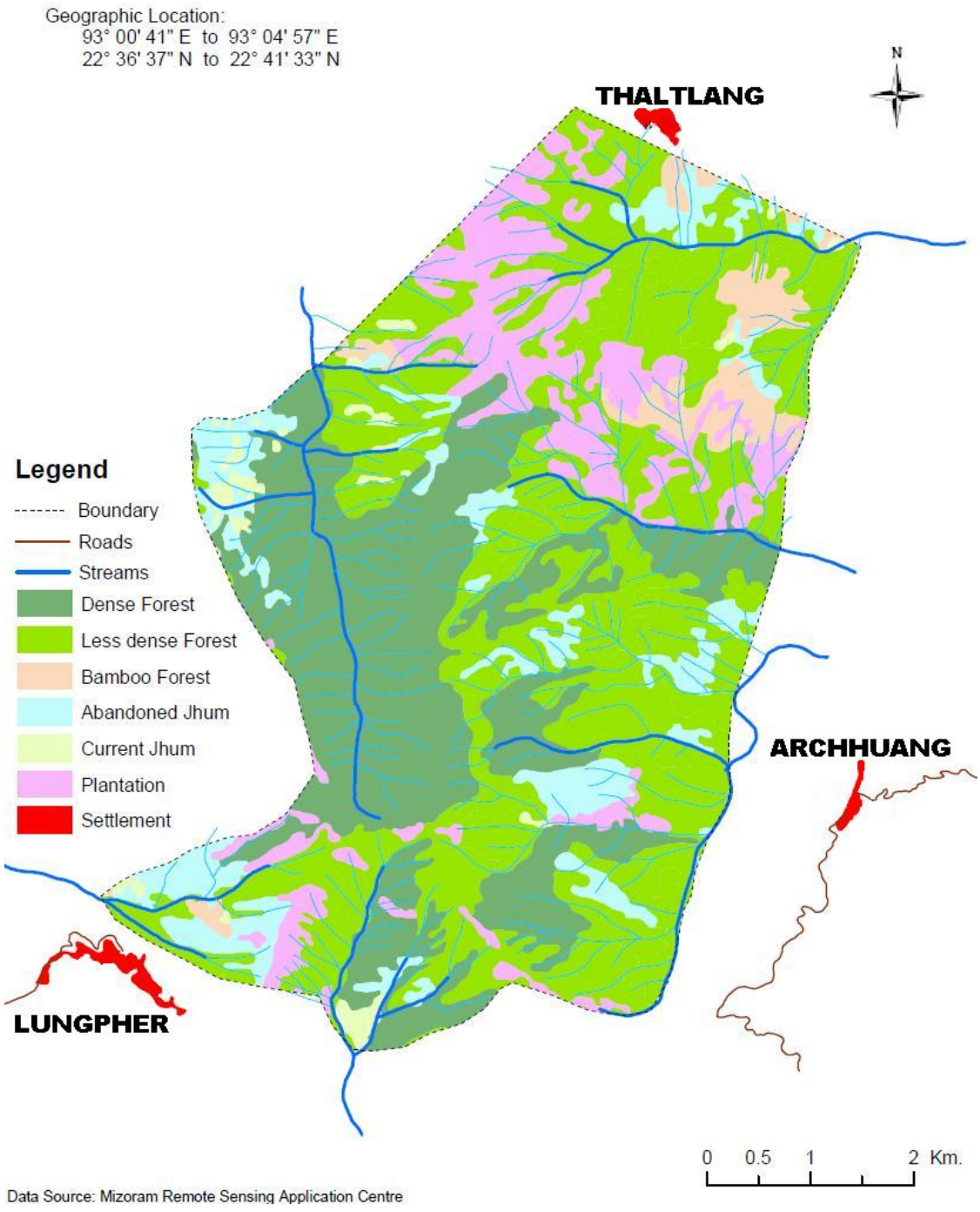
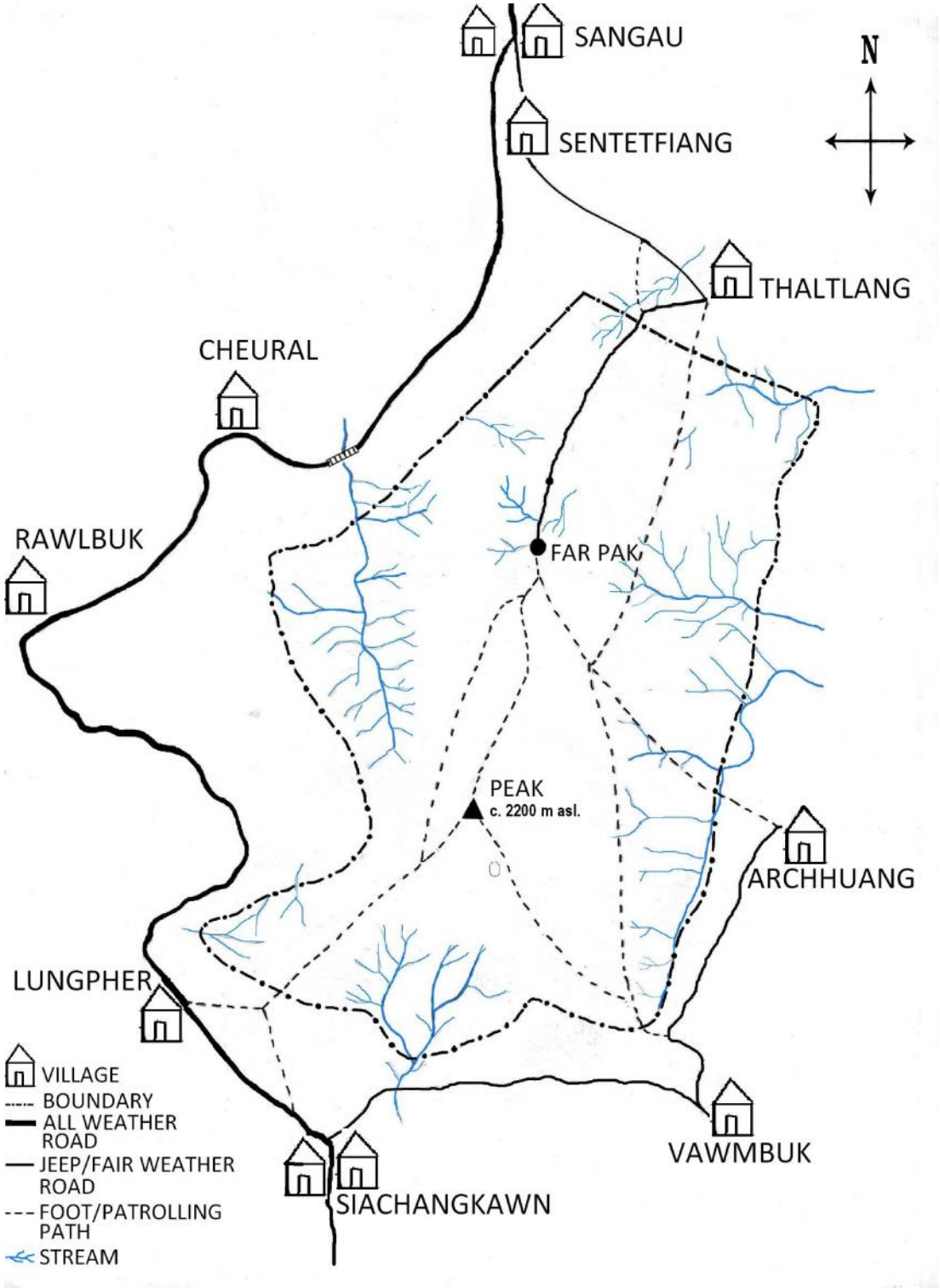



**Fig. 3.** Landuse/ Landcover map of Phawngpui National Park.




Not to scale

**Fig. 4.** A Sketch Map of Phawngpui National Park

**Photo 1**. Phawngpui National Park -View from the Peak.

**Photo 2**. Sylvan of grassland (Far Pak) in Phawngpui National Park

**Photo 3.** Semi circular cliff (Thlazuang Kham): Home of the Serows

**Chapter - 4**

# METHODOLOGY

The following methodologies were employed for the present study:

## 4.1. Pre-survey and Demarcations:

During the month of November and December 2006, the Study Area (Phawngpui National Park) was surveyed and demarcated into three different sites ***viz.***, Site-A, Site-B and Site-C respectively with corresponding to altitudinal levels. Site-A is the lower site ranging from 1500 m asl. to 1700 m asl. Site-B is the middle site and it lies between 1700 m asl. and 1900 m asl. Site-C is the uppermost site ranging from 1900 m asl. to the highest peak, which is *c.*2200 m asl. including "Blue Mountain" which is the highest mountain peak in Mizoram.

## 4.2 Socio-economic survey

Socio-economic survey of the adjacent villages of the study area was done during 2007 by adopting PRA technique (Mukherjee, 2003).

### 4.2.1. PRA Technique:

Participatory Rural Appraisal (PRA) is a methodology for interacting with villagers, understanding them and learning from them. It involves a set of principles, a process of communication and a menu of methods for seeking villagers' participation in putting forward their points of view about any issue and enabling them to do their own analysis with a view to make use of such learning (Mukherjee, 2003). McCracken *et al.* (1988) define PRA as "a semi-structured activity carried out in the

field, by a multi-disciplinary team and designed to quickly acquire new information on, and new hypothesis about rural life". According to Sam Joseph, 'PRA is both an attitude and a method. It helps an outsider to quickly understand the village system from the villagers' point of view' (Narayanasamy, 2009). PRA is a means of collecting different kinds of data, identifying and mobilizing intended groups and evoking their participation and also opening ways in which intended groups can participate in decision making, project design, execution and monitoring (Mukherjee, 2003). A PRA technique is 'the art and science of collecting baseline information from the villagers or local people through various processes and making them involve in the implementation of programmes, decision-making and monitoring the development programmes'.

A PRA technique is a useful methodology to focus attention on people, their livelihoods and their inter-relationships with socio-economic and ecological factors (Mukherjee, 2003).

There are several methods in PRA techniques. In the present research work, interview method has been employed. During 2007 the President of the Village Council and several local people of the adjacent villages of the study area were interviewed to know about the socio-economic conditions of their respective villages.

### 4.3. Layout of Plots/ Quadrats:

The study area was demarcated and divided into three sites ***viz***., Site A, Site B and Site C, respectively at different altitudes in Phawngpui National Park. During the month of March and May 2007, 25 number of quadrats (10 m x 10 m size)

in each site (Site A, Site B and Site C) were laid randomly and marked for woody plants upto 5cm dbh class. Five quadrats of size 1 m x 1 m in each 10 m x 10 m quadrats were laid by nested quadrat method for herbs and 5 m x 5 m quadrats for shrubs as in **Fig. 5.**

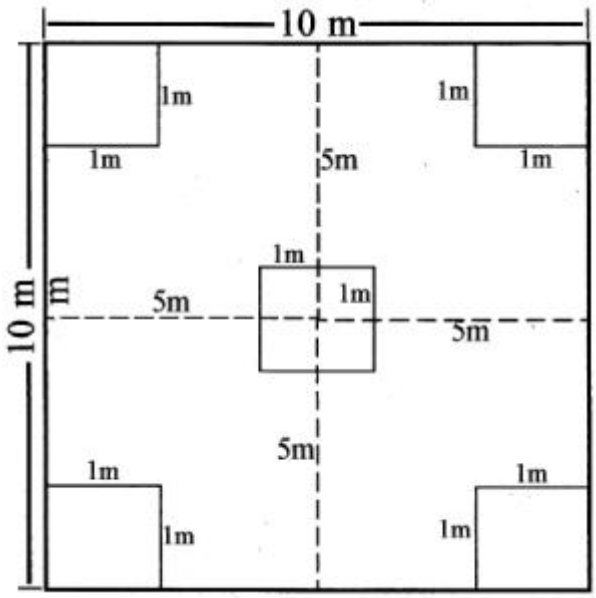



**Fig. 5**: Layout of Plots/ Quadrats

### 4.4. Vegetation Analysis:

During the month of July and August 2007 and 2008, vegetation analysis has been done when majority of herbs and shrubs were at the peak of their growth. Plant species (trees, shrubs, herbs, epiphytes, climbers, bamboos and canes) present inside each quadrats were counted and recorded. In each quadrat, diameter at breast height (dbh) for trees and diameter at ground level for herbs and shrubs was taken and recorded which were used for calculating their respective importance value index.

### 4.4.1. Quantitative Analysis:

The field data were taken into consideration for determining important quantitative analysis such as frequency, density and abundance of plant species as per Curtis and McIntosh (1950). The formula for computing frequency, density and abundance were given as follows:

(a). Frequency (%):

It refers to the degree of dispersion of individual species in an area and expressed in terms of percentage. It was studied by sampling the study area randomly at several places and recording the name of the species that occurred in each sampling unit or quadrat, it is calculated by the equation:

$$\text{Frequency (\%)} = \frac{\text{Number of quadrats in which species occured}}{\text{Total number of quadrats studied}} \text{ X } 100$$

(b) Density:

Density is the numerical strength of a species where the total number of individuals of each species in all the quadrats is divided by the total number of quadrats studied. It is calculated by the equation:

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

(c) Abundance:

Abundance is the study of the number of individuals of different species in which the number of individuals of each species was summed up for all the quadrats divided by the total number of quadrats in which the species occurred. It is represented by the equation:

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

### 4.4.2. Importance Value Index (IVI)

All the tree, shrubs and herbs species counted will be used for determining dominance of a species. In order to express the dominance and ecological success of any species, with a single value, the concept of the importance value index has been used. This index utilizes three characters ***viz***, relative frequency, relative density and relative dominance (Misra, 1968). The importance value index (I.V.I) is defined as the sum of relative dominance, relative frequency, and relative density (Muller-Dombois and Ellenberg, 1974).

(a). Relative Frequency:

The degree of dispersion of individual species in an area in relation to the number of all the species occurred.

$$\text{Relative frequency} = \frac{\text{Number of quadrats of occurrences of a species}}{\text{Number of quadrats of occurrences of all species}} \text{ X } 100$$

(b). Relative density:

Relative density is the study of numerical strength of a species in relation to the total number of individuals of all the species and can be calculated as:

$$\text{Relative density} = \frac{\text{Number of individuals of a species}}{\text{Number of individuals of all species}} \text{ X } 100$$

(c) Relative dominance:

Dominance of a species is determined by the value of the basal cover. Relative dominance is the coverage value of a species with respect to the sum of coverage of the rest of the species in the area.

$$\text{Relative dominance} = \frac{\text{Total basal area of a species}}{\text{Total basal area of all species}} \text{ X } 100$$

The diameter (cm) at breast height (dbh) (1.5 m above the ground) for trees and diameter at ground level for shrubs and herbs is converted to basal area (Sq.cm) as follows,

$$\text{Basal area} = \pi r^2 \text{ X } D$$

$$\text{Where, } r = \frac{\text{average diameter}}{2}$$

D = Density

The IVI was computed by using the following formula as given by Phillips (1959):

IVI = Relative Frequency + Relative Density + Relative Dominance

### 4.5. Plant diversity indices:

In order to study the diversity of plants of the National Park, the following diversity indices were computed.

#### 4.5.1. Shannon-Wiener diversity index (1963):

One of the most enduring index among the other plant diversity indices. The equation used to calculate Shannon-Wiener diversity index is:

$$H' = - \Sigma\, p_i / \ln\ p_i$$

Where, H' = Shannon-Wiener diversity index

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

$p_i = n_i / N$ ; $n_i$ is the important value index of $i^{th}$ species and N is the important value index of all the species).

#### 4.5.2. Whittaker's ($\beta_W$) diversity index (1975):

This index is used to determine the diversity of plants in the forest:

$$\beta_W = (S/\alpha)-1$$

Where, $\beta_W$ = β diversity;

S = Total number of species recorded in the forest.

α = The mean species richness.

### 4.5.3. Evenness index (Pielou's index, 1969):

The equation is given as follows;

$$J' = H'/H_{max}$$

$$J' = H' / \ln S$$

Where, H' = Shannon's index value.

S = Total number of species.

$H_{max}$ = Maximum diversity

### 4.5.4. Sorensen's index of similarity:

Indices of similarity were calculated by using formulae as per Misra (1989) and Sorensen (1948) as follows:

$$S = \frac{C}{½ (A+B)}$$

$$\text{Or, } S = \frac{2\,C}{(A+B)}$$

where, A = number of species at site A.

B = number of species at site B.

C = number of species common to two sites ***i.e.,*** site A and site B.

### 4.5.5. Margalef's index of species richness (1972):

Margalef's index of species richness was calculated by using the formula (Magurran, 2004)

$$D_{mg} = (S-1)/\ln N$$

$$\text{Or, } D_{mg} = \frac{(S-1)}{\text{Log } N}$$

Where, S = Number of species; N = Number of the individuals.

### 4.5.6. Simpson's index of Dominance (1949):

The equation formulated by Simpson is given below:-

$$D = \Sigma p^2_i$$

Where $p_i$ = proportion of individuals in the $i$ th species.

The form of the index appropriate for a finite community is:

$$D = -\Sigma \frac{[n_i (n_i-1)]}{[N (N-1)]}$$

Where, $n_i$ = the number of individuals in the $i^{th}$ species,

N = total number of individuals.

### 4.6. Profile diagram:

Stratification in the national park was carried out by drawing a profile diagram. The profile diagram were drawn along belt transect (1 m thickness X 100 m lenght) in each sites. The height of the trees was measured with the help of Abbney level or Brunton Compass (Muller-Dombois and Ellenberg, 1974).

### 4.7. Population structure of the National Park:

The population structure of vegetation in the national park were studied by randomly laying 25 quadrats of 10 m X 10 m size in each Sites (Site A, Site B and Site C respectively) for woody plant species of diameter greater than or equal to 5 cm at breast height (≥ 5 cm dbh) regardless of tree or shrub characteristic. All the plant species recorded inside the quadrats were classified in a series of seven dbh classes (5 – 15, 15.01 – 25, 25.01 – 35, 35.01 – 45, 45.01 – 55, 55.01 – 65, 65.01 – 75) at the intervals of 10 cm.

### 4.8. Herbarium Methodology

A herbarium is a store-house of plant specimens collected from far and wide, mounted on appropriate sheets, arranged according to some known system of classification, and kept in pigeon-holes of steel or wooden cupboards, usually prepared for the purpose (Jain and Rao, 1977). The guidelines suggested by Jain and Rao (1977) and Womersley (1981) were adopted in collection and preparation of herbarium. The steps involved in Herbarium methods are as follows:

(a) **Plant collection:** The flowers or fruits of different plant species inside the study area were collected as far as possible and in some cases twigs and leaves were also collected. In case of grasses, sedges and other herbs, the whole plant including the underground parts were collected and were prepared in a herbarium for identification by following the works of Jain and Rao (1977) and Womersey (1981).

(b) **Field notes and field numbers**: An important part of the plant collection work is the record of field notes in the field note book. Field note books are specially prepared note books for labeling the plants and for recording notes about them in the field. The pages are serially numbered and there are six tags or tickets on each page having the same number; these are detachable on lines of perforation, and were tied to the specimens with the thread provided in the punched hole of each tag. Detailed notes like location, habit and growth form, flowers and fruits, architecture of shoot and root, bark character of trees, nodes and internodes for bamboos, arrangement of leaves, shape of stem, petiole base etc. were entered in the field note book at the time of collection in the field.

(c) **Preservation of plants before drying:** The specimens collected were poisoned immediately in the camp for longer storage. Poisoning kills the plant thereby the formation of abscission layer and decay was prevented. For poisoning the specimen, 30% para-formaldehyde solution (300g of para-formaldehyde dissolved in 3000ml luke warm water) was poured over the bundles of collected specimens, so that the bundles just get soaked thoroughly. The bundles were then put in a bag and then tied airtight. No further change of folders is necessary till reaching the laboratory. On reaching the laboratory, the bundles were opened out; the specimens were exposed to the air to drive away the excess of paraformaldehyde fumes.

(d) **Pressing and drying plant specimens:** Pressing is the process of placing specimens between absorbents under heavy pressure. Specimens were pressed in a plant press, which consists of a wooden frame (for rigidity), corrugated cardboard ventilators (to allow air to flow through the press), blotter paper (to absorb moisture), and folded newspaper (to contain the plant material). In order to fit on a standard herbarium sheet, plant specimens were pressed flat to no more than 1 1 X 1 6 inches. If the specimen were not fit to those dimensions, it was folded or cut into sections. Large fruits or bulbs are cut in half lengthwise or in slices prior to pressing. Each specimen consists of a stem with attached leaves, flowers or fruits. The roots of herbaceous plants were also included. Plants specimens were carefully arranged while they are placed in the press to maximize preservation of diagnostic features. Leaves, flowers, and fruits were spread out so that they do not overlap and can be observed from different perspectives. The plant press was kept tight; this prevents shrinkage and wrinkling of the plant material and yields specimens that are easier to mount securely on herbarium paper. The objective of pressing plants is to flatten the plant and to extract moisture in the shortest period of time, while preserving the morphological integrity of the plant and to yield material that can be readily mounted on herbarium paper for long term storage.

The pressed plants were thoroughly dried by placing in the sun prior to storage and mounting. To obtain best results the plant press was kept in an oven and provides steady bottom heat between 95°F and 113°F. A low ambient humidity and good airflow around and through the presses also insures rapid and thorough drying of plant material. As the specimens dry, straps on the press were further tighten to minimize shrinkage and wrinkling.

e) **Fumigation:** This was done for killing pests and fungal attack on the plant specimens. The properly dried plant materials were poisoned by dipping into a plastic tray or sprayed with *'Kew Mixture'* (115 gms. of Mercuric Chloride dissolved in 4.5 litres of Ethyl alcohol or Rectified Spirit). One should be very careful while using *'Kew Mixture'* as it is harmful to health. The dried specimens were then mounted on herbarium sheets for identification.

f) **Mounting and stitching:** After the specimen was pressed, dried and poisoned, it was affixed (along with a label) on a mounting sheet with the help of glue. The mounting sheets were made from heavy long-lasting white card sheet in uniform size of 28 x 42 cm (± 1 cm). The attachment or gluing of the specimen was done carefully in such a way to allow maximum observation of diagnostic (usually reproductive) features as well as the range of variation in vegetative structures, including both sides of the leaves. Plants are generally positioned in a lifelike arrangement (that is, with roots or lower stem toward the bottom of the sheet and flowers toward the top). The mounting sheets with specimens glued with fevicol on them were kept in press for one day for proper sticking and drying. Large or bulky items were sewn onto the sheet with a sturdy thread. The objective is to secure the specimen firmly to the mounting paper, while leaving some pieces of the plant loose enough to be removed if necessary.

g) **Labelling:** Mounting of the specimens was followed by pasting of herbarium labels. A plant specimen is incomplete without labeled data. Labeled data is a form of field data and must be accurate. After mounting the specimens on herbarium sheets, each sheet was labeled. A label was pasted on the lower right-hand corner. Herbarium

labels are important parts of finished specimens. The standard size of the label is 4” X 2.5”.

The labels contained the following data.

(i) Collection No. and Date

(ii) Name of the family

(iii) Name of the genus and species

(iv) Locality of collection

(v) Phenology

(vi) Distribution

(vii) Notes

(viii) Collector’s name and number.

### 4.9. Plant identification:

The plant specimens collected during the research work were identified with the help of various regional floras, including the books of “Flora of British India Vol 1-7” (Hooker, 1892-1897), ”Flora of Assam Vol 1-5 (Kanjilal *et al.*, 1934-1940), Flora of Mizoram (Vol. 1) by Singh *et al.* (2002), “A Handbook of Common Trees of Mizoram” (Lalramnghinglova, 1997), “Ethno- Medicinal Plants of Mizoram” (Lalramnghinglova,1997) and “The book of Mizoram Plants” (Sawmliana, 2003). Unidentified specimens were taken to the Botanical Survey of India, Eastern Circle, Shillong, Meghalaya for proper identification and matching of the specimens. Identified specimens were deposited in the Herbarium of the Department of Environmental Science, Mizoram University, Aizawl.

### 4.10. Screening of endemic, rare and endangered species:

Quantification of plants specimens was screened with the help of biodiversity indices, IVI, IUCN criteria, Red Data Sheet and published materials of Botanical Survey of India.

### 4.11. Soil Sampling and Analysis

#### 4.11.1. Soil Sampling:

Soil samples were collected seasonally during the first two years of the research work (2007-2008). From the three different sites, ***viz***., Site A, Site B and Site C, ten number each of soil samples were collected from the top soil (0-15 cm) layer. The composite samples were used for detailed analysis as follows:-

#### 4.11.2. Soil Analysis:

The physical and chemical properties of the collected soil samples were analysed in the laboratory of the Department of Environmental Science, Mizoram University, Aizawl. The physical properties of soil analyzed were temperature, soil moisture content, bulk density, total porosity and water holding capacity of soil, and the chemical properties of soil analyzed were soil pH, Total Nitrogen (TKN) by using micro-Kjeldahl method, Soil Organic carbon content by rapid titration method (Walkley and Black, 1934), exchangeable potassium using flame photometer and available phosphorous using spectrophotometer by Olsen's method.

#### 4.11.2.1. Physical properties of the soil:

The physical properties of soil which were analysed were given as follows:

(a). Soil Temperature:

Soil temperature of the study area was taken with the help of soil thermometer at the sites itself.

(b). Soil Moisture:

The moisture content of soil was determined by Gravimetric method/Oven dry method (Allen *et al.,* 1974). 10 gram of freshly collected soil sample was kept in a hot air oven at 105 $^{o}$C for 24 hours. The air dried soil was then weighted again and recorded. It was calculated by using the formula:

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

where, $W_1$ = initial weight of soil

$W_2$ = final weight (oven dried) of soil.

(c). Bulk Density:

Bulk density is defined as the ratio of the mass of dry soil to its volume. Bulk density varies from one soil type to another. The presence of organic matters lowers the volume of density. Samples of soil were collected with the help of known

volume of soil corer. The collected soil samples were put on the petriplates and put it in the oven at 105 $^0$C for 28-48 hours; then the dry weight of the soil samples were weighted. The Bulk Density of soil was calculated by using the formula

$$\text{Bull Density (D)} = \frac{\text{Mass}}{\text{Volume}} \text{ g/cm}^3$$

$$= \frac{\text{dry weight of the soil}}{\pi r^2 h} \text{ g/cm}^3$$

where, r = radius of the soil corer.

H = height of the soil corer.

(d). Total porosity:

Porosity is an index of the relative pore space in the soil. Soil pore may be small or large, thin or thick, capillary or non-capillary. It also relates to the density of soil. A sample of soil was collected with the help of known volume of soil corer. The collected soil samples were put on the petriplates and put it in the oven at 105 $^0$C for 28-48 hours, and then the dry weight of the soil sasmples were weighted. It was calculated by the formula:

$$\text{Porosity of soil (\%)} = \frac{S - D}{S} \text{ X } 100$$

Where, D = Bulk Density

S = Particle Density ***i.e.,*** 2.65 g/cm$^3$

(e). Water holding capacity:

The water holding capacity of the soil is related to the amount of maximum water, which is found in the saturated soils. Under the standardized condition, when the soil is immersed in water, it has been observed that how much amount of water to be taken up by the unit weight of dry soil. The determination of water-holding-capacity of soil was carried out in a small circular brass-box with a perforated base as suggested by Knowles and Watkin (1950). The internal diameter and height of the circular brass box (square box can also be used) was measured and the bottom of this box was perforated with many holes. In the brass box a filter paper (Whatman No. 1 or 44) was placed at the bottom of the circular box and weighed out. The filter paper was allowed to cover the whole perforated bottom of the brass box. After taking the weight of brass box and filter paper ($W_1$), the air dry soil was first crushed and ground and passes through 0.5 mm sieve. The dry soils of approx. 0.5 mg, each were allowed to filter with the mixture of distilled water into the box, until the box is nearly full. Finally to fill the box more soil was added and the extra soil was removed with the help of spatula. In this way, the sufficient soil was allowed to fill the box-full. In a petri-plate, the packed brass box was placed and the water is added upto a depth of approx. 1 cm. When the soil absorbed certain amount of water, then there was restoration of depth of water in petri plate by adding more water and keep overnight. The next day, the box was removed and the soil is allowed to dry by wipe it out and take the weight ($W_2$). Approx. at 105°C, the soil was dried in an oven for 24 hours. After that the soil was allowed to cool in a desiccators, the weight ($W_3$) was again taken. Separately, the amount of water-absorption by the filter paper can be observed. For this purpose, the weight of 3 to 4 pieces of dry filter paper was taken and after saturation with water, the weight was again taken. So the amount of water

absorbed by a single filter paper = W4. The filter papers were saturated with water and the surplus water was removed with a glass rod.

The water holding capacity of soil was calculated mathematically by-

$$\text{Water Holding capacity (\%)} = \frac{W_2 - W_3 - W_4}{W_2 - W_1} \text{ X } 100$$

Where, $W_1$ = Weight of brass box + filter paper

$W_2$ = Weight of brass box + saturated soil

$W_3$ = Weight of brass box + oven-dry soil

$W_4$ = Amount of water obtained by the filter paper

#### 4.11.2.2. Chemical Properties of soil:

The chemical properties of soil which were analysed during the research work were given as follows:

(a). Soil pH:

Soil pH was measured by mixing 10 gram of freshly soil sample and 50ml of distilled water and stirred for 20 minutes in a 100 ml beaker using magnetic stirrer. The soil-water mixture was kept overnight and taken the reading with the help of Digital pH meter (Systronics 335).

(b). Soil organic carbon:

Soil organic carbon was determined by rapid dichromate oxidation technique or, Walkley and Black Method (1934). The organic matters in the soil were

oxidized by chromic acid (Potassium dichromate plus cone. $H_2 SO_4$ utilizing the heat of dilution of $H_2 SO_4$. The unreacted dichromate was determined by back titration with ferrous sulphate (Maiti, 2003).

*Procedure*

The oven dried soil is ground completely and passed through 0.2 mm sieve (80-mesh) and 0.5g sample is placed at the bottom of dry 500ml conical flask.10ml of 1N potassium dichromate was added in the conical flask and the flask was swirled gently to disperse the soil in the dichromate solution. The flask is kept on asbestos sheet. 20ml of conc. Sulphuric acid was carefully added from a measuring cylinder and was swirled 2 – 3 times. The flask was allowed to stand for 30 minutes. 200ml of distilled water and 10ml of ortho-phosphoric was added to get a sharper end point of titration. After the addition of 1ml diphenylamine indicator, the content was titrated with ferrous ammonium sulfate solution till the colour flashed from blue-violet to green. Simultaneously, a blank is run without soil.

The soil organic carbon content was calculated by the following formula,

$$\text{Organic carbon (\%)} = \frac{10\,(B-T)}{B} \times 0.003 \times \frac{100}{S}$$

Where, B = Volume of ferrous ammonium sulfate solution required for blank titration in ml.

T = Volume of ferrous ammonium sulfate solution required for soil sample in ml.

S = Wt. of soil in gram.

(c). Total Nitrogen:

The total nitrogen was determined by Kjeldahl method which involves three steps which were done as follows:

*(i). Digestion*

5g of air dried soil sample was transfer to the digestion tube.10-15ml of conc. Sulphuric acid ($H_2SO_4$) was added and 5-7g of catalyst mixture of the sample. The digestion tubes were loaded in the Digester and the digestion block was heated to 410 $^oC$ till the sample colour turns colorless or light green colour.

*(ii). Distillation*

The main AC power and the Rear side Green colour of the distillation unit was switched on. The distilled water tap was kept in ON condition. The power was switched in control panel. The Digestion tube large (DTL) was taken with digested sample. After the addition of 10ml distilled water it was shaken well. The DTL was loaded in Distillation Unit using the slider mechanism. 25 ml of 40% Boric acid plus 3 drops of Methyl red and 3 drops of Bromocresol green was taken in a 250ml conical flask and kept in the receiver end. Then, 40ml of 40% NaOH was added by using the control panel. The timer was set at 20 sec. on the upper button. After the process was over the boric acid turned colourless. After the READY signal was glowing, the tap water inlet was opened for condensation. The required process time was set at 6 minutes for distillation on the lower button. The run key was pressed at the lower button. After the process time was over, steam was automatically cut off and the condensation tap water inlet was closed. The conical flask containing boric acid was taken out from the receiver end and the sample was ready for titration.

*(iii). Titration.*

The solution of Boric acid was titrated against 0.1N HCl. Or 0.1N $H_2SO_4$ until the Boric acid turned pink. The burette reading was taken and the percentage of

Total Nitrogen was calculated with the help of the formula.

$$\text{Percentage of } N_2 = \frac{14 \text{ X Normality of acid X Titrant value X } 100}{\text{Sample weight X } 1000}$$

(d). Available phosphorus:

Available phosphorus was determined after extracting soil phosphorus in 0.5 M sodium bicarbonate solution by Olsen's method. The extract was prepared by adding 2.5 g of soil sample in the 250 ml conical flask containing 50 ml of extracting solution (NaHCO), shaken for 30 minutes and the suspension was filtered through a Whatman No. 40 paper. Activated carbon (free of phosphorous) was added to obtain a clear filtrate. The flask was again shaken immediately before pouring the suspension into the funnel.

*Colour development*

5 ml of the extract was taken into a 25 ml conical flask, to which 5 ml of Dickman and Bray's reagent was added drop by drop till the effervescence ceased. The content was diluted to 22 ml. adjusted the pH to 5.0 and added 1ml of diluted $SnCl_2$ (2.5g in 100 ml glycerol heat in water bath for mixture). The colour was stable

for 24 hours and maximum intensity was obtained just after 10 minutes with the help of Systronics Spectrophotometer 119 at 660 nm (Maiti. 2003).

*Preparation of standard curve*.

For preparation of standard curve different concentration of phosphorus (1, 2, 3, 4, 5 and 10 ml of 2 ppm phosphorus solution) were taken in 25ml volumetric flask. The standard concentration of phosphorus was prepared in the range of 0.08ug/ml to 0.80ug/ml (Spectophotometer 660nm).

The curve was plotted taking the colorimeter reading on the vertical axis and the amount of phosphorus (in μg P/ml) in the horizontal axis.

Calculation:

Olsen's phosphorus (Kg/ha) = R X V/v X 1S x (2.24 X $10^6/10^6$)

= R X (50/5) X (1/2.5) X 2.24

= μg P X 8.96

Where, V = Total volume of extractant (50ml)

v = Volume of aliquot taken for analysis (5ml)

S = Wt. of soil (2.5g)

R = Wt. of the aliquot in ug (from standard)

(e). Exchangeable potassium:

Exchangeable potassium of soil was determined by using flame photometer after extracting with IN ammonium acetate solution. 5 g of soil sample was shaken with 25 ml of IN ammonium acetate solution for 5 minutes and filtered

through Whatman No. 1. Then the potassium concentration was determined by flame photometer by using K-filter (Ghosh *et al.,* 1983, Maiti, 2003). The first few ml of the filtrate was rejected. The potassium concentration in the extract was determined by flame photometer using K filter.

*Preparation of standard curve:*

Prepare 10 to 60 ppm K solutions was prepared from the stock solution by adding ammonium acetate solution. After attaching the appropriate filter, gas and air pressure in the flame photometer were also adjusted. The reading was adjusted to zero for the blank in flame photometer. The readings at the different conc. for K solution were noted. The readings were plotted against the concentrations.

Calculation:

i) Available potassium (mg of K/g of soil) = $\frac{A \times V}{W \times 100}$

ii) Available K (Kg/ha) = $R \times \frac{V}{W} \times 2.24 \times \frac{10^6}{10^6}$

= ppm of K X 11.2

Where, A = K content of soil extract from standard curve, mg/L

V = Volume of the soil extract ml.

W = weight of air-dried sample taken for extraction in g. (5g)

R = ppm of K in the extractant.

**Chapter – 5**

# RESULTS AND DISCUSSIONS

## 5.1. Results

### 5.1.1. Socio- econonomic status

The socio-economic status of the surrounding villages of the Study Area shows that the economic conditions were poor. Among the 8 villages Sangau has the highest population with 6,800 inhabitants and Tialdawngilung has the lowest population with 355 inhabitants. Almost all of the family depends on traditional jhuming for their livelihoods (81.37%) while the rest engaged in Govt. services, small business and cottage industries **(Table 4)**.

The standard of living is medium. Out of 1,856 houses in the adjacent villages of the study area, 70.47% of the houses are tin roofs, 27.42% are local materials or thatched roofs and 2.10% are R.C.C. buildings. Since most of the houses are built with local materials, their dependencies on forest for timber wood are still very large. Of all the houses in the study area, 80.10% were electrified, 35.02% with LPG connection and 16.10% houses with Telephone connections (Landline and Wireless Local Loop). Houses with LPG connections are low which shows that the use of firewood is still common and even among the user families of LPG connections, because of the poor condition of the roads; transportation is a big hindrance as it is difficult to replace the cylinder once it is used up. So, it is clear that majority of the families are still depending on fuelwood for cooking. In the villages adjoining

Phawngpui National Park, there are 18 Govt. Primary Schools, 10 Govt. Middle Schools, 6 High Schools and 20 Anganwadi Centers. The community health centers were also few with only three Health Centes, one each in three villages which results in traditional healing practices, thereby, collecting valuable medicinal plants from the forests. Though their dependency on the forest and its products are high, they are not aware of the sustainable utilization and habitat destruction of wild species which could lead to biodiversity loss and extinction of valuable species of plants and animals. Therefore, steps should be taken in these regards.

Collective important forest resources of the surrounding villages of Phawngpui National Park are listed in **Table 5.**

### 5.1.2. Plant Community Analysis

#### 5.1.2.1. Altitudinal distribution of plant species

A total of 208 species of vascular plants belonging to 150 genera and 71 families have been recorded from the sampling units. Out of 208 plant species, 84 species of trees, 31 shrubs, 45 species of herbs, 33 climbers and epiphytes, 5 species of canes and palms, and 10 species of grasses and bamboos were enumerated.

The diversity or richness of plants along altitudinal gradient was studied by enumerating the total number of species present in each Site within the quadrats studied and it was found out that in Site A (1500 - 1700 m asl.) 134 plant species belonging to 56 family and 102 genera were recorded. Out of 134 plant species recorded in Site A, 62 species were trees, 17 species were shrubs, 24 species were

herbs, 20 species comprised of climbers and epiphytes, 6 species comprised of grasses and bamboos, and 5 species of canes and palms.

In Site B (1700 - 1900 m asl.) 142 species of plants belonging to 60 family and 107 genera were recorded. Out of 142 plant species recorded, 67 species were trees, 20 species were shrubs, 27 species were herbs, 22 species comprised of climbers and epiphytes, 4 species comprised of grasses and bamboos and, 2 species of canes and palms.

In Site C (1900 - 2200 m asl.), 91 plant species belonging to 43 family and 74 genera were recorded. Out of 91 plant species recorded in Site A, 30 species were trees, 18 species were shrubs, 23 species were herbs, 10 species comprised of climbers and epiphytes, 8 species comprised of grasses and bamboos and, 2 species comprised of canes and palms. Ecological data of plant species in Site A, Site B and Site C were presented in **Table 6 (a), (b), (c)** and **Fig. 6**

Thus, plant species richness or diversity increases up to the middle altitude (Site B) and then declines as we move to higher altitude (Site C) which shows a hump-shaped distribution of plant species in the study area **(Fig. 7)**. A hump-shaped distribution pattern of plant species richness in relation to altitude have been observed by various workers such as Whittaker (1960), Janzen, (1973), Whittaker and Niering (1975), Tilman (1982), Schmida and Wilson (1984), McCoy (1990), Tilman and Pacala (1993), Lieberman *et al.* (1996), Rahbek (1997), Gutierrez (1997), Fleishman *et al.* (1998), Grytnes and Vetaas (2002), Oommen and Shanker (2005), Kharkwal *et al.* (2005), Jiang *et al.* (2007), Gairola *et al.* (2008) and Aynekulu (2008).

### 5.1.2.2. Quantitative analysis of Plant species

In Site A, *Curculigo crassifolia* (110 indv. $ha^{-1}$), *Blumes lanceolaris* (92 indv. $ha^{-1}$) and *Castanopsis tribuloides* (256 indv. $ha^{-1}$) shows the highest density among the herbs, shrubs and trees, respectively. The most abundant species amongst herbs, shrubs and trees were *Curculigo crassifolia* (1.96), *Strobilanthes capitatus* (1.72) and *Castanopsis tribuloides* (3.55), respectively. Among the trees *Castanopsis tribuloides* shows the highest IVI value (43.50) followed by *Engelhardtia spicata* (21.03) **{Table 7 (a), (b) & (c)}.**

In Site B, *Curculigo crassifolia* (136 indv. $ha^{-1}$), *Artemesia nilagirica* (102 indv. $ha^{-1}$) and *Helicia eratica* (388 indv. $ha^{-1}$) has the highest density among the herbs, shrubs and trees, respectively. Species of *Curculigo crassifolia* (64 %), *Vernonia volkameriafolia* (58 %) and *Helicia eratica* (88 %) show the highest frequency percentage. The most abundant species of herb, shrub and tree were *Curculigo crassifolia* (2.13), *Artemesia nilagirica* (2.43) and *Quercus leucotrichophora* (4.55), respectively. The dominant species with highest IVI among the herbs, shrubs and trees were *Curculigo crassifolia* (42.22), *Clerodendron siphonanthus* (26.14) and *Engelhardtia spicata* (37.92), respectively **{Table 8 (a), (b) & (c)}.**

In Site C, *Curculigo crassifolia* (170 indv. $ha^{-1}$), *Osbeckia sikkimensis* (176 indv. $ha^{-1}$) and *Helicia eratica* (380 indv. $ha^{-1}$) has the highest density amongst herbaceous, shrub and tree species, respectively. The species like *Curculigo crassifolia* (76 %), *Blumes lanceolaris* (80 %) and *Helicia eratica* (72 %) shows the highest frequency percentage of herbaceous, shrub and tree species, respectively. The most

abundant species are *Crotalaria albida* (2.5), *Osbeckia sikkimensis* (2.59) and *Engelhardtia spicata* (5.52). *Boehmeria platyphylla* (48.49), *Osbeckia sikkimensis* (27.62) and *Helicia erratica* (44.33) shows dominance with highest IVI amongst herbaceous, shrub and tree species, respectively **{Table 9 (a), (b) & (c)}.**

### 5.1.2.3. Plant Diversity Indices

The species richness of the study area was calculated by using Margalef's index of species richness. The value of herbaceous species richness ($D_{mg}$) was found to be highest in Site B (4), followed by Site A (3.17) and Site C (3.68). The highest value of shrub species richness ($D_{mg}$) was observed in Site B (2.96) followed by Site A (2.6) and Site C (2.49). The value of tree species richness ($D_{mg}$) was found to be highest in Site B (9.88) followed by Site A (9.39) and lowest in Site C (4.44).

Shannon's diversity index was calculated on the basis of important values. The diversity (H') of herbaceous species was highest in middle altitude (Site B) with a value of (3.08) and lowest in the higher altitude (2.95). The shrubs species diversity (H') was highest in middle altitude (2.93) followed by higher altitude (2.84) and lower altitude (2.8); diversity (H') of tree species was highest in lower altitude (3.68) and lowest in higher altitude (2.9). The Shannon-Wiener's index (H') values for trees, shrubs and herbs at the three altitudinal gradient of the study area were higher than the record for sub-alpine zone of west Himalaya, India (Gairola *et al.*, 2008) but lower than the record for Parshuram Kund Area in Lohit District of Arunachal Pradesh, India (Rana and Gairola, 2009).

The index of dominance was calculated by using Simpson's index (Simpson, 1949) for a finite community. The dominance (D) of herbaceous species was found to be highest in Site A (0.05) and lowest in Site B (0.047); the value of dominance (D) of shrubs was highest in Site C (0.061) and lowest in Site B (0.053); and the highest value of dominance of trees was observed in Site C (0.072) and lowest in Site A (0.032).

The evenness index (e) of the community was calculated by adopting Pielou's index (1969). The highest evenness of herb species was observed in Site B (0.94) while Site A and Site C share the same evenness index (0.93) respectively. Both Site A and Site C shows highest evenness of shrub species (0.98). The value of Pielou's evenness index for trees were highest in Site A (0.89) followed by Site B (0.88) and then Site C (0.85) respectively.

The turnover in species composition along altitudinal gradient in the study area was calculated using Whittaker's beta (βw) diversity considered by Shmida and Wilson (1984). The Whittaker's beta diversity for trees was highest in Site B (2.85) and lowest in Site C (1.98). The shrubs species in the lower altitude (Site A) show the highest beta diversity (1.73) while the higher altitude shows the lowest beta diversity (1.01) in the study area. The beta diversity for herbs was highest in the middle altitude (2.08) and lowest in the higher altitude (1.10). The overall beta diversity index of plants (trees, shrubs and herbs) in the study area was highest in Site A followed by Site B and Site C respectively. This shows that Whittaker's beta diversity of plant species in the study area decreases with increase in altitude. Graphical representation of Species diversity index for trees, shrubs and herbs in the three Sites were given in **Fig. 8.**

Sorensen's index of similarity (S) in the three sites was not too high. The value of similarity (S) of herb species was found to be highest between Site B and Site C (0.6) followed by between Site A and Site B (0.54), and lowest between Site A and Site C (0.38). The value of similarity (S) of shrubs species was found to be highest between Site B and Site C (0.78) followed by between Site A and Site B (0.59), and lowest between Site A and Site C (0.57). The value of similarity (S) of tree species was found to be highest between Site A and Site B (0.77) followed by between Site B and Site C (0.55), and lowest between Site A and Site C (0.34). The value of similarity (S) of climbers and epiphytes was found to be highest between Site B and Site C (0.63) followed by between Site A and Site B (0.45), and lowest between Site A and Site C (0.06). The value of similarity (S) of grasses and canes was found to be highest between Site B and Site C (0.7) followed by between Site A and Site B (0.62), and lowest between Site A and Site C (0.47) (**Fig. 9**). The overall Sorensen's index of similarity of plant species was found to be highest between Site A and Site B (0.67) followed by between Site B and Site C (0.59) and lowest between Site A and Site C (0.36).

The values of plant diversity indices computed were given in **Table 10.**

### 5.1.3. Analysis of soil physico-chemical properties

#### 5.1.3.1. Physical properties

*Soil Temperature:* It has been found that during the 2 years of seasonal analysis (2007 & 2008), temperature is highest during Summer in the lower altitude (Site A) which is 15.20 $^{0}$C and lowest during Winter in the higher altitude (Site C)

which is 6.50 $^0$C **(Fig. 10)**. The annual soil temperature of the three different sites was also recorded in which the lower altitude show the highest soil temperature (13.87$^0$C) and decreases by 2$^0$C or more as we ascend to the higher altitude.

*Soil moisture content:* The soil moisture content of the study area was highest during Monsoon in Site C (42%) while it was lowest during Winter in Site A (15.43%) (**Fig.11**). The average annual soil moisture content of the three sites was 24.03%, 26.77% and 30.54% in Site A, Site B and Site C, respectively.

*Porosity and Bulk Density:* Porosity and Bulk Density of soil are inversely proportional to each other. If porosity is high, bulk density is low and *vice versa*. The porosity of soil was highest during Monsoon in Site C (70.89%) while lowest during winter in Site A (53.64%) (**Fig. 12**) and hence, bulk density is highest during winter in Site A (0.82 gm/cm$^3$) and lowest during Monsoon in Site C (0.37gm/cm$^3$) (**Fig. 13**). The average annual porosity are 57.32%, 61.16% and 67.31% in Site A, Site B and Site C, respectively, while Bulk Density were 0.64 gm/cm$^3$, 0.62 gm/cm$^3$ and 0.58 gm/cm$^3$ in Site A, Site B and Site C, respectively. Thus, Porosity of soil increases with altitude whereas bulk density decreases with altitude.

*Water holding capacity (WHC):* The percentage of Water Holding Capacity at 0-15 cm soil depth was found to be 72.50%, 85.40% and 63.40% in Site A, Site B and Site C, respectively (**Fig. 14**). The Water holding capacity of the soil was highest in Site B which has the highest plant species richness followed by Site A and lowest in Site C which have the lowest species richness in the Study area. Thus, it can be stated that water holding capacity of soil is influenced by vegetations.

### 5.1.3.2. Chemical properties

*Soil pH:* From the analysis of soil pH it was found out that the soil of the study area is acidic in nature. The acidity of soil in the three sites does not show much variation. The highest pH value (5.95) was observed in Site C while lowest pH (4.43) was observed in Site A during winter (**Fig. 15**).

*Soil organic carbon:* The amount of soil organic carbon was determined by Walkley and Black Method (1934). In all the three Sites the amount of organic carbon was found to be highest during monsoon and lowest during winter. In Site A, the amount of soil organic carbon content was found to be 3.91%, 4.73% and 3.58% during Summer, Monsoon and Winter respectively. In Site B, it was found to be 4.53%, 5.42% and 4.18% during Summer, Monsoon and Winter respectively. In Site C the amount of soil organic carbon content was found to be 5.33%, 6.09% and 4.90% during Summer, Monsoon and Winter respectively (**Fig.16)**. The average annual soil organic carbon content of the three sites were found to be 4.07%, 4.71% and 5.44% in Site A, Site B and Site C, respectively. Thus, the study shows that soil organic carbon content increases with increase in altitude in the study area.

*Total soil nitrogen:* Total nitrogen in soil was determined by Kjeldhal method. In all the three sites, the total soil nitrogen was highest during monsoon and lowest during winter. In Site A, the highest amount of total soil nitrogen was found to be 0.54% during monsoon season and lowest during winter which is 0.28%. In Site B, total soil nitrogen was highest during monsoon (0.58%) and lowest during winter (0.30%) an in Site C, it was found to be highest during monsoon (0.61%) and lowest during winter (0.33%) (**Fig. 17)**. The average annual total soil nitrogen in the three

sites was 0.43%, 0.46% and 0.49% in Site A, Site B and Site C, respectively. Thus, the study reveals that total soil nitrogen increases with increase in altitude.

*Available phosphorus:* Available phosphorus was determined by adopting Olsen's method. The amount of available phosphorus in Site A was found to be 3.82 µg/g in Summer, 3.89 µg/g in Monsoon and 3.36 µg/g in Winter. In Site B it was found to be 3.84 µg/g in Summer, 3.99 µg/g in Monsoon and 3.30 µg/g in Winter. In Site C, the amount of available phosphorus was found to be 3.56 µg/g in Summer, 3.95 µg/g in Monsoon and 3.21 µg/g in Winter. It was also found out that the amount of available phosphorus was highest in Monsoon season in all the three Sites (Site A- 3.89 µg/g; Site B- 3.99 µg/g; and Site C- 3.95 µg/g) and lowest in winter (Site A-3.36 µg/g, Site B- 3.30 µg/g and Site C- 3.21 µg/g) (**Fig. 18)**. The average seasonal analysis shows that phosphorus was highest in Site B (3.71 µg/g) followed by Site A (3.69 µg/g) and Site C (3.57).

*Exchangeable potassium:* Exchangeable potassium of soil was determined by using flame photometer. In Site A, the highest amount of exchangeable potassium was observed during summer (472.80 kg/ha) and lowest during winter (370.44 kg/ha); in Site B, the concentration of exchangeable potassium was highest during summer (467.04 kg/ha) and lowest during winter (343.60 kg/ha) and in Site C, the highest amount of exchangeable potassium was recorded during monsoon (392.00 kg/ha) at 0-15 cm and lowest during winter (304.23 kg/ha) (**Fig. 19)**. The average seasonal potassium concentration in the soil was 418.71 kg/ha., 407.54 kg/ha. and 357.99 kg/ha. in Site A, Site B and Site C, respectively.

Data of soil analysis of Phawngpui National Park is given in **Table 11.**

### 5.1.4. Stratification of the forest

The stratification of the forest was studied by drawing a profile diagram along belt transect (1 m thickness X 100 m length) in each sites.

From the profile diagram of Site A {**Fig. 20(a)}** the forest could be stratified into three layers ***viz.***, the top layer which were above 20 m high; the middle layer which were between 8 and 20 m high and the ground vegetation. The top canopy species are *Duabanga grandiflora, Engelhardtia spicata, Quercus dealbata, Helicia erratica, Castanopsis tribuloides, Cinnamomum verum, Antidesma bumis, Quercus lanceaefolia, Chukrasia velutina, Vitex peduncularis, Olia salicifolia, Sapium baccatum, Litsea semicarpifolia, Prunus jenkinsii, Quercus leucotrichophora, Derris robusta, Syzygium cumini, Eleocarpus tectorius, Quercus helferiana, Zizyphus incurva, Ficus religiosa, Debregae velutina, Eleocarpus aristatus, Ficus rigida* and *Aphanantha cuspida.* The middle layer consists of *Wandlandia grandis, Macaranga indica, Mallotus macrostachyus, Styrax serrulatum, Schima wallichii, Rhus semialata, Litsea cubeba, Drimycarpus racemosus, Saurauia punduana, Ostades paniculata, Kydia calycina, Euria japonica, Pithecolobium bigeminum, Pithecolobium heterophyllum, Myrica esculenta, Ailanthus integrifolia, Dysoxylum binecteriferum* and *Glochidion velutinum.* The ground vegetation consists of several herbs, shrubs and grass species like *Ammomum dealbatum, Gynura bicolor, Eupatorium odoratisum, Curculigo crassifolia, Boehmeria platyphylla, Bergenia roxburghii, Sinarundinaria griffithiana* and *Sinarundinaria falcata*.

The profile diagram of Site B {**Fig. 20(b)}** of the study area showed that the forest could be stratified into three layers ***viz.***, the top layer which were above

15 m high; the middle layer which were between 6 and 15 m high and the ground vegetation. The top canopy species are *Helicia erratica, Engelhardtia spicata, Alseodaphne petiolaris, Castanopsis tribuloides, Phoebe lanceolata, Olia salicifolia, Lasianthus biermanni, Quercus dilatata, Quercus lanceaefolia, Lithocarpus elegans, Syzygium cumini, Quercus leucotrichophora, Ficus rigida, Quercus helferiana, Litsea semicarpifolia, Vitex peduncularis, Aphanantha cuspida, Sapium bacatum* and *Cinnamomum verum.* The middle layer consists of *Euria japonica, Litsea cubeba, Myrica esculenta, Prunus cerasoides, Rhus semialata, Schima wallichii, Saurauia punduana, Pithecolobium bigeminum, Pithecolobium heterophyllum, Albizzia chinensis, Drimycarpus racemosus, Glochidion velutinum, Macaranga indica, Castanopsis indica, Mallotus macrostachyus, Rhus succedanea, Olea dioica, Ostades paniculata, Hetyeropanax fragrans, Schima khasiana, Kydia calycina, Styrax serrulatum, Dysoxylum binecteriferum, Rhododendron arboretum, Macropanax undulatum* and *Xantolis hookeri.* The ground vegetation consists of several herbs, shrubs and grass species like *Arisaema speciosum, Blumea alata, Gynura bicolor, Ammomum dealbatum, Curculigo crassifolia, Artemesia nilagirica, Circium interpositum, Boehmeria platyphylla, Osbeckia sikkimensis, O. chinensis, Schizostachyum capitatum, Sinarundinaria griffithiana* and *Sinarundinaria falcata*.

From the profile diagram of Site C {**Fig. 20(b)}** of the study area, the forest could be stratified into three layers ***viz.***, the top canopy layer which were above 10 m high; the middle layer which were between 2 and 10 m high and the ground vegetation. The top canopy species are *Engelhardtia spicata, Helicia erratica, Castanopsis tribuloides, Quercus leucotrichophora, Ficus rigida, Alseodaphne petiolaris* and *Phoebe lanceolata.* The middle canopy layers are *Schima wallichii,Olea*

*salicifolia, Xantolis hookeri, Rhus succedanea, Eleocarpus tectorius, Cinnamomum verum, Camelia kissi, Syzygium cumini, Lithocarpus elegans, Quercus dilatata, Euria japonica, Rhododnedron arboreum, Hetyeropanax fragrans, Schima khasiana* and *Cinnamomum obtusifolium.* The ground vegetation consists of species like, *Curculigo crassifolia, Artemesia nilagirica, Circium interpositum, Boehmeria platyphylla, Osbeckia sikkimensis, O. chinensis, Schizostachyum capitatum, Sinarundinaria griffithiana, Sinarundinaria falcata, Calamus erectus, Leersia hexandra, Circium interpositum, Microstegium petiolare* and *Ardisia macrocarpa.*

From the profile diagrams of each Site of the study area, we could stratify the forest of the study area into three layers such as the top canopy layer which were above 15 m high; the middle layer consists of a wide range from 2 m to 15 m high; then the ground vegetation below 2 m high. From the profile diagrams it is clear that trees in the lower altitude (Site A) are higher than the trees in the higher altitude (Site C) which shows that vertical growth of trees is controlled by altitude and climatic conditions.

### 5.1.5. Population Structure of the forest

The results of population structure showed that all the three study sites (Site A, Site B and Site C) of the study area have high floristic composition. Total number of plant species having diameter greater than or equal to 5 cm (≥ 5 cm dbh) in Site A were 65 species, in Site B it was 72 species and in Site C it was 35 species, respectively (**Table 12, 13 & 14).** In Site A, highest density of species was observed in 15.01 – 25.00 cm dbh classs followed by 5.00 – 15.00 and lowest in 65.01 – 75.00 cm dbh class. In site B, highest density of species was observed in 5.00 – 15.00 cm dbh

classes followed by 15.01 – 25.00 cm dbh and lowest in 65.01 – 75.00 cm dbh class. In site C, highest density of species was observed in 5.00 – 15.00 cm dbh classes followed by 15.01 – 25.00 cm dbh and lowest in 55.01 - 65.00 cm dbh class (**Fig. 22, 23 & 24**).

### 5.1.6. Endemic, Rare and Endangered Species

The study recorded few species of plants which are described as endemic, rare and endangered based on the sample survey and IUCN criteria. Among the orchids, *Eria lacei* is recorded as endemic, rare and endangered. *Dendrobium pychnostachyum* and *Dendrobium formosum* were rare and endangered while *Gastrochilus calceolaris* were critically endangered (IUCN, 2009). *Mantisia spathulata* Schult. which is recorded as endemic, rare and endangered is also listed in the Red Data sheet of Indian plants as being rare and endangered species by Botanical Survey of India (www.envfor.nic.in/bsi/research.html). It also recorded *Mahonia borealis* and *Rhododendron veitchianum* as endemic and critically endangered. Other species ***viz***., *Camelia kissi, Cephalotaxus griffithii* and *Helicia robusta* are recorded as rare and endangered.

## 5.2. Discussions

The results show that plant diversity of Phawngpui National Park follow a hump-shaped pattern. This falls within the general pattern of an initial increase in species richness with elevation, followed by a peak in the middle and then a decline with further increase in elevation. This pattern is typical of many mountain systems, and is similar to those found of the vegetation of the Siskiyou Mountain,

Oregon and California (Whittaker, 1960); of the Santa Catalina Mountain, Arizona (Whittaker and Niering, 1975); along a steppe Tundra gradient in Alaska (Edwards and Armbruster, 1989); along an elevational gradient in Israel (Shmida and Wilson, 1985); of Tropical rain forest species (Lieberman *et al.,* 1996); in the Central Himalayan (Kumaun) region of India (Kharkwal *et al.,* 2005); along the valley of the R´ıo Loa, II Region, Chile (Gutierrez *et al.,* 1998); on Helan Mountain, China (Jiang *et al.,* 2007); of forest vegetation in sub-alpine zone of west Himalaya, India (Gairola *et al.,* 2008); along the Himalayan Altitudinal Gradient, Nepal (Grytnes and Vetaas, 2002); in Himalaya woody plants (Oomen and Shanker, 2005); in the Eastern Escarpment of the Rift Valley of Northern Ethiopia (Aynekulu, 2008).

There are several hypotheses explaining high plant species richness in the mid-altitude range. For example; optimum climatic conditions at mid-elevation that allow many species to coexist (Hemp, 2006). Mild climatic conditions at mid-elevation (high humidity, moderate temperatures) permit the co-existence of taxa which otherwise have high, mid or low-elevation centers of distribution (Becker *et al.,* 2007; Kessler, 2001; Körner, 2003; Bhattarai *et al.,* 2004); high productivity in the mid-elevation region which resulted by optimal combination resource availability (Rosenzwieg, 1995). The decrease in species richness and diversity of plants in the higher altitude might be due to harsh environment at higher elevation, reduced growing season, low temperature and low productivity (Gutierrez, 1997; Korner, 1998). Soil fertility and topography may also affect the distribution of plant species along altitudinal gradient. It might also be due to the conical shape of the mountain. As mountains become narrower with increasing elevation, the habitat area per elevation belts get smaller (Körner 2000; Colwell *et al.,* 2004), and species richness decreases. It

may also be due to the fact that the mid-altitude is far from human settlements and suffered less anthropogenic disturbances such as cutting of timber trees, collection of firewood and NTFPs and grazing animals which are threats to biodiversity loss.

The results show that Margalef's index of species richness and Shannon index of diversity present the unimodal variable trend, with a peak in the mid-altitudinal zone showing a hump-shaped curved along altitudinal gradient whereas Pielou's evenness index and Whittaker's beta diversity decreases with increasing altitude. This is similar with the report from the Northwestern Red Sea (Hegazy *et al.*, 2007) except for evenness which shows a hump-shaped curve in their findings and from the Gaundishan Pangquangou Nature Reserve in Guandi Mountain (Gao and Yun-xiang, 2006).

Sorensen's index characterizes the variation of plant species across the different study sites or altitudinal gradient in the study area. The Sorensen's index of similarity of plant species was found to be highest between lower and middle altitude (Site A and Site B) followed by between middle and higher altitude (Site B and Site C) and lowest between lower and higher altitude (Site A and Site C). The values of Sorensen's index between the three study sites lies between 0.36 and 0.7 which shows that the similarity between the neighbouring/ corresponding sites of the study area was not high and may be explained by their transitional position from the base lower altitude to the vertical higher altitude as discussed by Jiang *et al.* (2007). Kumar *et al.* (2004) have also evaluated the similarity and dissimilarity of tree and shrubby species between mildly disturbed area and highly disturbed area in the sub-tropical forest of Garhwal Himalayas.

Simpson's index of dominance of species shows positive correlation with altitude. As altitude increase Simpson's index of dominance increases. It also shows a negative correlation with Shannon diversity index. The low values of the Shannon-Wiener Index at the higher altitudes were due to higher dominance values of one or more species. Aynekulu (2008) have reported that low value of Shannon-Wiener Index at the higher altitudes were due to higher dominance of *J. procera.* The calculated values for index of dominance for herbs, shrubs and trees at different altitudinal gradient in the study area were lower than the values recorded for Parshuram Kund Area in Lohit District of Arunachal Pradesh, India (Rana and Gairola, 2009).

Soil temperature is one of the most important factor affecting soil productivity as it influence the rate and direction of many physical, chemical and biological processes in the soil. The result shows that soil temperature of the study area decreases with increase in altitude which have significant effect on vegetation and root growth. A decrease in soil temperature have been reported by Griffiths *et al.* (2009) and Sevgi and Tecimen (2009). Plants require optimum soil temperature for their growth and this may be explained by the fact that the higher altitude having the lowest soil temperature have the lowest number of species while the middle altitude which is assumed to have optimum soil temperature have the highest number of plant species in the study area.

Soil moisture content or soil water is another important factor affecting the growth of plants as it acts as a medium in which transport of elements and nutrients occurs. The result shows that soil moisture content in the study area increases with altitude. This is similar to the result obtained by Kharkwal *et al.* (2005); Griffiths *et al.*

(2009) and Kumar *et al.* (2010), while Sharma *et al.* (2009) reported higher soil moisture content in the middle altitude. Higher soil moisture content in higher altitude might be due to lower soil temperature which results in lower evaporation from the soil. It might also be due to higher porosity and lower bulk density of soil in the higher altitude. Higher pore space with lower bulk density helps to retain water by the soil. A decreased in bulk density (or increased porosity) of soil with altitude have been reported by Griffiths *et al.* (2009) and Kumar *et al.* (2010). Higher bulk density and lower porosity in Site A might be due to compaction of the soil through anthropogenic disturbances and cattle grazing. The result also show that soil moisture content was highest during monsoon season in all the three sites of the study area which shows that soil moisture content was fully controlled by the seasonal rainfall in the study area. Lower soil moisture in the surface soil layer during winter season could be the result of higher evaporation from the soil and plant surfaces and percolation and infiltration of water to the lower depths (Tiwari *et al.*, 1992). The amount of water in the soil affects directly the growth of plants (Topp, 1993).

Water holding capacity of soil in the study area was highest in Site B and then decline towards Site A and Site C relating to species composition and richness. Thus, it can be stated that vegetation has significant influenced on the water holding capacity of soil. Kumar *et al.* (2010) reported an increase in water holding capacity with altitude.

Soil pH affects productivity and distribution of plants. It also influences the solubility of nutrients, microbial activity and physical conditions of the soil. It affects the activity of micro organisms responsible for breaking down organic matter and most chemical transformation in the soil. In natural systems, the pH of soil is

affected by the mineralogy, climate and weathering (Nilsson, 2004). The result shows that the soils of the study area are acidic in nature and does not show much variation with altitude. This is similar with those of Singh and Datta (1987) and with several other works (Toky and Ramakrishnan, 1981; Andresse and Koopmans, 1984; Okigbo, 1984; Kumada *et al.*, 1985). The acidity of the forest soil is due to organic matter additions (**e.g.,** leaves, roots, twigs, reproductive structures) from over story trees and the acids produced during microbial decomposition (Barnes *et al.*, 1998). An example of how individual trees influence soil acidity is provided by tulip tree and eastern hemlock in eastern Kentucky (Boettcher and Kalisz, 1990).

In the present study, the amount of soil organic carbon in the study area were highest during monsoon in all the three sites which might be due to high rate of decomposition in the presence of moisture and optimum temperature. The analysis of soil organic carbon shows that the soil organic carbon increases with increase in altitude. The similar results have been worked out by Kitayama and Aiba (2002), Zhu *et al.* (2010), Kumar *et al.* (2010) and Sharma *et al.* (2009) while Sheikh *et al.* (2009) and Singh *et al.* (2009) reported a decrease in soil organic carbon with altitude in Garhwal Himalaya. Kamei *et al.* (2009) have reported 3.11% of soil organic carbon from the humid subtropical forest ecosystem of northeast India. An increase in soil organic carbon might be due to increased in precipitation and clay content and decreased with temperature (Jobbagy and Jackson, 2000), which has been confirmed on regional and local scales (Wang *et al*., 2004b; Yang *et al*., 2007).

The study reveals that the total nitrogen was highest during monsoon and lowest during winter. Lower concentration of total nitrogen in winter could be due to low decomposition rate due to the lesser amount of soil moisture and decreased in

temperature. It also shows that total nitrogen increases with increase in altitude. The increase in total nitrogen with altitude have been reported by Kumar *et al.* (2010) and Kitayama and Aiba (2002). Singh *et al.* (2009) reported a decrease in total nitrogen in soil with altitude in Garhwal Himalaya. Deka (1981) reported lower values of total nitrogen during dry winter period while Kamei *et al.* (2009) reported a higher value of total Nitrogen (0.89%) from the humid subtropical forest ecosystem of northeast India.

The study shows that available phosphorus in the soil was highest in Site B followed by Site A and lowest in Site C which shows a hump-shaped pattern. It also reveals that available soil phosphorus content in the study area is positively correlated with vegetation. The highest available phosphorus content in the soil in Site B (3.71 μg/g) could be due to the faster decomposition rate of litter and animal debris in the presence of adequate temperature and soil moisture. Higher value of available Phosphorus (5.16 μg/g) have been reported by Kamei *et al.* (2009) from the humid subtropical forest ecosystem of northeast India. Singh *et al.* (2009) and Sharma *et al.* (2009) have reported an increase of phosphorus with increase in altitude in Garhwal Himalaya.

The study found that the concentration of potassium in the soil decreases with increase in altitude. This is similar to the findings of Sharma *et al.* (2009) while it was contrasting with the findings of Singh *et al.* (2009). Higher potassium concentration found in Site A (418.71 kg/ha.) might be due to the presence or brought in of ash by wind during and after jhum burning from the nearby villages. Forest fires inside the study area due to jhum burning around the study area which happened during soil sample collection might also increase the ash content in the soil thereby increasing potassium concentration.

The stratification of the forest of the study area was studied by drawing a profile diagram. From the profile diagrams of each site of the study area, we could stratify the forest of the study area into three layers such as the top canopy layer which were above 15 m high; the middle layer consists of a wide range from 2 m to 15 m high; then the ground vegetation below 2 m high. From the profile diagrams it is clear that trees in the lower altitude (Site A) are higher than the trees in the higher altitude (Site C) which shows that vertical growth of trees is controlled by altitude and climatic conditions. Description of forest using profile diagram have been done by various workers such as Davis and Richards (1934) in the forest of Guyana, Brown (1919) of the Philippine *Dipterocarp* forest and Beard (1946) of Mora associations of Trinidad.

The results show that population structure of the three sites of the study area show a humped-shaped distribution pattern which shows positive correlation with species richness of the study area. It also shows that with increase in diameter classes, species richness and density decreases. This trend of decreasing diversity and density with increasing diameter class is in conformity with the studies of Hara *et al.* (1997), Jeffre and Veillon (1990), Kadavul and Parthasarathy (1999), Newbery *et al*. (1992) and Paijmans (1970). It also show that diameter class distribution yielded a reverse J-shaped curve (**Fig. 25, 26 & 27**) which is similar to those reported from the forests at Costa Rica (Nadkarni *et al.,* 1995); Brazalian Amzon (Campbell *et al.,* 1992); Meghalaya, Northeast, India (Upadhaya *et al.,* 2004) and Eastern Ghats (Kaduval & Parathasarathy, 1999), and in conformity with that of Rao *et al.* (1990) and Schmeiz and Lindley (1965). All of them have the preponderance of young individuals. Whitmore (1975) has ascribed such a tree population structure in the mature forest to the fast rate of turnover of the gaps. The lower density of lower diameter class (5.00 –

15.00 cm dbh) as compared to intermediate girth class (15.01- 25.00 dbh) in Site A give the appearance of a positively skewed distribution curve which might be due to felling of lower girth classes of trees in Site A as it is nearest to human settlement of the study sites.

The study reveals that Phawngpui National park is fairly rich in plant diversity. It harbors a great diversity of trees, shrubs, herbs, climbers, endemics, rare and threatened plant species. Phawngpui National Park was surrounded by eight villages and the villager depends on the forest for their livelihoods and also shifting cultivation have been practiced for a long time. These activities would probably lead to loss of biodiversity and the loss could not be evaluated as there was no previous study or documentations on biodiversity of the Park. Due to increase human population, dependency on forest and its products increases and so, conservation of the Park from anthropogenic disturbances such as illegal collection of timber and NTFPs, poaching, cattle grazing and forest fire was difficult. Hence, the forest of Phawngpui National Park suffered from various anthropogenic disturbances and these needs to be checked.

The Park harbors several species of plants having botanic importance based on importance values, endemism, medicinal, rarity and threatened species as per IUCN criteria, Red Data Sheet of Indian Plants and sample survey. Some species of trees such as *Helicia erratica* (Roxb.); *Engelhardtia spicata* Lechen *ex* Blume.; *Quercus dilatata* Lindl.; *Rhododendron arboretum* Sm.(**Photo Plate-1**) have high importance values. Species like *Eria lacei* Summerh; *Rhododendron veitchianum* Hook.***f.;*** *Mantisia spathulata* Schult. and *Mahonia borealis* Takeda. (**Photo Plate-2**) are endemic plants which need special emphasis in conservation. *Dendrobium pygnostachyum* Lindl.; *Bergenia ciliata* (Haw.) Sternb.*f.; Dendrobium devonianum*

Paxt. **a**nd *Helicia robusta* (Roxb.) R.Br. *ex* Blume (**Photo Plate-3**) are having medicinal value and are rare and endangered species. These plants are illegally collected from the Park and therefore, conservation of these plants should be done at all cost. The study also recorded other rare and endangered species like *Anoetochilus brevilabris* Lindl.; *Zeuxine goodyeriodes* Lindl.; *Dendrobium peguanum* Lindl.; *Cephalotaxus griffithii* Hook. *f*.; *Xantolis hookeri* (C.B.Clarke) P. Royen. and *Camelia kissi* Wallich. (**Photo Plate-4**) which must be conserved.

The study recorded three species of bamboos and canes inside the Park (**Photo Plate-5**). It also recorded a wide diversity of herbs with a few species of grasses. Some of the herb species and grasses are presented in **Photo Plate 6.**

The study also encountered a great forest fire for a consecutive of three years (2006 - 2008) which shows that the National Park is prone to fire. This forest fire is due to the burning of jhum land around the National Park. This forest fire even reached upto the 'Far Pak' which is at 1900 m asl (**Photo Plate-7**). Therefore, immediate steps should be taken in this regards. Though conservation of forest has been carried on, cattle grazing inside the park are still observed (**Photo Plate-7**).

**Table 4**. Socio-economic status of surrounding villages of Phawngpui National Park.

| Sl. No | Name of village | Population | No. of Family | No. of Houses | | | Occupation Data | | | | Educational Level | | | | | Local Institutions | | | | Standard of Living | | | Social Welfare Services | | | | | Animal Husbandry | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | R.C.C. | Tin Roof | Local Materials | Cultivators (Family) | Gov't. Servant | Industry/ Carpentry | Business | Post Graduate | Graduate | Higher Secondary | Matric | Under Matric | High School | Middle School | Primary School | Anganwadi | Houses electrified | Houses with LPG | Houses withTelephone connection | Public Water Point | Health Centre | Community Hall | V.C. House/ Court | Gov't. Rest House / Buildings | Cows | Piggery | Pony/Horse | Goat | Dog | Buffaloes | Poultry |
| 1 | Thaltlang | 509 | 118 | Nil | 60 | 20 | 110 | 24 | 1 | 8 | 1 | 5 | 8 | 12 | 182 | Nil | 1 | 1 | 2 | 56 | 32 | 8 | 8 | Nil | Nil | Nil | Nil | 35 | 80 | 2 | 15 | 3 | Nil | 1600 |
| 2 | Sentetfiang | 365 | 74 | Nil | 22 | 45 | 70 | 5 | Nil | Nil | Nil | Nil | 5 | 7 | 25 | Nil | 1 | 1 | 1 | 30 | 3 | 1 | 1 | Nil | 1 | Nil | Nil | Nil | 50 | Nil | 31 | 6 | Nil | 350 |
| 3 | Sangau | 6800 | 870 | 23 | 575 | 214 | 595 | 107 | 5 | 56 | 12 | 177 | 36 | 60 | 143 | 3 | 2 | 6 | 7 | 602 | 369 | 233 | 13 | 1 | 2 | 2 | 40 | 240 | 760 | 32 | 360 | 400 | 14 | 20400 |
| 4 | Pangkhua | 1500 | 240 | 2 | 175 | 55 | 230 | 15 | 1 | 2 | Nil | 8 | 11 | 23 | 45 | 1 | 1 | 2 | 2 | 202 | 39 | 16 | 2 | Nil | 1 | Nil | Nil | 35 | 80 | 30 | 25 | 50 | 24 | 1400 |
| 5 | Cheural | 1081 | 195 | 4 | 121 | 70 | 128 | 28 | 1 | 3 | 2 | 6 | 12 | 24 | 36 | 1 | 1 | 3 | 3 | 182 | 61 | 18 | 2 | 1 | Nil | Nil | 12 | 151 | 200 | Nil | 82 | 45 | Nil | 1323 |
| 6 | Vawmbuk | 2302 | 334 | 10 | 264 | 55 | 328 | 50 | 3 | 7 | 1 | 5 | 12 | 25 | 30 | 1 | 2 | 3 | 3 | 297 | 125 | 21 | 4 | 1 | 1 | 1 | 1 | 101 | 60 | 7 | 2 | 100 | Nil | 800 |
| 7 | Tialdawngi lung | 355 | 87 | Nil | 41 | 20 | 81 | 13 | 1 | 4 | Nil | 2 | 3 | 8 | 14 | Nil | 1 | 1 | 1 | 48 | 18 | Nil | 2 | Nil | Nil | Nil | Nil | 60 | 30 | 15 | 2 | 10 | Nil | 500 |
| 8 | Archhuang | 550 | 101 | Nil | 50 | 30 | 101 | 8 | 1 | 1 | Nil | 2 | 4 | 8 | 16 | Nil | 1 | 1 | 1 | 71 | 3 | 2 | 1 | Nil | Nil | Nil | Nil | 85 | 43 | 15 | 5 | 10 | 5 | 879 |

**Table 5. (a - h):** Collective important Forest resources of the surrounding villages of Phawngpui National Park.

**(a) Timber Species**

| | |
|---|---|
| 1 | *Michelia champaca* L. |
| 2 | *Terminalia myriocarpa* Heurch *et* Muell.-Arg. |
| 3 | *Juglans regia* L. |
| 4 | *Gmelina arborea* Roxb. |
| 5 | *Anogeissus acuminata* (Roxb. *ex* DC.) Guillemin & Perrottet. |
| 6 | *Toona ciliata* Roem. |
| 7 | *Elmus spp.* |
| 8 | *Phoebe lanceolata* Nees. |
| 9 | *Duabanga glandiflora* (Roxb. *ex* DC.) Walp. |
| 10 | *Schima wallichii* (DC.) Korthals |
| 11 | *Albizzia chinensis*(Osb.) Merr |

**(b) Medicinal Plants**

| | |
|---|---|
| 1 | *Mikania micrantha* Kunth |
| 2 | *Vitex peduncularis* Wallich ex Schauer |
| 3 | *Alstonia scholaris* (L.) R.Br. |
| 4 | *Bergenia ciliata* (Haw.) Sternb.*f.* |
| 5 | *Elaeagnus caudata* Schlecht. *Ex* Momiy |
| 6 | *Lindernia ruellioides* (Colsm.) Pennell. |
| 7 | *Osbeckia sikkimensis* Craib. |
| 8 | *Centella asiatica* (L.) Urban |
| 9 | *Clerodendrum colebrookianum* Walp. |
| 10 | *Vernonia squarrosa* (D.Don.) Less. |
| 11 | *Eupatorium odoratum* L. |

**(c) Fuelwood**

| | |
|---|---|
| 1 | *Anogeissus acuminata* (Roxb. *ex* DC.) Guillemin& Perrottet. |
| 2 | *Macaranga spp.* |
| 3 | *Lithocarpus pachyphylla* (Kurz.) Rehder. |
| 4 | *Quercus polystachya* Wall *ex* DC. |
| 5 | *Schima wallichii* (DC.) Korthals |
| 6 | *Vitex peduncularis* Wallich *ex* Schauer |
| 7 | *Rhus semialata* Miller |
| 8 | *Calicarpa arborea* Roxb. |
| 9 | *Albizzia chinensis* (Osb.) Merr |

**(d) Edible Plants**

| | |
|---|---|
| 1 | *Holigarna longiflora* |
| 2 | *Spondias pinata* (L.*f.*) Kurz. |
| 3 | *Emblica officinalis* Gaertn. |
| 4 | *Magnifera indica* L. |
| 5 | *Melocanna baccifera* (Roxb.) Kurz |
| 6 | *Rhus chinensis* Miller |
| 7 | *Calamus erectus* (Roxb.) |
| 8 | *Elaeagnus caudata* Schlecht. *Ex* Momiy |
| 9 | *Myrica esculenta* Ham. |

| | | | |
|---|---|---|---|
| 10 | *Kydia calycina* Roxb. | 10 | *Prunus jenkinsii* Hook.*f.*& Thomson |
| | **(e) Fruit Plants** | 11 | *Musa balbisiana* Colla |
| 1 | *Citrus sinensis* (L.) Osbeck. | 12 | *Amomum dealbata* Roxb. |
| 2 | *Citrus limetta* Rosso. | 13 | *Dysoxylum gobara* (Buch.-Ham.) Merr. |
| 3 | *Citrus macroptera* Montr. | 14 | *Clerodendrum colebrookianum* Walp. |
| 4 | *Musa balbisiana* Colla | 15 | *Citrus sinensis* (L.) Osbeck. |
| 5 | *Citrus medica* L. | | **(f) Canes and Palms** |
| 6 | *Psidium guajava* L. | 1 | *Calamus flagellum* Roxb. |
| 7 | *Prunus persica* (L.) Batsch. | 2 | *Calamus khasianus* Becc. |
| 8 | *Magnifera indica* L. | 3 | *Caryota urens* L. |
| 9 | *Carica papaya* L. | 4 | *Arenga pinnata* (O.Kuntze) Merr. |
| 10 | *Elaeagnus caudata* Schlecht. *Ex* Momiy | 5 | *Caryota mitis* L. |
| 11 | *Prunus napaulensis* (Ser.) Steud. | | **(h) Bamboos** |
| | **(g) Agricultural Crops** | 1 | *Dendrocalamus longispathus* Kurz. |
| 1 | *Capsicum annum* L. | 2 | *Dinochloa compactiflora* (Kurz) McClure |
| 2 | *Solanum melogena* L. | 3 | *Melocanna baccifera* (Roxb.) Kurz. |
| 3 | *Colocasia esculente* (L.) Schott. | 4 | *Sinarundinaria griffithiana* (Munro) Chao & Renvoize |
| 4 | *Solanum anguivi* Lamk. | 5 | *Sinarundinaria longispeculata* Chao & Renvoize |
| 5 | *Cucumis sativus* L. | 6. | *Schizostachyam capitatum* (Munro) R. Majumdar |
| 6 | *Cucurbita maxima* Duch. e*x* Lamk. | | |
| 7 | *Sorghum cervuum* | | |
| 8 | *Zingiber officinale* Roscoe | | |
| 9 | *Brassica oleracea* L. | | |
| 10 | *Coffea arabica* L. | | |
| 11 | *Zea mays* L. | | |
| 12 | *Oriza sativa* L. | | |

**Table 6 (a), (b) & (c)**: Field data of plant species of the three different sites.

| (a). **SITE A** | | (b). **SITE B** | | (c). **SITE C** | |
|---|---|---|---|---|---|
| 1 | *Ageratum conyzoides* L.Hook.*f.* | 1 | *Agrostophyllum callosum* Recihb.*f.* | 1 | *Ainsliaea latifolia* D.Don |
| 2 | *Agrostophyllum callosum* Recihb.*f.* | 2 | *Ainsliaea latifolia* D.Don | 2 | *Ainsliaea pteropoda* D.C |
| 3 | *Ailanthus integrifolia* Lam. | 3 | *Ainsliaea pteropoda* DC | 3 | *Alseodaphne petiolaris* Hook.*f.* |
| 4 | *Ainsliaea latifolia* D.Don | 4 | *Albizzia chinensis* (Osb.) Merr. | 4 | *Amomum dealbatum* Rosb. |
| 5 | *Albizzia chinensis* (Osb.) Merr. | 5 | *Alseodaphne petiolaris* Hook.*f.* | 5 | *Ardisia macrocarpa* Wall. |
| 6 | *Amomum dealbatum* Roxb. | 6 | *Amomum dealbatum* Roxb. | 6 | *Arisaema speciosum* (Wall.) Schott. |
| 7 | *Antidesma bumis* (L.) Spreng. | 7 | *Anoetochilus brevilabris* Lindl. | 7 | *Artemisia nilagirica* (C.B.Clarke) Pamp. |
| 8 | *Aphananthe cuspida* (Bl.) Planch | 8 | *Aphanantha cuspida* (Bl.) Planch. | 8 | *Arundinella khasiana* Nees.*ex* Steud. |
| 9 | *Arenga pinnata* (O.Kuntze.) Merr | 9 | *Ardisia macrocarpa* Wall. | 9 | *Bergenia ciliata* (Haw.) Strenb.*f.* |
| 10 | *Arisaema speciosum* (C.B.Clarke) Pamp. | 10 | *Arisaema speciosum* (Wall.) Schott. | 10 | *Blumea lanceolaris* (Roxb.) Druce |
| 11 | *Bambusa tulda* Roxb. | 11 | *Artemisia nilagirica* (C.B.Clarke) Pamp. | 11 | *Boehmeria platyphylla* D.Don. |
| 12 | *Begonia roxburghii* Miq. In. DC. | 12 | *Begonia roxburghii* Miq. In. DC. | 12 | *Boenninghausenia albiflora* (Hook.*f.*) Meissner. |
| 13 | *Betula alnoides* Buch.-Ham. *ex.* D.Don. | 13 | *Bergenia ciliata* (Haw.) Strenb.*f.* | 13 | *Bulbophyllum khasianum* Griff. |
| 14 | *Bidens pilosa* L. | 14 | *Betula alnoides* Buch.-Ham. *ex.* D.Don. | 14 | *Calamus flagellum* Roxb. |
| 15 | *Blumea alata* (D.Don) DC. | 15 | *Blumea alata* (D.Don) DC. | 15 | *Calamus khasianus* Becc. |
| 16 | *Blumea lanceolaris* (Roxb.) Druce. | 16 | *Blumea lanceolaris* (Roxb.) Druce | 16 | *Camelia kissi* Wallich |
| 17 | *Boehmeria platyphylla* D.Don. | 17 | *Boehmeria platyphylla* D.Don. | 17 | *Castanopsis tribuloides* (Sm) DC. |
| 18 | *Boehmeria rugulosa* Wedd. | 18 | *Boehmeria rugulosa* Wedd. | 18 | *Centella asiatica* (L.) Urban |
| 19 | *Bruinsmia polysperma* Cl. | 19 | *Buddleia macrostachya* Benth. | 19 | *Cephalotaxus graffithii* Hook.*f.* |

| | | | | | |
|---|---|---|---|---|---|
| 20 | *Buddleia macrostachya* Benth. | 20 | *Bulbophyllum khasianum* Griff. | 20 | *Cicerbita macrorhiza* (Royle) Beauv. |
| 21 | *Bulbophyllum cylindraceum* Wall. *ex* Lindl. | 21 | *Calamus flagellum* Roxb. | 21 | *Cinnamomum bejolghota* Buch.Ham. |
| 22 | *Calamus flagellum* Roxb. | 22 | *Calamus khasianus* Becc. | 22 | *Cinnamomum verum* Presl. |
| 23 | *Calamus khasianus* Becc. | 23 | *Castanopsis indica* (Roxb. *ex* Lindl.) A. DC. | 23 | *Circium interpositum* Patrak. |
| 24 | *Carallia brachiata* (Lour.) Merr. | 24 | *Castanopsis tribuloides* (Sm) DC. | 24 | *Cleisostoma racemiferum* Lindl. |
| 25 | *Caryota urens* L. | 25 | *Centella asiatica* (L.) Urban | 25 | *Clerodendrum infortunatum* Linn. |
| 26 | *Castanopsis indica* (Roxb. *ex* Lindl.) A. DC. | 26 | *Cephalotaxus graffithii* Hook.*f.* | 26 | *Coelogyne ovalis* Lindl. |
| 27 | *Castanopsis tribuloides* (Sm) DC. | 27 | *Cinnamomum bejolghota* Buch.Ham | 27 | *Crotalaria albida* Heyne *ex* Roth. |
| 28 | *Centella asiatica* (L.) Urban | 28 | *Cinnamomum verum* Presl. | 28 | *Curculigo crassifolia* Hook.*f.* |
| 29 | *Chukrasia tabularis* A. Juss. | 29 | *Circium interpositum* Patrak. | 29 | *Cymbopogon khasianus* (Hackel) Stapf. *ex* Bor |
| 30 | *Cinnamomum bejolghota* Buch.Ham. | 30 | *Cissampelos pareira var. hirsuta* Linn. (Buch.-Ham. *ex.* DC) | 30 | *Desmodium heterocarpon* (L.) DC. |
| 31 | *Cinnamomum verum* Presl. | 31 | *Cleisostoma racemiferum* Lindl. | 31 | *Dinochloa compactiflora* Kurz. Mc Clure |
| 32 | *Cissampelos pareira var. hirsuta* Linn. (Buch.-Ham. *ex* DC) | 32 | *Clerodendrum bracteatum* Wall. e*x* Walp. | 32 | *Disporum pullum* Sallish. |
| 33 | *Crassocephalum crepidiodes* (Benth.) S. Moore | 33 | *Clerodendrum infortunatum* Linn. | 33 | *Eleocarpus tectorius* (Lour.) Pioret *in* Lam. |
| 34 | *Crotalaria cytisoides* Roxb. *ex* DC | 34 | *Coelogyne ovalis* Lindl. | 34 | *Engelhardtia spicata* Lechen *ex* Blume |
| 35 | *Curculigo crassifolia* Hook.*f.* | 35 | *Conyza bonariensis* (L.) Cronq. | 35 | *Eria discolor* Lindl. |
| 36 | *Cymbidium devonianum* Paxt. | 36 | *Curculigo crassifolia* Hook.*f.* | 36 | *Eria lacei* Summerh. |
| 37 | *Cyratia mollis* Wall. | 37 | *Cymbidium devonianum* Paxt. | 37 | *Eria pannea* Lindl. |

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|---|---|---|---|---|---|
| 38 | *Debregeasia velutina* Gaud. | 38 | *Cyratia mollis* Wall. | 38 | *Euria japonica* Thunb. |
| 39 | *Dendrobium capillipes* Reichb.*f.* | 39 | *Debregeasia velutina* Gaud. | 39 | *Ficus religiosa* L. |
| 40 | *Dendrobium devonianum* Paxt. | 40 | *Dendrobium capillipes* Reichb.*f.* | 40 | *Ficus rigida* Jacq. |
| 41 | *Dendrobium formosum* Roxb. *ex* Lindl. | 41 | *Dendrobium devonianum* Paxt. | 41 | *Glochidion velutinum* Wight |
| 42 | *Dendrobium infundibulum* Lindl. | 42 | *Derris robusta* (Roxb. *ex* DC) Benth. | 42 | *Gynura bicolor* (Roxb. *ex* Willd) DC. |
| 43 | *Dendrobium logicornu* Lindl. | 43 | *Desmodium heterocarpon* (L.) DC. | 43 | *Hedera nepalensis* K.Koch. |
| 44 | *Dendrobium peguanum* Lindl. | 44 | *Dinochloa compactiflora* Kurz. Mc Clure | 44 | *Helicia erratica* Hook.*f.* |
| 45 | *Dendrocalamus hookeri* Munro | 45 | *Disporum pullum* Sallish. | 45 | *Heteropanax fragrans* (Roxb.) Seem. |
| 46 | *Derris robusta* (Roxb. *ex.* DC) Benth. | 46 | *Drimycarpus racemosus* (Roxb.) Hook.*f.* | 46 | *Inula eupatoriodes* DC. |
| 47 | *Dinochloa compactiflora* Kurz. Mc Clure | 47 | *Drymaria diandra* Blume | 47 | *Inula nervosa Wallich ex DC.* |
| 48 | *Drimycarpus racemosus* (Roxb.) Hook.*f.* | 48 | *Dysoxylum alliarum* (Buch.-Ham.) Balak. Null. | 48 | *Isodon repens* (Wall.) Murata |
| 49 | *Drocera peltata* Smith *ex* Willd | 49 | *Dysoxylum binecteriferum* (Roxb.) Hook.*f. ex* Beddome | 49 | *Leersia hexandra* Sw. |
| 50 | *Duabanga grandiflora* (Roxb. *ex* DC) Walp. | 50 | *Eleocarpus lanceaefolius* Roxb. | 50 | *Lithocarpus elegans* (Blume) Hatus. *ex* Soepadmo |
| 51 | *Dysoxylum alliarum* (Buch.-Ham.) Balak. Null. | 51 | *Eleocarpus tectorius* (Lour.) Poir. | 51 | *Mahonia borealis* Takeda |
| 52 | *Dysoxylum binecteriferum* (Roxb.) Hook.*f. ex* Baddome | 52 | *Engelhardtia spicata* Lechen *ex* Blume | 52 | *Mahonia nepalensis* Kanjilal *et al.* |
| 53 | *Dysoxylum gobarum* (Buch.-Ham.) Merr. | 53 | *Entada rheedei* Spreng. | 53 | *Microlepia strigosa* (Thunb.) Presl. Epim. |
| 54 | *Eleocarpus aristatus* Roxb. | 54 | *Eria discolor* Lindl. | 54 | *Microstegium petiolare* (Hackel) Bor. |

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|---|---|---|---|---|---|
| 55 | *Eleocarpus lanceaefolious* Roxb. | 55 | *Eria pannea* Lindl. | 55 | *Myriactis wallichii* Less. *in* Linn. |
| 56 | *Eleocarpus tectorius* (Lour.) Poir. | 56 | *Euria japonica* Thunb. | 56 | *Myrica esculenta* Ham. |
| 57 | *Engelhardtia spicata* Lechen *ex* Blume | 57 | *Ficus religiosa* L. | 57 | *Olea salicifolia* Wall. *ex* G. Don |
| 58 | *Entada rheedei* Spreng. | 58 | *Ficus rigida* Jacq. | 58 | *Osbeckia chinensis* L. |
| 59 | *Eupatorium odoratisum* (Linn) King & Robinson | 59 | *Galium elegans* Wallich *ex.* Roxb. | 59 | *Osbeckia sikkimensis* Craib. |
| 60 | *Euria japonica* Thunb. | 60 | *Glochidion velutinum* Wight | 60 | *Phoebe lanceolata* Nees. |
| 61 | *Ficus religiosa* L. | 61 | *Gynura bicolor* (Roxb. *ex.* Willd) DC. | 61 | *Pholidota imbricata* Lindl. |
| 62 | *Ficus rigida* Jacq. | 62 | *Hedychium villosum* J. E. Sm. | 62 | *Pinus kesiya* Royle *ex.* Gordon |
| 63 | *Galium elegans* Wallich *ex* Roxb. | 63 | *Helicia erratica* Hook.*f.* | 63 | *Platycerium wallichii* Hook. |
| 64 | *Gastrochillus calceolaris* (Buch.-Ham.*ex* J. E. Smith) D. Don. | 64 | *Hemistepta lyrata* Bunge *ex* C.E.C. Fischer | 64 | *Potentilla lineate* Trevir. *ex* Reich. |
| 65 | *Glochidion velutinum* Wight | 65 | *Heteropanax fragrans* (Roxb.) Seem. | 65 | *Prenanthes khasiana* C.B.Clarke |
| 66 | *Gynura bicolor* (Roxb. *ex* Willd) DC. | 66 | *Homolium debbarmani* Kanjilal *et al.* | 66 | *Quercus dilatata* Lindl. |
| 67 | *Helicia erratica* Hook.*f.* | 67 | *Hypericum elodeoides* Choisy *in* DC. | 67 | *Quercus leucotrichophora* A. Camus |
| 68 | *Helicia robusta* (Roxb.) R.Br. *ex.* Blume | 68 | *Hypericum monanthemum Hook.f. & Thomson ex Dyer in Hook.f.* | 68 | *Rhododendron wallichii* Hook.*f.* |
| 69 | *Heracleum burmanicum* Kurz. | 69 | *Indigofera heterantha* Wallich *ex* Brandis | 69 | *Rhododnedron arboretum* Sm. |
| 70 | *Homalium bhamoense* var. *debbarmani* Kanjilal *et al.* | 70 | *Indigofera stachyodes* Lindl. | 70 | *Rhus succedanea* L. |
| 71 | *Kydia calycina* Roxb. | 71 | *Isodon repens* (Wall.) Murata | 71 | *Rubus burmanicus* Hook.*f.* |

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|---|---|---|---|---|---|
| 72 | *Litsea cubeba* (Lour.) Pers. | 72 | *Kydia calycina* Roxb. | 72 | *Rubus ellipticus* Smith. |
| 73 | *Litsea monopetala* (Roxb.) Pers. | 73 | *Lasianthus biermanni* King *ex* Hook.*f.* | 73 | *Rubus niveus* Thunb. |
| 74 | *Macaranga indica* Wight. | 74 | *Lithocarpus elegans* (Blume) Hatus *ex* Soepadmo. | 74 | *Rubus rosaefolius* Smith |
| 75 | *Mallotus macrostachyus* (Miq.) Muell. Arg. | 75 | *Litsea cubeba* (Lour.) Pers. | 75 | *Rubus rugosus* Smith |
| 76 | *Mantisia spathulata* Schult. | 76 | *Litsea monopetala* (Roxb.) Pers. | 76 | *Saussurea deltoidea* (DC.) Sch.-Bip. *in* Linn. |
| 77 | *Melothria heterophylla* (Lour.) Cogn. | 77 | *Macaranga indica* Wight. | 77 | *Schima khasiana* Dyer |
| 78 | *Michelia champaka* L. | 78 | *Macropanax undulates* Wall *ex*. G.Don | 78 | *Schima wallichii* (DC.) Korthals |
| 79 | *Microlepia strigosa* (Thunb.) Presl., Epim. | 79 | *Mallotus macrostachyus* (Miq.) Muell. Arg. | 79 | *Schizostachyum capitatum* (Munro) R. Majumdar |
| 80 | *Myrica esculenta* Ham. | 80 | *Melothria heterophylla* (Lour.) Cogn. | 80 | *Scleria levis* Retzius |
| 81 | *Oberonia acaulis* Griff. | 81 | *Michelia doltsopa* Buch.-Ham. *ex* DC. | 81 | *Scleria terrestris* (L.) Fass. |
| 82 | *Olea dioica* Roxb. | 82 | *Microlepia strigosa* (Thunb.) Presl., Epim. | 82 | *Sinarundinaria falcata* (Nees.) Chao & Renvoize |
| 83 | *Olea salicifolia* Wall. *ex* G.Don | 83 | *Myrica esculenta* Bauch.-Ham. | 83 | *Sinarundinaria griffithiana* (Munro) Chao&Renvoize. |
| 84 | *Ophiorrhiza treutleri* Hook.*f.* | 84 | *Oberonia acaulis* Griff. | 84 | *Strobilanthes capitatus* T. Anders |
| 85 | *Ornithochillus difformis* (Schltr.) | 85 | *Olea dioica* Roxb. | 85 | *Swertia cordata* Cl. |
| 86 | *Osbeckia chinensis* L. | 86 | *Olea salicifolia* Wall *ex.* G.Don. | 86 | *Syzygium cumini* (L.) Skeels |
| 87 | *Osbeckia sikkimensis* Benth. *ex*.C.B. Clarke | 87 | *Ornithochillus difformis* (Schltr.) | 87 | *Viola pilosa* Blume |
| 88 | *Ostades paniculata* Blume | 88 | *Osbeckia chinensis* L. | 88 | *Viscum articulatum* Burm. *f.* |
| 89 | *Pholidota rubra* Lindl. | 89 | *Osbeckia sikkimensis* Benth. *ex*.C.B. Clarke | 89 | *Vitex heterophylla* Roxb. |

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|---|---|---|---|---|---|
| 90 | *Pilea symeria* Wedd. | 90 | *Ostades paniculata* Blume. | 90 | *Xantolis hookeri* (C.B.Clarke) P.Royen |
| 91 | *Pinus kesiya* Royle *ex.* Gordon | 91 | *Otochilus albus* Lindl. | 91 | *Zeuxine goodyeriodes* Lindl. |
| 92 | *Pithecellobium bigeminum* (L.) Mart. | 92 | *Otochilus porrectus* Lindl., Gen. *sp.* | | |
| 93 | *Pithecellobium heterophyllum* (Roxb.) J.F. Macbr. | 93 | *Persea glaucescens* Nees. | | |
| 94 | *Platycerium wallichii* Hook. | 94 | *Phoebe lanceolata* Nees. | | |
| 95 | *Pleione humilis* D.Don. | 95 | *Pholidota rubra* Lindl. | | |
| 96 | *Polygonatum oppositifolium* (Wall.) Royle | 96 | *Pinus kesiya* Royle *ex.* Gordon | | |
| 97 | *Porpax fibuliformis* King & Pantling | 97 | *Pithecellobium bigeminum* (L.) Mart. | | |
| 98 | *Prunus jenkinsii* Hook.*f.* & Thomson | 98 | *Pithecellobium heterophyllum* (Roxb.) J.F. Macbr. | | |
| 99 | *Prunus undulata* Bauch.-Ham. *ex.* | 99 | *Platycerium wallichii* Hook. | | |
| 100 | *Quercus dealbata* Hook.*f.* & Thompson *ex* Miq. | 100 | *Pleione humilis* D.Don. | | |
| 101 | *Quercus helferiana* A.DC. | 101 | *Porpax fibuliformis* King & Pantling | | |
| 102 | *Quercus lanceafolia* | 102 | *Prunus cerasoides* D.Don. | | |
| 103 | *Quercus leucotrichophora* A. Camus | 103 | *Prunus jenkinsii* Hook.*f.* & Thomson | | |
| 104 | *Rhus semialata* Miller | 104 | *Quercus dilatata* Lind. | | |
| 105 | *Rubus birmanicus* Hook.f. | 105 | *Quercus helferiana* A.DC. | | |
| 106 | *Rubus ellipticus* Smith. | 106 | *Quercus lanceaefolia* | | |

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|---|---|---|---|
| 107 | *Rubus niveus* Thunb. | 107 | *Quercus leucotrichophora* A. Camus |
| 108 | *Rubus rosaefolius* Smith | 108 | *Quercus polystachya* Wall. *ex* A.DC. |
| 109 | *Rubus rugosus* Smith | 109 | *Rhododendron veitchianum* Hook.*f.* |
| 110 | *Sanicula elata* Buch.-Ham. *ex* .D.Don. | 110 | *Rhododnedron arboretum* Sm. |
| 111 | *Sapium baccatum* Roxb. | 111 | *Rhus semialata* Miller |
| 112 | *Saurauia punduana* Wallich. | 112 | *Rhus succedanea* L. |
| 113 | *Schima wallichii* (DC.) Korthals | 113 | *Rubus birmanicus* Hook.f. |
| 114 | *Schizostachyum capitatum* (Munro) R. Majumdar | 114 | *Rubus ellipticus* Smith. |
| 115 | *Scleria levis* Retzius | 115 | *Rubus niveus* Thunb. |
| 116 | *Scleria terrestris* (L.) Fass. | 116 | *Rubus rosaefolius* Smith |
| 117 | *Scutellaria discolor* Colebr. | 117 | *Rubus rugosus* Smith |
| 118 | *Sinarundinaria falcata* (Nees.) Chao & Renvoize | 118 | *Sapium bacatum* Roxb. |
| 119 | *Sinarundinaria griffithiana* (Munro) Chao&Renvoize. | 119 | *Saurauia punduana* Wallich. |
| 120 | *Smilax ovalifolia* Roxb. | 120 | *Schima khasiana* Dyer |
| 121 | *Caryota mitis* L. | 121 | *Schima wallichii* (DC.) Korthals |
| 122 | *Strobilanthes capitatus* T. Anders | 122 | *Schizostachyum capitatum* (Munro) R. Majumdar |
| 123 | *Strobilanthes parryorum* T. Anders | 123 | *Scleria levis* Retzius |

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|---|---|---|---|
| 124 | *Styrax serrulatum* Roxb. | 124 | *Nyssa javanica* (Blume) Wanger |
| 125 | *Syzygium cumini* (L.) Skeels. | 125 | *Scleria terrestris* (L.) Fass. |
| 126 | *Toona ciliata* M. Roem | 126 | *Sinarundinaria falcata* (Nees.) Chao & Renvoize |
| 127 | *Trema orientalis* (L.) Blume | 127 | *Sinarundinaria griffithiana* (Munro) Chao&Renvoize. |
| 128 | *Trichodesma khasianum* T. Anders | 128 | *Smilax ovalifolia* Roxb. |
| 129 | *Turpinia cochinchinensis* (Lour.) Merr. | 129 | *Strobilanthes microstegium* |
| 130 | *Uncaria laevigata* Wallich. | 130 | *Styrax serrulatum* Roxb. |
| 131 | *Vernonia volkameriaefolia* Wall. *ex* DC. | 131 | *Swertia cordata* Cl. |
| 132 | *Vitex peduncularis* Wallich *ex* Schauer | 132 | *Syzygium cumini* (L.) Skeels |
| 133 | *Wandlandia grandis* (Hook.*f*.) Cowan | 133 | *Trema orientalis* (L.) Blume. |
| 134 | *Zizyphus incurva* Roxb. | 134 | *Vernonia volkameriaefolia* Wall. *ex* DC. |
| | | 135 | *Viola betonicifolia* J.Smith |
| | | 136 | *Viola hamiltoniana* D.Don. |
| | | 137 | *Viola pilosa* Blume |
| | | 138 | *Vitex heterophylla* Roxb. |
| | | 139 | *Vitex peduncularis* Wall *ex.* Sch. |
| | | 140 | *Wandlandia grandis* (Hook.*f*.) Cowan. |
| | | 141 | *Xantolis hookeri* (C.B.Clarke) P.Royen |
| | | 142 | *Zizyphus incurva* Roxb. |

**Table 7(a).** Frequency (%), Density, Abundance and IVI of tree species in Site A

| Sl. No. | Name of the Species | Frequency (%) | Density (indv.ha$^{-1}$) | Abundance | IVI |
|---|---|---|---|---|---|
| 1 | *Ailanthus integrifolia* L. | 36 | 56 | 1.55 | 6.12 |
| 2 | *Albizzia chinensis* (Osb.) Mer. | 16 | 16 | 1 | 2.65 |
| 3 | *Antidesma bumis* (L.) Spreng | 36 | 64 | 1.77 | 5.50 |
| 4 | *Aphanantha cuspida* (Bl.) Planch | 24 | 32 | 1.33 | 2.88 |
| 5 | *Betula alnoides* Buch.-Ham. *ex* D.Don. | 36 | 40 | 1.11 | 4.83 |
| 6 | *Boehmeria rugulosa* Wedd. | 20 | 32 | 1.6 | 3.01 |
| 7 | *Bruinsmia polysperma* Cl. | 12 | 20 | 1.66 | 1.81 |
| 8 | *Buddleia macrostachya* Benth. | 28 | 28 | 1.2 | 2.94 |
| 9 | *Carallia brachiata* (Lour.) Merr. | 20 | 28 | 1.4 | 2.81 |
| 10 | *Castanopsis indica* (Roxb. *ex* Lindl.) DC. | 32 | 60 | 1.87 | 4.83 |
| 11 | *Castanopsis tribuloides* DC. | 72 | 256 | 3.55 | 43.50 |
| 12 | *Chukrasia velutina* A. Juss | 12 | 16 | 1.33 | 1.99 |
| 13 | *Cinnamomum bejolghota* (Buch.-Ham.) | 24 | 24 | 1 | 2.55 |
| 14 | *Cinnamomum verum* Presl. | 28 | 40 | 1.42 | 3.55 |
| 15 | *Debregeasia velutina* Gaud. | 16 | 20 | 1.25 | 2.10 |
| 16 | *Derris robusta* (Roxb. *ex* DC.) Benth. | 32 | 40 | 1.25 | 3.88 |
| 17 | *Drimycarpus racemosus* (Roxb.) Hook.f. | 20 | 24 | 1.2 | 3.71 |
| 18 | *Duabanga grandiflora* (Roxb. *ex* DC.) Walp. | 12 | 16 | 1.33 | 1.93 |
| 19 | *Dysoxylum binecteriferum* (Roxb.) Hook.*f*. Beddome | 28 | 44 | 1.57 | 3.73 |
| 20 | *Dysoxylum alliarum* (Buch.-Ham.) Balak. Null. | 16 | 20 | 1.25 | 1.92 |
| 21 | *Dysoxylum gobarum* (Buch.-Ham.) Merr. | 20 | 20 | 1 | 2.60 |
| 22 | *Eleocarpus aristatus* Roxb. | 20 | 24 | 1.2 | 2.81 |
| 23 | *Eleocarpus lanceaefolious* Roxb. | 20 | 32 | 1.6 | 3.11 |

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|---|---|---|---|---|---|
| 24 | *Eleocarpus tectorius* (Lour.) Poiret in Lam. | 12 | 16 | 1.33 | 1.74 |
| 25 | *Engelhardtia spicata* Lechen *ex* Blume | 64 | 148 | 2.31 | 21.03 |
| 26 | *Euria japonica* Thunb. | 24 | 40 | 1.66 | 3.19 |
| 27 | *Ficus religiosa* L. | 12 | 20 | 1.66 | 2.13 |
| 28 | *Ficus rigida* Jacq. | 16 | 16 | 1 | 1.67 |
| 29 | *Glochidion velutinum* Wight. | 12 | 12 | 1 | 1.38 |
| 30 | *Helicia erratica* (Roxb.) Blume | 68 | 200 | 2.94 | 19.10 |
| 31 | *Helicia robusta* (Roxb.) R.Br. *ex* Blume | 8 | 8 | 1 | 1.10 |
| 32 | *Homalium debbarmani* Kanjilal *et al.* | 12 | 12 | 1 | 1.49 |
| 33 | *Kydia calycina* Roxb. | 12 | 12 | 1 | 1.41 |
| 34 | *Litsea cubeba* (Lour.) Pers. | 32 | 48 | 1.5 | 4.14 |
| 35 | *Litsea monopetala* (Roxb.) Pers. | 16 | 24 | 1.5 | 3.17 |
| 36 | *Macaranga indica* W. | 40 | 56 | 1.4 | 5.75 |
| 37 | *Mallotus macrostachyus* (Miq.) Muell. Arg. | 40 | 48 | 1.2 | 5.04 |
| 38 | *Michelia champaca* L. | 28 | 32 | 1.14 | 3.86 |
| 39 | *Myrica esculenta* Ham. | 20 | 24 | 1.2 | 2.71 |
| 40 | *Olea dioica* Roxb. | 12 | 20 | 1.66 | 2.28 |
| 41 | *Olea salicifolia* Wall. *ex* G.Don. | 32 | 40 | 1.25 | 4.96 |
| 42 | *Ostades paniculata* Blume | 12 | 20 | 1.66 | 2.31 |
| 43 | *Pinus kesiya* Royle *ex.* Gordon | 40 | 80 | 2 | 7.52 |
| 44 | *Pithecellobium bigeminum* (L.) Mart. | 24 | 32 | 1.33 | 2.94 |
| 45 | *Pithecellobium heterophyllum* (Roxb.) J. F. Macbr. | 36 | 48 | 1.33 | 4.51 |
| 46 | *Prunus jenkinsii* Hook.*f.* & Thomson | 16 | 16 | 1 | 2.24 |
| 47 | *Prunus undulata* Buch.-Ham. *ex* D.Don. | 12 | 16 | 1.3 | 2.04 |
| 48 | *Quercus dealbata* Hook.*f.* & Thompson *ex* Miq. | 64 | 100 | 1.56 | 11.63 |
| 49 | *Quercus helferiana* A.DC. | 16 | 24 | 1.5 | 2.78 |

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|---|---|---|---|---|---|
| 50 | *Quercus lanceafolia* | 24 | 32 | 1.33 | 3.59 |
| 51 | *Quercus leucotrichophora* A. Camus | 64 | 128 | 2 | 15.88 |
| 52 | *Rhus semialata* Miller | 20 | 32 | 1.6 | 2.93 |
| 53 | *Sapium baccatum* Roxb. | 8 | 12 | 1.5 | 1.29 |
| 54 | *Saurauia punduana* Wallich | 44 | 56 | 1.27 | 5.77 |
| 55 | *Schima wallichii* (DC.) Korthals | 40 | 64 | 1.6 | 5.80 |
| 56 | *Styrax serrulatum* Roxb. | 20 | 40 | 2 | 3.88 |
| 57 | *Syzygium cumini* (L.) Skeels | 12 | 12 | 1 | 2.85 |
| 58 | *Toona ciliata* M. Roem. | 12 | 12 | 1 | 1.83 |
| 59 | *Trema orientalis* (L.) Blume | 24 | 32 | 1.33 | 3.65 |
| 60 | *Vitex peduncularis* Wallich *ex* Schauer | 12 | 20 | 1.66 | 2.40 |
| 61 | *Wandlandia grandis* (Hook.*f.*) Cowan | 60 | 116 | 1.93 | 11.39 |
| 62 | *Zizyphus incurva* Roxb. | 12 | 20 | 1.6 | 1.88 |

**Table 7(b).** Frequency %, Density, Abundance and IVI of shrubs species in Site A

| Sl. No. | Name of the Species | Frequency (%) | Density (indv.ha$^{-1}$) | Abundance | IVI |
|---|---|---|---|---|---|
| 1 | *Amomum dealbatum* Roxb. | 46 | 70 | 1.52 | 17.30 |
| 2 | *Blumea lanceolaris* (Roxb.) Druce | 56 | 96 | 1.71 | 19.52 |
| 3 | *Crotalaria cytisoides* Roxb. | 32 | 42 | 1.31 | 13.96 |
| 4 | *Mantisia spathulata* Schult. | 24 | 24 | 1.00 | 7.79 |
| 5 | *Osbeckia chinensis* L. | 34 | 56 | 1.33 | 16.42 |
| 6 | *Osbeckia sikkimensis* Craib. | 26 | 40 | 1.54 | 10.80 |
| 7 | *Pilea symeria* Wedd. | 30 | 38 | 1.27 | 18.21 |
| 8 | *Rubus burmanicus* Hook.*f.* | 30 | 42 | 1.40 | 12.72 |
| 9 | *Rubus ellipticus* Smith | 40 | 60 | 1.50 | 18.22 |
| 10 | *Rubus niveus* Thunb. | 42 | 58 | 1.71 | 23.47 |
| 11 | *Rubus rugosus* Smith | 38 | 62 | 1.63 | 18.29 |

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|---|---|---|---|---|---|
| 12 | *Rubus rosaefolius* Smith | 40 | 54 | 1.35 | 16.16 |
| 13 | *Strobilanthes capitatus* T. Anders | 36 | 66 | 1.83 | 27.16 |
| 14 | *Strobilanthes parryorum* T.Anders | 34 | 54 | 1.59 | 23.01 |
| 15 | *Trichodesma khasianum* T. Anders | 34 | 50 | 1.47 | 15.77 |
| 16 | *Turpinia cochinchinensis* (Lour.) Merr. | 36 | 54 | 1.50 | 15.43 |
| 17 | *Vernonia volkameriaefolia* Wall. *ex* DC. | 44 | 74 | 1.68 | 25.01 |

**Table 7(c).** Frequency %, Density, Abundance and IVI of herb species in Site A

| Sl. No. | Name of the Species | Frequency (%) | Density (indv.ha$^{-1}$) | Abundance | IVI |
|---|---|---|---|---|---|
| 1 | *Ageratum conyzoides* L. | 38 | 52 | 1.37 | 11.80 |
| 2 | *Ainsliaea latifolia* (D.Don.) Sch.-Bip. | 28 | 38 | 1.36 | 9.60 |
| 3 | *Arisaema speciosum* (Wall.) Schott. | 44 | 54 | 1.23 | 38.24 |
| 4 | *Begonia roxburghii* Miq. in DC. | 30 | 36 | 1.2 | 8.90 |
| 5 | *Bidens pilosa* L. | 34 | 36 | 1.06 | 11.37 |
| 6 | *Blumea alata* (D.Don.) DC. | 34 | 36 | 1.06 | 9.15 |
| 7 | *Boehmeria platyphylla* D.Don | 50 | 90 | 1.8 | 27.47 |
| 8 | *Centella asiatica* (L.) Urban | 44 | 74 | 1.68 | 12.92 |
| 9 | *Cissampelos pareira var. hirsuta* (Buch.-Ham. *ex* DC.) | 26 | 36 | 1.38 | 7.00 |
| 10 | *Crassocephalum crepidiodes* (Benth.) S.Moore | 24 | 36 | 1.5 | 7.92 |
| 11 | *Curculigo crassifolia* Hook.*f.* | 56 | 110 | 1.96 | 39.84 |
| 12 | *Drocera peltata* Smith *ex* Willd. | 26 | 30 | 1.15 | 7.21 |
| 13 | *Eupatorium odoratisum* (L.) King & Robinson | 40 | 62 | 1.55 | 12.74 |
| 14 | *Galium elegans* Wallich *ex* Roxb. | 20 | 26 | 1.3 | 5.24 |
| 15 | *Gynura bicolor* (Roxb. *ex* Willd.)DC. | 46 | 76 | 1.65 | 18.18 |

| | | | | | |
|---|---|---|---|---|---|
| 16 | *Heracleum burmanicum* Kurz. | 22 | 26 | 1.18 | 6.11 |
| 17 | *Melothria heterophylla* (Lour.) Cogn. | 24 | 30 | 1.25 | 7.77 |
| 18 | *Microlepia strigosa* (Thunb.) Presl. Epim. | 42 | 76 | 1.81 | 13.87 |
| 19 | *Ophiorrhiza treutleri* Hook.*f.* | 18 | 22 | 1.22 | 5.75 |
| 20 | *Polygonatum oppositifolium* (Wall.) Royle | 18 | 26 | 1.44 | 5.44 |
| 21 | *Sanicula elata* Buch.-Ham. *ex* D.Don. | 20 | 24 | 1.2 | 6.36 |
| 22 | *Scleria levis* Retzius | 38 | 62 | 1.63 | 11.50 |
| 23 | *Scleria terrestris* (L.) Fass. | 38 | 56 | 1.47 | 10.67 |
| 24 | *Scutellaria discolor* Colebr. | 20 | 20 | 1 | 4.95 |

**Table 8(a).** Frequency (%), Density, Abundance and IVI of tree species in Site B

| Sl. No | Name of Species | Frequency (%) | Density (indv.ha$^{-1}$) | Abundance | IVI |
|---|---|---|---|---|---|
| 1 | *Albizzia chinensis* (Osb.) Mer. | 12 | 12 | 1 | 1.66 |
| 2 | *Alseodaphne petiolaris* Hook.*f* | 32 | 36 | 1.12 | 6.49 |
| 3 | *Aphanantha cuspida* (Bl.) Planch | 24 | 36 | 3.9 | 2.50 |
| 4 | *Betula alnoides* Buch.-Ham. *ex* D.Don. | 36 | 40 | 1.11 | 4.97 |
| 5 | *Boehmeria rulugosa* | 28 | 32 | 1.14 | 3.03 |
| 6 | *Buddleia macrostachya* Benth. | 20 | 24 | 1.2 | 1.94 |
| 7 | *Castanopsis indica* (Roxb. *ex* Lindl.) DC. | 32 | 44 | 1.37 | 3.70 |
| 8 | *Castanopsis tribuloides* DC. | 72 | 288 | 4 | 21.90 |
| 9 | *Cephalotaxus graffithii* Hook. *f.* | 12 | 12 | 1 | 1.10 |
| 10 | *Cinnamomum cecicodaphne* Ness. | 20 | 32 | 1.6 | 3.05 |
| 11 | *Cinnamomum bejolghota* (Buch.-Ham.) | 28 | 40 | 1.4 | 3.08 |
| 12 | *Cinnamomum verum* Presl. | 32 | 48 | 1.5 | 3.51 |
| 13 | *Clerodendrum bracteatum* Wall. *ex* Walp. | 16 | 20 | 1.25 | 1.61 |

| | | | | | |
|---|---|---|---|---|---|
| 14 | *Debrageasia velutina* Gaud. | 44 | 44 | 1 | 4.57 |
| 15 | *Derris robusta* (Roxb. *ex* DC.) Benth. | 16 | 16 | 1 | 1.49 |
| 16 | *Drimycarpus racemosus* (Roxb.) Hook.*f.* | 20 | 24 | 1.35 | 3.36 |
| 17 | *Dysoxylum alliarum* (Buch.-Ham.) Balak. Null. | 12 | 12 | 1 | 1.18 |
| 18 | *Dysoxylum binecteriferum* (Roxb.) Hook.*f. ex* Beddome | 28 | 28 | 1 | 2.73 |
| 19 | *Eleocarpus lanceaefolius* Roxb. | 20 | 24 | 1.2 | 2.11 |
| 20 | *Eleocarpus tectorius* (Lour.) Poiret in Lam. | 8 | 8 | 1 | 0.83 |
| 21 | *Engelhardtia spicata* Lechen *ex* Blume | 76 | 304 | 4 | 37.92 |
| 22 | *Euria japonica* Thunb. | 24 | 24 | 1 | 2.29 |
| 23 | *Ficus regida* Jacq. | 28 | 32 | 1.17 | 2.82 |
| 24 | *Ficus religiosa* L. | 20 | 20 | 1 | 2.28 |
| 25 | *Glochdion velutinum* Wight. | 24 | 32 | 1.33 | 2.85 |
| 26 | *Helicia erratica* (Roxb.) Blume | 88 | 388 | 4.4 | 26.2 |
| 27 | *Heteropanax fragrans* (Roxb.) Seem. | 8 | 12 | 1.5 | 0.97 |
| 28 | *Homalium debbarmani* Kanjilal *et al.* | 12 | 1 | 8.11 | 1.32 |
| 29 | *Kydia calycina* Roxb. | 16 | 20 | 1.25 | 1.82 |
| 30 | *Lasianthus biermanni* King *ex* Hook.*f.* | 24 | 32 | 1.33 | 3.37 |
| 31 | *Lithocarpus elegans* Hatus. *ex* Soepadmo | 16 | 16 | 1 | 1.65 |
| 32 | *Litsea cubeba* (Lour.) Pers. | 28 | 28 | 1 | 2.76 |
| 33 | *Litsea monopetala* (Roxb.) Pers. | 12 | 12 | 1 | 1.73 |
| 34 | *Macaranga indica* W. | 28 | 32 | 1.14 | 3.57 |
| 35 | *Macropanax undulatum* (Wallich *ex* G.Don.) Seem. | 48 | 88 | 1.83 | 7.60 |
| 36 | *Mallotus macrostachyus* (Miq.) Muell. Arg. | 24 | 24 | 1 | 2.71 |
| 37 | *Michelia doltsopa* Buch.-Ham. *ex* DC. | 24 | 24 | 1 | 2.18 |
| 38 | *Myrica esculenta* Ham. | 64 | 112 | 1.75 | 8.98 |
| 39 | *Olea dioica* Roxb. | 12 | 20 | 10.33 | 2.04 |
| 40 | *Olea salicifolia* Wall. *ex* G.Don. | 24 | 40 | 1.66 | 3.47 |

| | | | | | |
|---|---|---|---|---|---|
| 41 | *Ostades paniculata* Blume | 28 | 40 | 1.42 | 4.05 |
| 42 | *Phoebe lanceolata* Nees. | 28 | 32 | 1.14 | 3.34 |
| 43 | *Pinus kesiya* Royle *ex.* Gordon | 32 | 56 | 1.75 | 4.05 |
| 44 | *Pithecellobium bigeminum* (L.) Mart. | 24 | 32 | 4.5 | 2.56 |
| 45 | *Pithecellobium heterophyllum* (Roxb.) J.F. Macbr. | 36 | 48 | 5.1 | 3.93 |
| 46 | *Prunus cerasoides* D.Don. | 8 | 8 | 1 | 0.75 |
| 47 | *Prunus jenkinsii* Hook.*f.* & Thomson | 16 | 1 | 10.45 | 2.00 |
| 48 | *Quercus dilatata* Lindl. | 36 | 48 | 1.33 | 4.42 |
| 49 | *Quercus helferiana* A.DC. | 16 | 16 | 1 | 1.93 |
| 50 | *Quercus lanceaefolia* | 44 | 48 | 1.09 | 5.46 |
| 51 | *Quercus leucotrichophora* A. Camus | 80 | 364 | 4.55 | 31.39 |
| 52 | *Quercus polystachya* Wall. *ex* A.DC. | 20 | 20 | 1 | 1.85 |
| 53 | *Rhododendron arboreum* Sm. | 28 | 56 | 2 | 3.72 |
| 54 | *Rhus semialata* Miller | 16 | 16 | 1 | 1.47 |
| 55 | *Rhus succedanea* L. | 20 | 24 | 1.2 | 2.68 |
| 56 | *Sapium baccatum* Roxb. | 28 | 28 | 1 | 3.55 |
| 57 | *Saurauia punduana* Wallich | 28 | 28 | 1 | 2.90 |
| 58 | *Schima khasiana* Dyer | 24 | 28 | 1.16 | 2.45 |
| 59 | *Schima wallichii* (DC.) Korthals | 32 | 48 | 1.5 | 3.88 |
| 60 | *Styrax serrulatum* Roxb. | 20 | 2 | 8.8 | 3.44 |
| 61 | *Syzygium cumini* (L.) Skeels | 8 | 8 | 1 | 1.56 |
| 62 | *Trema orientalis* (L.) Blume | 24 | 32 | 1.33 | 3.14 |
| 63 | *Vitex heterophylla* Roxb. | 16 | 16 | 1 | 2.27 |
| 64 | *Vitex peduncularis* Wallich *ex* Schauer | 12 | 20 | 11.11 | 2.15 |
| 65 | *Wandlandia grandis* (Hook.*f.)* Cowan | 28 | 64 | 2.28 | 5.27 |
| 66 | *Xantolis hookeri* (C.B.Clarke) P. Royen | 8 | 8 | 1 | 0.73 |
| 67 | *Zizyphus incurva* Roxb. | 12 | 20 | 7.2 | 1.65 |

**Table 8(b).** Frequency (%), Density, Abundance and IVI of shrubs species in Site B

| Sl. No. | Name of Species | Frequency (%) | Density (indv.ha$^{-1}$) | Abundance | IVI |
|---|---|---|---|---|---|
| 1 | *Amomum dealbatum* Roxb. | 44 | 70 | 1.591 | 15.04 |
| 2 | *Ardisia macrocarpa* Wall. | 56 | 76 | 1.357 | 21.99 |
| 3 | *Artemisia nilagirica* (C.B.Clarke) Pamp | 42 | 102 | 2.429 | 22.72 |
| 4 | *Blumea lanceolaris* (Roxb.) Druce | 48 | 76 | 1.583 | 12.42 |
| 5 | *Circium interpositum* Patrak. | 38 | 44 | 1.158 | 10.03 |
| 6 | *Clerodendron infortunatum* Linn. | 52 | 76 | 1.462 | 26.14 |
| 7 | *Desmodium heterocarpon* (L.) DC. | 34 | 38 | 1.118 | 7.37 |
| 8 | *Hedychium villosum* J.E. Sm. | 36 | 38 | 1.056 | 9.00 |
| 9 | *Hypericum elodeoides* Choisy in DC. | 36 | 38 | 1.056 | 9.82 |
| 10 | *Indigofera heterantha* Wallich *ex* Brandis | 38 | 42 | 1.105 | 10.04 |
| 11 | *Indigofera stachyodes* Lindl. | 36 | 38 | 1.056 | 9.54 |
| 12 | *Osbeckia chinensis* L. | 50 | 84 | 1.68 | 18.75 |
| 13 | *Osbeckia sikkimensis* Craib. | 54 | 100 | 1.852 | 23.28 |
| 14 | *Rubus burmanicus* Hook.*f.* | 36 | 42 | 1.167 | 10.76 |
| 15 | *Rubus ellipticus* Smith | 48 | 64 | 1.333 | 15.11 |
| 16 | *Rubus niveus* Thunb. | 46 | 52 | 1.13 | 11.65 |
| 17 | *Rubus rosaefolius* Smith | 44 | 48 | 1.091 | 11.88 |
| 18 | *Rubus rugosus* Smith | 40 | 54 | 1.35 | 13.57 |
| 19 | *Strobilanthes macrostegius* | 46 | 68 | 1.478 | 20.67 |
| 20 | *Vernonia volkameriaefolia* Wall. *ex* DC. | 58 | 70 | 1.207 | 20.21 |

**Table 8(c).** Frequency (%), Density, Abundance and IVI of herb species in Site B

| Sl. No. | Name of Species | Frequency (%) | Density (indv.ha$^{-1}$) | Abundance | IVI |
|---|---|---|---|---|---|
| 1 | *Ainsliaea latifolia* (D.Don.) Sch.-Bip. | 26 | 44 | 1.692 | 8.93 |
| 2 | *Ainsliaea pteropoda* DC. | 28 | 44 | 1.571 | 8.06 |
| 3 | *Arisaema speciosum* (Wall.) Schott. | 30 | 50 | 1.667 | 29.4 |
| 4 | *Begonia roxburghii* Miq. in DC. | 24 | 36 | 1.5 | 6.89 |
| 5 | *Bergenia ciliata* (Haw.) Sternb.*f.* | 24 | 36 | 1.5 | 12.9 |
| 6 | *Blumea alata* (D.Don.) DC. | 46 | 72 | 1.565 | 13.2 |
| 7 | *Boehmeria platyphylla* D.Don | 56 | 108 | 1.929 | 27.8 |

| | | | | | |
|---|---|---|---|---|---|
| 8 | *Centella asiatica* (L.) Urban | 34 | 50 | 1.471 | 8.10 |
| 9 | *Cissampelos pareire var. hirsute* (Buch.-Ham. Ex DC.) | 30 | 38 | 1.267 | 6.70 |
| 10 | *Conyza bonariensis* (L.) Cronq. | 34 | 44 | 1.294 | 8.56 |
| 11 | *Curculigo crassifolia* Hook.*f.* | 64 | 136 | 2.125 | 42.2 |
| 12 | *Disporum pullum* Sallish | 24 | 26 | 1.083 | 5.32 |
| 13 | *Drymaria diandra* Blume | 26 | 26 | 1 | 5.53 |
| 14 | *Galium elegans* Wallich *ex* Roxb. | 32 | 36 | 1.125 | 6.82 |
| 15 | *Gynura bicolor* (Roxb. *ex* Willd.)DC. | 36 | 56 | 1.556 | 11.9 |
| 16 | *Hemistepta lyrata* Bunge *ex* C.E.C. Fischer | 30 | 50 | 1.667 | 10.27 |
| 17 | *Hypericum monanthemum* Hook.*f.* & Thomson *ex* Dyer in Hook.*f.* | 24 | 24 | 1 | 6.41 |
| 18 | *Isodon repens* (Wall.) Murata | 26 | 34 | 1.308 | 6.69 |
| 19 | *Melothria heterophylla* (Lour.) Cogn. | 30 | 34 | 1.133 | 7.51 |
| 20 | *Microlepia strigosa* (Thunb.) Presl. Epim. | 36 | 64 | 1.778 | 11.05 |
| 21 | *Scleria levis* Retzius | 52 | 94 | 1.808 | 14.4 |
| 22 | *Scleria terrestris* (L.) Fass. | 42 | 76 | 1.81 | 11.8 |
| 23 | *Swertia cordata* Cl. | 24 | 28 | 1.167 | 5.55 |
| 24 | *Uncaria laevigata* Wallich | 20 | 22 | 1.1 | 5.26 |
| 25 | *Viola betonicifolia* J. Smith | 24 | 30 | 1.25 | 5.69 |
| 26 | *Viola hamiltoniana* D.Don. | 22 | 26 | 1.182 | 4.98 |
| 27 | *Viola pilosa* Blume | 32 | 38 | 1.188 | 7.82 |

**Table 9(a).** Frequency (%), Density, Abundance and IVI of tree species in Site C

| Sl. No. | Name of Species | Frequency (%) | Density (indv.ha$^{-1}$) | Abundance | IVI |
|---|---|---|---|---|---|
| 1 | *Alseodaphne petiolaris* Hook.*f* | 32 | 44 | 1.38 | 6.55 |
| 2 | *Camelia kissi* Wallich | 8 | 8 | 1.00 | 1.23 |
| 3 | *Castanopsis tribuloides* DC. | 64 | 124 | 1.94 | 19.15 |
| 4 | *Cephalotaxus griffithi* Hook.*f.* | 8 | 12 | 1.50 | 1.28 |
| 5 | *Cinnamomum bejolghota* (Buch.-Ham.) | 36 | 64 | 1.78 | 6.14 |
| 6 | *Cinnamomum verum* Presl. | 36 | 52 | 1.44 | 5.96 |

| | | | | | |
|---|---|---|---|---|---|
| 7 | *Eleocarpus tectorius* (Lour.) Poiret in Lam. | 16 | 20 | 1.25 | 2.69 |
| 8 | *Engelhardtia spicata* Lechen *ex* Blume | 68 | 376 | 5.53 | 41.65 |
| 9 | *Euria japonica* Thunb. | 64 | 200 | 3.13 | 15.26 |
| 10 | *Ficus religiosa* L. | 12 | 12 | 1.00 | 1.75 |
| 11 | *Ficus rigida* Jacq. | 16 | 24 | 1.50 | 2.57 |
| 12 | *Glochidion velutinum* Wight. | 20 | 24 | 1.20 | 2.97 |
| 13 | *Helicia erratica* (Roxb.) Blume | 72 | 380 | 5.28 | 44.33 |
| 14 | *Heteropanax fragrans* (Roxb.) Seem. | 68 | 120 | 1.76 | 19.45 |
| 15 | *Lithocarpus elegans* Hatus. *ex* Soepadmo | 44 | 144 | 3.27 | 10.38 |
| 16 | *Mahonia nepalensis* Kanjilal *et al.* | 28 | 32 | 1.14 | 4.12 |
| 17 | *Myrica esculenta* Ham. | 48 | 160 | 3.33 | 12.40 |
| 18 | *Olea salicifolia* Wall. *ex* G.Don | 12 | 24 | 2.00 | 2.52 |
| 19 | *Phoebe lanceolata* Nees. | 28 | 36 | 1.29 | 4.46 |
| 20 | *Pinus kesiya* Royle *ex.* Gordon | 32 | 120 | 3.75 | 9.16 |
| 21 | *Quercus dilatata* Lindl. | 44 | 220 | 5.00 | 19.25 |
| 22 | *Quercus leucotrichophora* A. Camus | 64 | 204 | 3.19 | 23.39 |
| 23 | *Rhododendron wallichii* Hook.*f.* | 36 | 48 | 1.33 | 5.68 |
| 24 | *Rhododnedron arboreum* Sm. | 60 | 168 | 2.80 | 21.66 |
| 25 | *Rhus succedanea* L. | 20 | 32 | 1.60 | 3.56 |
| 26 | *Schima khasiana* Dyer | 12 | 40 | 3.33 | 3.15 |
| 27 | *Schima wallichii* (DC.) Korthals | 16 | 16 | 1.00 | 2.47 |
| 28 | *Syzygium cumini* (L.) Skeels | 24 | 24 | 1.00 | 4.42 |
| 29 | *Vitex heterophylla* Roxb. | 12 | 12 | 1.00 | 1.84 |
| 30 | *Xantolis hookeri* (C.B.Clarke) P. Royen | 4 | 4 | 1.00 | 0.56 |

**Table 9(b).** Frequency (%), Density, Abundance and IVI of shrub species in Site C

| Sl. No. | Name of Species | Frequency (%) | Density (indv.ha$^{-1}$) | Abundance | IVI |
|---|---|---|---|---|---|
| 1 | *Amomum dealbatum* Roxb. | 36.00 | 88 | 2.44 | 11.29 |
| 2 | *Ardisia macrocarpa* Wall. | 42.00 | 90 | 2.14 | 18.09 |
| 3 | *Artemisia nilagirica* (C.B.Clarke) Pamp | 72.00 | 150 | 2.08 | 25.44 |
| 4 | *Blumea lanceolaris* (Roxb.) Druce | 80.00 | 124 | 1.55 | 16.65 |
| 5 | *Circium interpositum* Patrak. | 36.00 | 58 | 1.61 | 9.73 |
| 6 | *Clerodendrum infortunatum* Linn. | 54.00 | 88 | 1.63 | 22.43 |
| 7 | *Desmodium heterocarpon* (L.) DC. | 36.00 | 62 | 1.72 | 7.98 |
| 8 | *Hedera nepalensis* K.Koch. | 36.00 | 82 | 2.28 | 11.67 |
| 9 | *Inula eupatorioides DC.* | 60.00 | 126 | 2.10 | 14.30 |
| 10 | *Mahonia borealis* Takeda | 6.00 | 8 | 1.33 | 11.84 |
| 11 | *Osbeckia chinensis* L. | 64.00 | 132 | 2.06 | 20.98 |
| 12 | *Osbeckia sikkimensis* Craib. | 68.00 | 176 | 2.59 | 27.62 |
| 13 | *Rubus burmanicus* Hook.*f.* | 54.00 | 114 | 2.11 | 18.94 |
| 14 | *Rubus ellipticus* Smith | 50.00 | 104 | 2.08 | 14.84 |
| 15 | *Rubus niveus* Thunb. | 48.00 | 100 | 2.08 | 13.85 |
| 16 | *Rubus rosaefolius* Smith | 52.00 | 108 | 2.08 | 15.88 |
| 17 | *Rubus rugosus* Smith | 50.00 | 102 | 2.04 | 17.71 |
| 18 | *Strobilanthes capitatus* T. Anders | 50.00 | 96 | 1.92 | 20.77 |

**Table 9(c).** Frequency (%), Density, Abundance and IVI of herb species in Site C

| Sl. No | Name of Species | Frequency (%) | Density (indv.ha$^{-1}$) | Abundance | IVI |
|---|---|---|---|---|---|
| 1 | *Ainsliaea latifolia* (D.Don.) Sch.-Bip. | 54.00 | 120 | 2.22 | 13.00 |
| 2 | *Ainsliaea pteropoda* DC. | 52.00 | 96 | 1.85 | 11.21 |
| 3 | *Arisaema speciosum* (Wall.) Schott. | 50.00 | 82 | 1.64 | 26.52 |
| 4 | *Bergenia ciliata* (Haw.) Sternb.*f.* | 30.00 | 44 | 1.47 | 10.49 |
| 5 | *Boehmeria platyphylla* D.Don | 64.00 | 136 | 2.13 | 48.49 |
| 6 | *Boenninghausenia albiflora* (Hook.) Meissner | 36.00 | 58 | 1.61 | 8.53 |
| 7 | *Centella asiatica* (L.) Urban | 56.00 | 76 | 1.36 | 9.33 |
| 8 | *Cicerbita macrorhiza* (Royle) Beauv. | 24.00 | 36 | 1.50 | 4.14 |
| 9 | *Crotalaria albida* Heyne *ex* Roth. | 24.00 | 60 | 2.50 | 6.70 |
| 10 | *Curculigo crassifolia* Hook.*f.* | 76.00 | 170 | 2.24 | 28.08 |
| 11 | *Disporum pullum* Sallish | 48.00 | 62 | 1.29 | 8.22 |
| 12 | *Gynura bicolar* (Roxb. *ex* Willd.) DC. | 64.00 | 130 | 2.03 | 14.75 |
| 13 | *Inula nervosa* Wallich *ex* DC. | 28.00 | 58 | 2.07 | 6.68 |
| 14 | *Isodon repens* (Wall.) Murata | 44.00 | 78 | 1.77 | 8.88 |
| 15 | *Microlepia strigosa* (Thunb.) Presl. Epim. | 68.00 | 88 | 1.29 | 11.74 |
| 16 | *Myriactis wallichii* Less. in Linnaea | 30.00 | 64 | 2.13 | 7.24 |
| 17 | *Potentilla lineata* Trevir. *ex* Reich. | 26.00 | 42 | 1.62 | 5.92 |
| 18 | *Prenanthes khasiana* C.B.Clarke | 52.00 | 104 | 2.00 | 11.81 |
| 19 | *Saussurea deltoidea* (DC.) Sch.-Bip. in Linn. | 58.00 | 116 | 2.00 | 13.77 |
| 20 | *Scleria levis* Retzius | 56.00 | 102 | 1.82 | 11.05 |
| 21 | *Scleria terrestris* (L.) Fass. | 48.00 | 98 | 2.04 | 10.04 |
| 22 | *Swertia cordata* Cl. | 46.00 | 82 | 1.78 | 9.19 |
| 23 | *Viola pilosa* Blume | 60.00 | 122 | 2.03 | 14.22 |

**Table 10**. Plant Diversity indices of different study sites of Phawngpui National Park.

| Species Diversity Index | SITE - A | | | SITE - B | | | SITE - C | | |
|---|---|---|---|---|---|---|---|---|---|
| | Trees | Shrubs | Herbs | Trees | Shrubs | Herbs | Trees | Shrubs | Herbs |
| Shannon-Wiener diversity index | 3.68 | 2.8 | 2.96 | 3.64 | 2.93 | 3.08 | 2.9 | 2.84 | 2.95 |
| Evenness index (Pielou's index, 1957) | 0.89 | 0.98 | 0.93 | 0.88 | 0.97 | 0.94 | 0.85 | 0.98 | 0.93 |
| Margalef's index of species richness (1972) | 9.39 | 2.6 | 3.63 | 9.88 | 2.96 | 4 | 4.44 | 2.49 | 3.17 |
| Simpson's index of Dominance (1949) | 0.032 | 0.062 | 0.051 | 0.052 | 0.053 | 0.047 | 0.072 | 0.0616 | 0.048 |
| Whittaker's ($\beta_W$) diversity index (1975) | 2.84 | 1.733 | 2.077 | 2.859 | 1.267 | 2.082 | 1.988 | 1.013 | 1.102 |

| **Sorensen's index of similarity** | | | |
|---|---|---|---|
| | A&B | B&C | A&C |
| Herbs | 0.54 | 0.6 | 0.38 |
| Shrubs | 0.59 | 0.78 | 0.57 |
| Trees | 0.77 | 0.55 | 0.34 |
| Climbers and Epiphytes | 0.45 | 0.63 | 0.06 |
| Grasses and canes | 0.62 | 0.7 | 0.47 |
| **Overall** | **0.67** | **0.59** | **0.36** |

**Table 11.** Data of soil analysis of Phawngpui National Park (2007 & 2008).

| Parameters | SITE A | | | | SITE B | | | | SITE C | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Summer | Monsoon | Winter | **Mean** | Summer | Monsoon | Winter | **Mean** | Summer | Monsoon | Winter | **Mean** |
| Soil Temperature ($^0$C) | 15.2 | 14.1 | 12.3 | **13.87** | 13.4 | 11.7 | 9.8 | **11.63** | 11.1 | 9.4 | 6.5 | **9** |
| pH | 5.22 | 5.77 | 4.43 | **5.14** | 5.24 | 5.22 | 4.92 | **5.13** | 4.58 | 4.88 | 5.95 | **5.14** |
| Soil Moisture Content (%) | 23.97 | 32.69 | 15.43 | **24.03** | 26.09 | 35.78 | 18.43 | **26.77** | 29.08 | 42 | 20.53 | **30.54** |
| Porosity (%) | 57.29 | 61.02 | 53.64 | **57.32** | 61.56 | 64.41 | 57.51 | **61.16** | 67.09 | 70.89 | 63.95 | **67.31** |
| Bulk Density (gm/cm$^3$) | 0.67 | 0.43 | 0.82 | **0.64** | 0.65 | 0.4 | 0.81 | **0.62** | 0.62 | 0.37 | 0.75 | **0.58** |
| Water Holding Capacity | 72.5 | | | | 85.4 | | | | 63.4 | | | |
| Organic Carbon (%) | 3.91 | 4.73 | 3.58 | **4.07** | 4.53 | 5.42 | 4.18 | **4.71** | 5.33 | 6.09 | 4.9 | **5.44** |
| Total Nitrogen (%) | 0.47 | 0.54 | 0.28 | **0.43** | 0.5 | 0.58 | 0.3 | **0.46** | 0.53 | 0.61 | 0.33 | **0.49** |
| Available Phosphorus (µg/g) | 3.82 | 3.89 | 3.36 | **3.69** | 3.84 | 3.99 | 3.3 | **3.71** | 3.56 | 3.95 | 3.21 | **3.57** |
| Exchangeable Potassium (kg/ha) | 472.8 | 412.9 | 370.44 | **418.71** | 467.04 | 412.14 | 343.6 | **407.59** | 377.74 | 392 | 304.23 | **357.99** |

**Table 12**. DBH Class Distribution of plant species at Site A

| Sl. No | Name of Species | dbh Class | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 5.00-15.00 | 15.01-25.00 | 25.01-35.00 | 35.01-45.00 | 45.01-55.00 | 55.01-65.00 | 65.01-75.00 |
| 1 | *Ailanthus integrifolia* L. | 6 | 8 | | | | | |
| 2 | *Albizzia chinensis* (Osb.) Mer. | | 1 | 3 | | | | |
| 3 | *Antidesma bumis* (L.) Spreng | 12 | 4 | | | | | |
| 4 | *Aphanantha cuspida* (Bl.) Planch | 6 | 2 | | | | | |
| 5 | *Betula alnoides* Buch.-Ham. *ex* D.Don. | 3 | 7 | | | | | |
| 6 | *Boehmeria rugulosa* Wedd. | 5 | 3 | | | | | |
| 7 | *Bruinsmia polysperma* Cl. | 4 | 1 | | | | | |
| 8 | *Buddleia macrostachya* Benth. | 6 | | | | | | |
| 9 | *Carallia brachiata* (Lour.) Merr. | 7 | | | | | | |
| 10 | *Castanopsis indica* (Roxb. *ex* Lindl.) DC. | 11 | 2 | 1 | 1 | | | |
| 11 | *Castanopsis tribuloides* DC. | 4 | 10 | 28 | 11 | 4 | 4 | 3 |
| 12 | *Chukrasia velutina* A. Juss | | 3 | 1 | | | | |
| 13 | *Cinnamomum bejolghota* (Buch.-Ham.) | 5 | 1 | | | | | |
| 14 | *Cinnamomum verum* Presl. | 8 | 2 | | | | | |
| 15 | *Debregeasia velutina* Gaud. | 5 | | | | | | |
| 16 | *Derris robusta* (Roxb. *ex* DC.) Benth. | 8 | 2 | | | | | |
| 17 | *Drimycarpus racemosus* (Roxb.) Hook.f. | | 1 | 5 | | | | |
| 18 | *Duabanga grandiflora* (Roxb. *ex* DC.) Walp. | 1 | 3 | | | | | |
| 19 | *Dysoxylum alliarum* (Buch.-Ham.) Balak. Null. | 4 | 1 | | | | | |
| 20 | *Dysoxylum binecteriferum* (Roxb.) Hook. f. *ex* DC | 9 | 2 | | | | | |
| 21 | *Dysoxylum gobarum* (Buch.-Ham.) Merr. | | 5 | | | | | |
| 22 | *Eleocarpus aristatus* Roxb. | | 6 | | | | | |
| 23 | *Eleocarpus lanceaefolious* Roxb. | 6 | 2 | | | | | |
| 24 | *Eleocarpus tectorius* (Lour.) Poiret in Lam. | | 4 | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 25 | *Engelhardtia spicata* Lechen *ex* Blume | 2 | 20 | 8 | 5 | 2 | | |
| 26 | *Euria japonica* Thunb. | 8 | 2 | | | | | |
| 27 | *Ficus religiosa* L. | | 5 | | | | | |
| 28 | *Ficus rigida* Jacq. | 4 | | | | | | |
| 29 | *Glochidion velutinum* Wight. | 3 | | | | | | |
| 30 | *Helicia erratica* (Roxb.) Blume | 2 | 25 | 11 | 7 | 5 | | |
| 31 | *Helicia robusta* (Roxb.) R.Br. *ex* Blume | | 2 | | | | | |
| 32 | *Homalium debbarmani* Kanjilal *et al.* | 3 | | | | | | |
| 33 | *Kydia calycina* Roxb. | 3 | | | | | | |
| 34 | *Litsea cubeba* (Lour.) Pers. | 10 | 2 | | | | | |
| 35 | *Litsea monopetala* (Roxb.) Pers. | | 5 | 1 | | | | |
| 36 | *Macaranga indica* W. | 9 | 3 | 2 | | | | |
| 37 | *Mallotus macrostachyus* (Miq.) Muell. Arg. | 8 | 3 | 1 | | | | |
| 38 | *Michelia champaca* L. | 5 | 2 | 1 | | | | |
| 39 | *Myrica esculenta* Ham. | 5 | 1 | | | | | |
| 40 | *Olea dioica* Roxb. | | 4 | 1 | | | | |
| 41 | *Olea salicifolia* Wall. *ex* G.Don. | | 8 | 2 | | | | |
| 42 | *Ostades paniculata* Blume | | 5 | | | | | |
| 43 | *Pilea symeria* Wedd. | 2 | | | | | | |
| 44 | *Pinus kesiya* Royle *ex*. Gordon | 2 | 11 | 5 | 2 | | | |
| 45 | *Pithecellobium bigeminum* (L.) Mart. | 7 | 1 | | | | | |
| 46 | *Pithecolobium heterophyllum* | 8 | 3 | 1 | | | | |
| 47 | *Prunus jenkinsii* Hook.f. & Thomson | | 3 | 1 | | | | |
| 48 | *Prunus undulata* Buch.-Ham. *ex* D.Don. | | 3 | 1 | | | | |
| 49 | *Quercus dealbata* Hook. f. & Thompson *ex* Miq. | 2 | 16 | 5 | 2 | | | |
| 50 | *Quercus helferiana* A. DC. | | 5 | 1 | | | | |
| 51 | *Quercus lanceafolia* | 1 | 6 | 1 | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 52 | *Quercus leucotrichophora* A. Camus | 2 | 15 | 6 | 5 | 3 | 1 | |
| 53 | *Rhus semialata* Miller | 7 | 1 | | | | | |
| 54 | *Rubus niveus* Thunb. | 1 | | | | | | |
| 55 | *Sapium baccatum* Roxb. | | 3 | | | | | |
| 56 | *Saurauia punduana* Wallich | 10 | 3 | 1 | | | | |
| 57 | *Schima wallichii* (DC.) Korthals | 9 | 5 | 2 | | | | |
| 58 | *Strobilanthes capitatus* T. Anders | 2 | | | | | | |
| 59 | *Strobilanthes parryorum* T.Anders | 1 | | | | | | |
| 60 | *Styrax serrulatum* Roxb. | 1 | 8 | 1 | | | | |
| 61 | *Syzygium cumini* (L.) Skeels | | | | 2 | 1 | | |
| 62 | *Toona ciliata* M. Roem. | | 2 | 1 | | | | |
| 62 | *Trema orientalis* (L.) Blume | | 6 | 2 | | | | |
| 63 | *Vitex peduncularis* Wallich *ex* Schauer | | 4 | 1 | | | | |
| 64 | *Wandlandia grandis* (Hook.f.) Cowan | 9 | 15 | 5 | | | | |
| 65 | *Zizyphus incurva* Roxb. | 4 | 1 | | | | | |
| | | 240 | 268 | 99 | 35 | 15 | 5 | 3 |

**Table 13**. DBH Class Distribution of plant species at Site B

| Sl. No | Name of Species | dbh Class | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 5.00 - 15.00 | 15.01- 25.00 | 25.01- 35.00 | 35.01- 45.00 | 45.01- 55.00 | 55.01- 65.00 | 65.01- 75.00 |
| 1 | *Albizzia chinensis* (Osb.) Mer. | | 3 | | | | | |
| 2 | *Alseodaphne petiolaris* Hook.*f* | | 2 | 5 | 1 | 1 | | |
| 3 | *Aphanantha cuspida* (Bl.) Planch | 6 | 2 | | | | | |
| 4 | *Ardisia macrocarpa* Wall. | 1 | | | | | | |
| 5 | *Artemesia nilagirica* (C.B. Clarke) Pamp. | 2 | | | | | | |
| 6 | *Betula alnoides* Buch.-Ham. *ex* D.Don. | 2 | 6 | 1 | 1 | | | |
| 7 | *Boehmeria rugulosa* Wedd. | 6 | 2 | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 8 | *Buddleia macrostachya* Benth. | 6 | | | | | | |
| 9 | *Castanopsis indica* (Roxb. *ex* Lindl.) DC. | 8 | 3 | | | | | |
| 10 | *Castanopsis tribuloides* DC. | 18 | 28 | 9 | 7 | 5 | 3 | 2 |
| 11 | *Cephalotaxus graffithii* Hook. *f.* | 3 | | | | | | |
| 12 | *Cinnamomum bejolghota* (Buch.-Ham.) | 1 | 6 | 1 | | | | |
| 13 | *Cinnamomum cecicodaphne* Ness. | 7 | 3 | | | | | |
| 14 | *Cinnamomum verum* Presl. | 9 | 3 | | | | | |
| 15 | *Clerodendron infortunatum* Linn. | 4 | | | | | | |
| 16 | *Clerodendrum bracteatum* Wall. *ex* Walp. | 5 | | | | | | |
| 17 | *Debrageasia velutina* Gaud. | 7 | 4 | | | | | |
| 18 | *Derris robusta* (Roxb. *ex* DC.) Benth. | 4 | | | | | | |
| 19 | *Drimycarpus racemosus* (Roxb.) Hook.*f.* | | 3 | 1 | | | | |
| 20 | *Dysoxylum alliarum* (Buch.-Ham.) Balak. Null. | 3 | | | | | | |
| 21 | *Dysoxylum binecteriferum* (Roxb.) Hook.f. *ex* Beddome | 6 | 1 | | | | | |
| 22 | *Eleocarpus lanceaefolius* Roxb. | 5 | 1 | | | | | |
| 23 | *Eleocarpus tectorius* (Lour.) Poiret in Lam. | 1 | 1 | | | | | |
| 24 | *Engelhardtia spicata* Lechen *ex* Blume | 14 | 11 | 27 | 11 | 6 | 4 | 3 |
| 25 | *Euria japonica Thunb.* | 5 | 1 | | | | | |
| 26 | *Ficus regida* Jacq. | 6 | 2 | | | | | |
| 27 | *Ficus religiosa* L. | 1 | 4 | | | | | |
| 28 | *Glochdion velutinum* Wight. | 6 | 2 | | | | | |
| 29 | *Helicia erratica* (Roxb.) Blume | 31 | 44 | 12 | 6 | 3 | 1 | |
| 30 | *Heteropanax fragrans* (Roxb.) Seem. | 3 | | | | | | |
| 31 | *Homalium debbarmani* Kanjilal *et al.* | 1 | 2 | | | | | |
| 32 | *Kydia calycina* Roxb. | 4 | 1 | | | | | |
| 33 | *Lasianthus biermanni* King *ex* Hook.*f.* | | 6 | 2 | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 34 | *Lithocarpus elegans* Hatus. *ex* Soepadmo | 3 | 1 | | | | | |
| 35 | *Litsea cubeba* (Lour.) Pers. | 5 | 2 | | | | | |
| 36 | *Litsea monopetala* (Roxb.) Pers. | | 1 | 2 | | | | |
| 37 | *Macaranga indica* W. | 1 | 5 | 2 | | | | |
| 38 | *Macropanax undulatum* (Wallich *ex* G.Don.) Seem. | 9 | 11 | 2 | | | | |
| 39 | *Mallotus macrostachyus* (Miq.) Muell. Arg. | | 5 | 1 | | | | |
| 40 | *Michelia doltsopa* Buch.-Ham. *ex* DC. | 6 | | | | | | |
| 41 | *Myrica esculenta* Ham. | 17 | 8 | 2 | 1 | | | |
| 42 | *Olea dioica* Roxb. | | 4 | 1 | | | | |
| 43 | *Olea salicifolia* Wall. *ex* G.Don. | 2 | 7 | 1 | | | | |
| 44 | *Ostades paniculata* Blume | 2 | 6 | 2 | | | | |
| 45 | *Phoebe lanceolata* Nees. | 2 | 6 | | | | | |
| 46 | *Pinus kesiya* Royle *ex.* Gordon | 12 | 2 | | | | | |
| 47 | *Pithecellobium bigeminum* (L.) Mart. | 8 | | | | | | |
| 48 | *Pithecellobium heterophyllum* (Roxb.) J.F. Macbr. | 11 | 1 | | | | | |
| 49 | *Prunus cerasoides* D.Don. | 2 | | | | | | |
| 50 | *Prunus jenkinsii* Hook.*f*. & Thomson | | 3 | 1 | | | | |
| 51 | *Quercus dilatata* Lindl. | 9 | 3 | | | | | |
| 52 | *Quercus helferiana* A. DC. | | 4 | | | | | |
| 53 | *Quercus lanceaefolia* | 3 | 8 | 1 | | | | |
| 54 | *Quercus leucotrichophora* A. Camus | 21 | 38 | 13 | 9 | 7 | 3 | |
| 55 | *Quercus polystachya* Wall. *ex* A. DC | 5 | | | | | | |
| 56 | *Rhododendron arboreum* Sm. | 8 | 6 | | | | | |
| 57 | *Rhus semialata* Miller | 4 | | | | | | |
| 58 | *Rhus succedanea* L. | 1 | 5 | | | | | |
| 59 | *Sapium bacatum* Roxb. | | 6 | 1 | | | | |
| 60 | *Saurauia punduana* Wallich | 5 | 2 | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 61 | *Schima khasiana* Dyer | 7 | | | | | | |
| 62 | *Schima wallichii* (DC.) Korthals | 10 | 2 | | | | | |
| 63 | *Strobilanthes macrostegium* | 2 | | | | | | |
| 64 | *Styrax serrulatum* Roxb. | 2 | 7 | 1 | | | | |
| 65 | *Syzygium cumini* (L.) Skeels | | | | 2 | | | |
| 66 | *Trema orientalis* (L.) Blume | 1 | 6 | 1 | | | | |
| 67 | *Vernonia volkameriaefolia* Wall. *ex* DC. | 1 | | | | | | |
| 68 | *Vitex heterophylla* Roxb. | | 1 | 5 | | | | |
| 69 | *Vitex peduncularis* Wallich *ex* Schauer | | 4 | 1 | | | | |
| 70 | *Wandlandia grandis* (Hook.*f.)* Cowan | 4 | 10 | 12 | | | | |
| 71 | *Xantolis hookeri* (C.B.Clarke) P. Royen | 2 | | | | | | |
| 72 | *Zizyphus incurva* Roxb. | 4 | 1 | | | | | |
| | | 344 | 306 | 107 | 38 | 22 | 11 | 5 |

**Table 14**. DBH Class Distribution of plant species at Site C

| Sl. No | Name of Species | dbh Class | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 5.00 - 15.00 | 15.01- 25.00 | 25.01- 35.00 | 35.01- 45.00 | 45.01- 55.00 | 55.01- 65.00 | 65.01- 75.00 |
| 1 | *Alseodaphne petiolaris* Hook.*f* | 3 | 7 | 1 | | | | |
| 2 | *Ardisia macrocarpa* Wall. | 2 | | | | | | |
| 3 | *Artemisia nilagirica* (C.B. Clarke) Pamp. | 3 | | | | | | |
| 4 | *Camelia kissi* Wallich | 2 | | | | | | |
| 5 | *Castanopsis tribuloides* DC. | 6 | 14 | 8 | 2 | 1 | | |
| 6 | *Cephalotaxus griffithi* Hook.*f.* | 3 | | | | | | |
| 7 | *Cinnamomum bejolghota* (Buch.-Ham.) | 16 | | | | | | |
| 8 | *Cinnamomum verum* Presl. | 13 | | | | | | |
| 9 | *Clerodendron infortunatum* Linn | 3 | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 10 | *Eleocarpus tectorius* (Lour.) Poiret in Lam. | 4 | 1 | | | | | |
| 11 | *Engelhardtia spicata* Lechen *ex* Blume | 29 | 40 | 14 | 5 | 4 | 2 | |
| 12 | *Euria japonica* Thunb. | 38 | 12 | | | | | |
| 13 | *Ficus religiosa* L. | 3 | | | | | | |
| 14 | *Ficus rigida* Jacq. | 6 | | | | | | |
| 15 | *Glochidion velutinum* Wight. | 6 | | | | | | |
| 16 | *Helicia erratica* (Roxb.) Blume | 19 | 37 | 18 | 11 | 7 | 3 | |
| 17 | *Heteropanax fragrans* (Roxb.) Seem. | 4 | 6 | 14 | 6 | | | |
| 18 | *Lithocarpus elegans* Hatus. *ex* Soepadmo | 36 | | | | | | |
| 19 | *Mahonia borealis* Takeda | 4 | | | | | | |
| 20 | *Mahonia nepalensis* Kanjilal *et al.* | 8 | | | | | | |
| 21 | *Myrica esculenta* Ham. | 27 | 10 | 2 | 1 | | | |
| 22 | *Olea salicifolia* Wall. *ex* G.Don | 5 | 1 | | | | | |
| 23 | *Phoebe lanceolata* Nees. | 9 | | | | | | |
| 24 | *Pinus kesiya* Royle *ex.* Gordon | 19 | 11 | | | | | |
| 25 | *Quercus dilatata* Lindl. | 20 | 28 | 5 | 2 | | | |
| 26 | *Quercus leucotrichophora* A. Camus | 15 | 23 | 5 | 4 | 3 | 1 | |
| 27 | *Rhododendron arboreum* Sm. | 9 | 25 | 6 | 2 | | | |
| 28 | *Rhododendron wallichii* Hook.*f.* | 12 | | | | | | |
| 29 | *Rhus succedanea* L. | 8 | | | | | | |
| 30 | *Schima khasiana* Dyer | 8 | 2 | | | | | |
| 31 | *Schima wallichii* (DC.) Korthals | 3 | 1 | | | | | |
| 32 | *Strobilanthes capitatus* T.Anders | 1 | | | | | | |
| 33 | *Syzygium cumini* (L.) Skeels | | 4 | 2 | | | | |
| 34 | *Vitex heterophylla* Roxb. | 3 | | | | | | |
| 35 | *Xantolis hookeri* (C.B.Clarke) P. Royen | 1 | | | | | | |
| | | 348 | 222 | 75 | 33 | 15 | 6 | 0 |

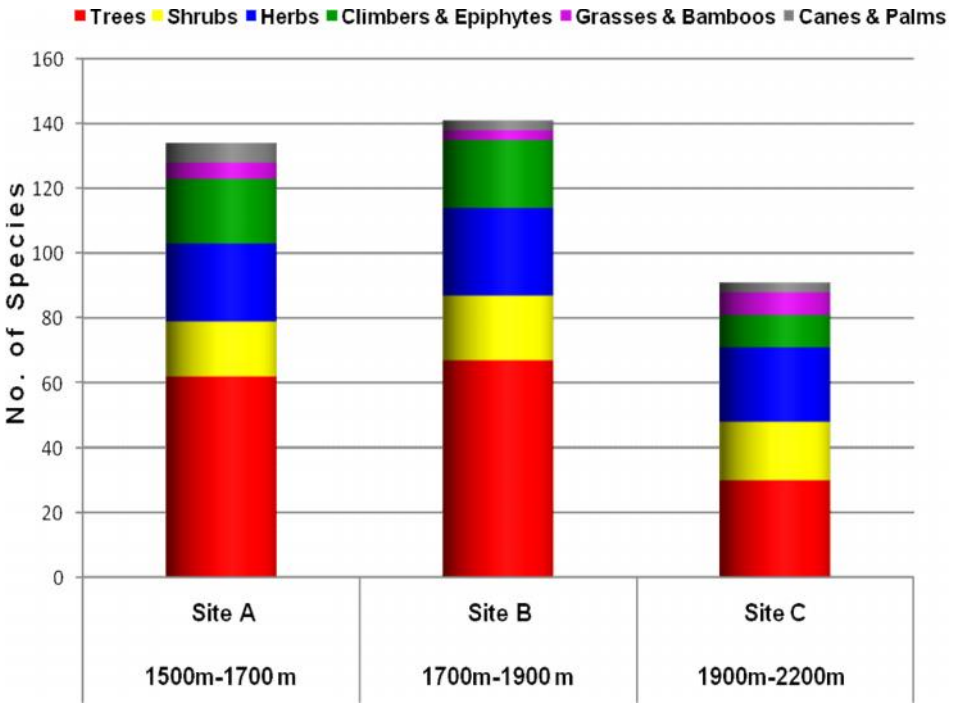


**Fig. 6.** Distribution of plant species at different Sites.

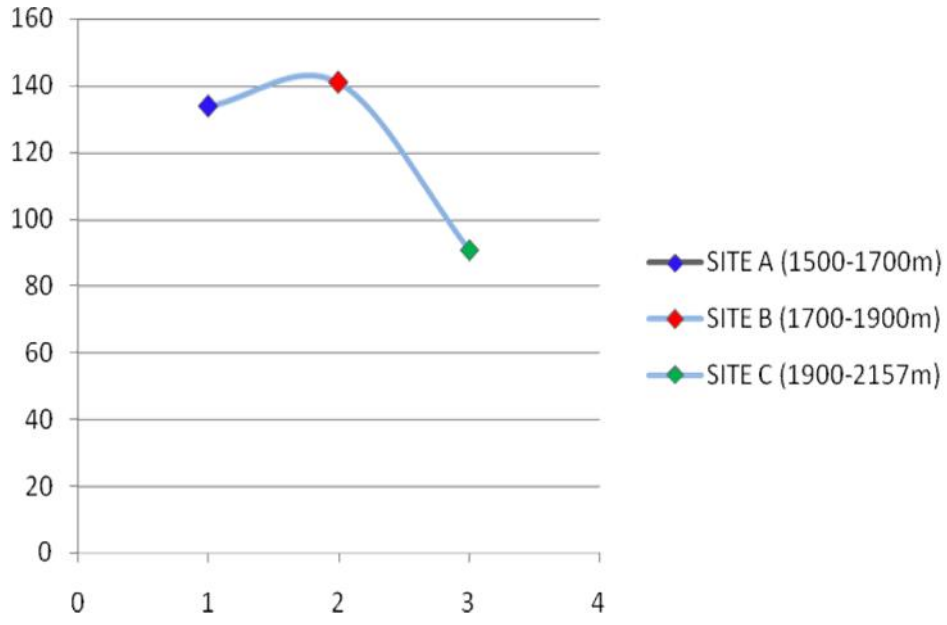


**Fig. 7**. Hump-shaped distribution of plant species.

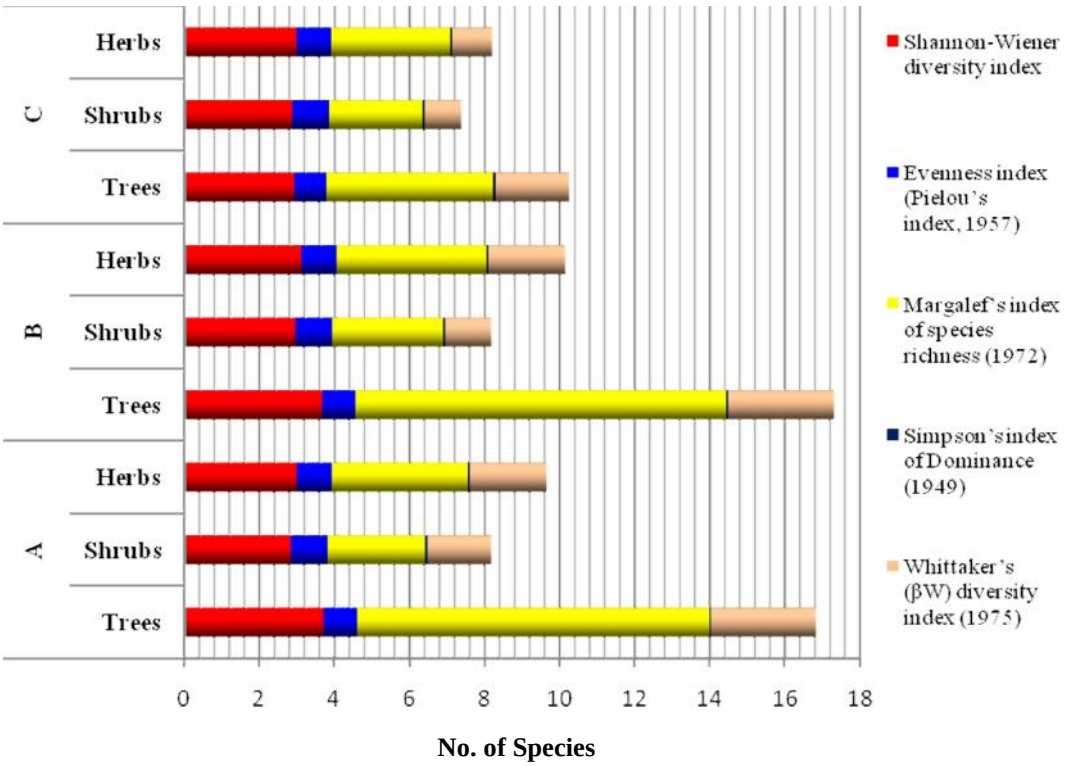


**Fig. 8**. Species Diversity Index of the three Sites.

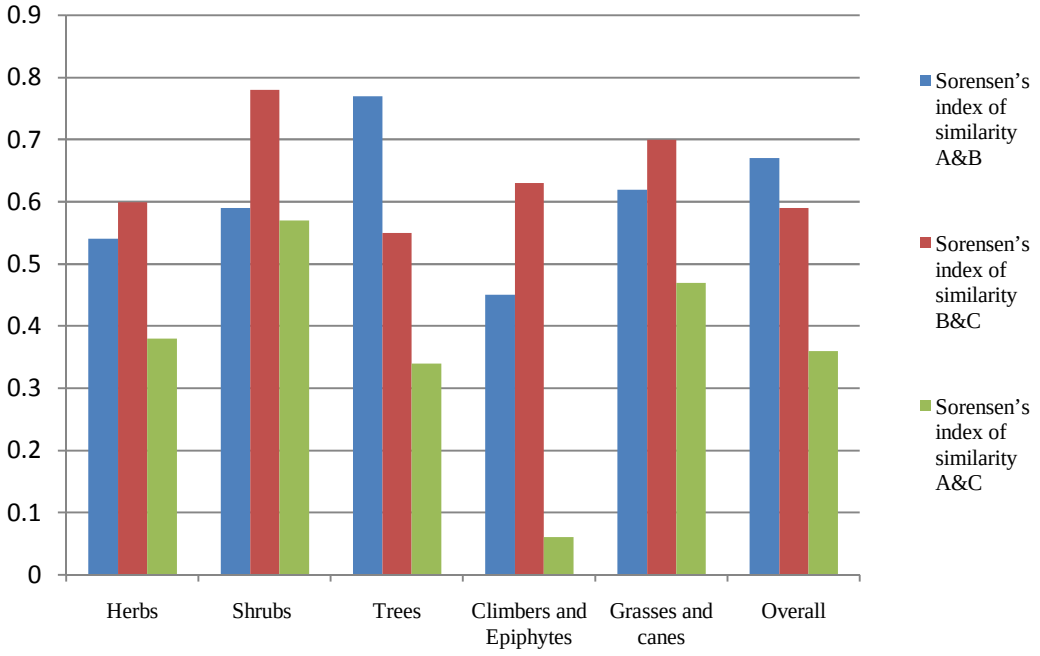


**Fig. 9.** Sorensen's index of Similarity.

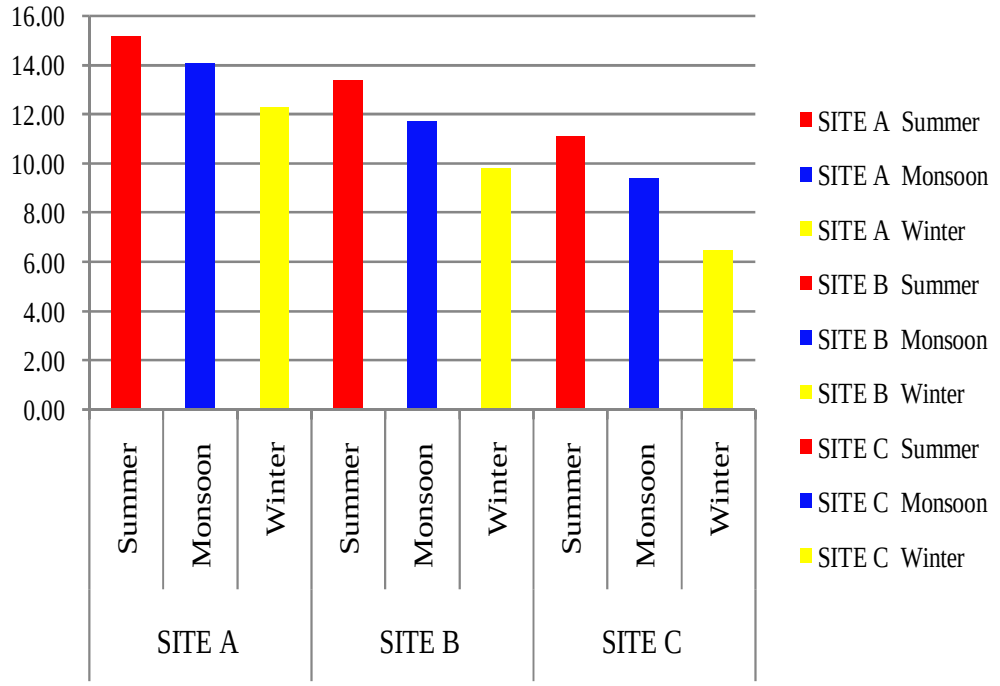


**Fig. 10**. Soil Temperature (2007-2008) of the Study Area

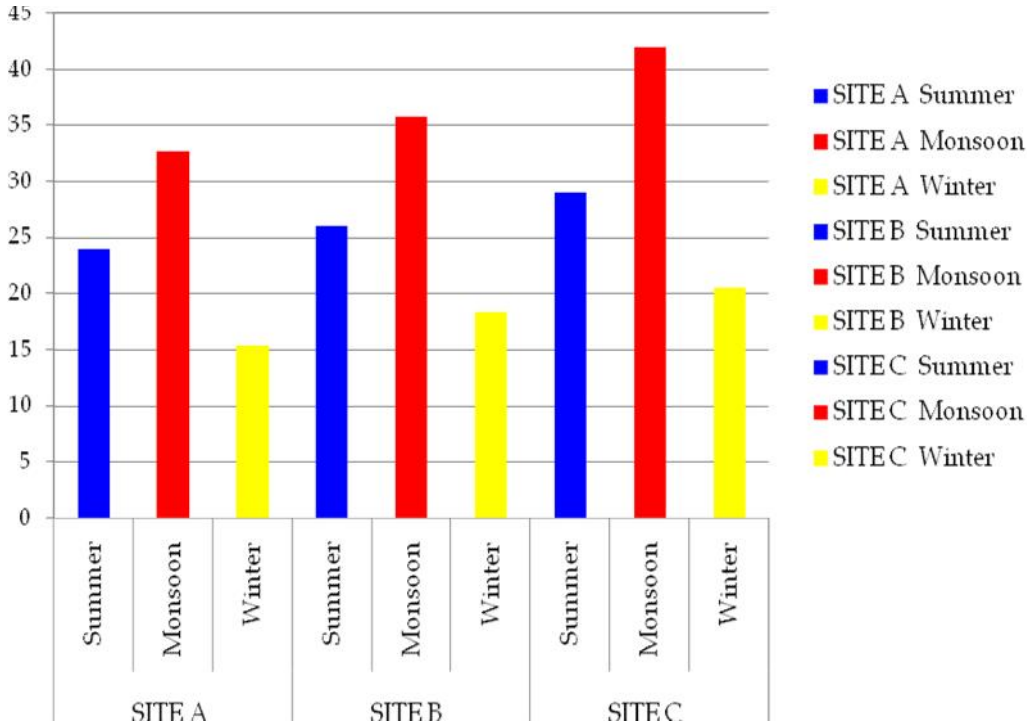


**Fig. 11.** Soil Moisture Content (2007-2008) of the Study Area

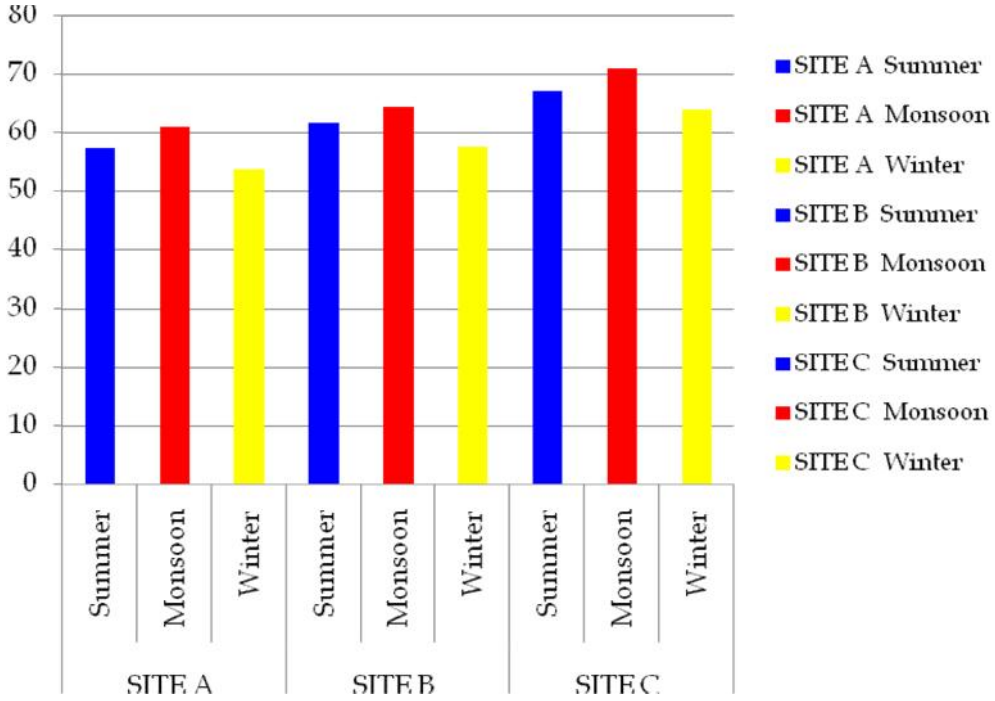


**Fig. 12.** Soil Porosity (2007-2008) of the Study Area

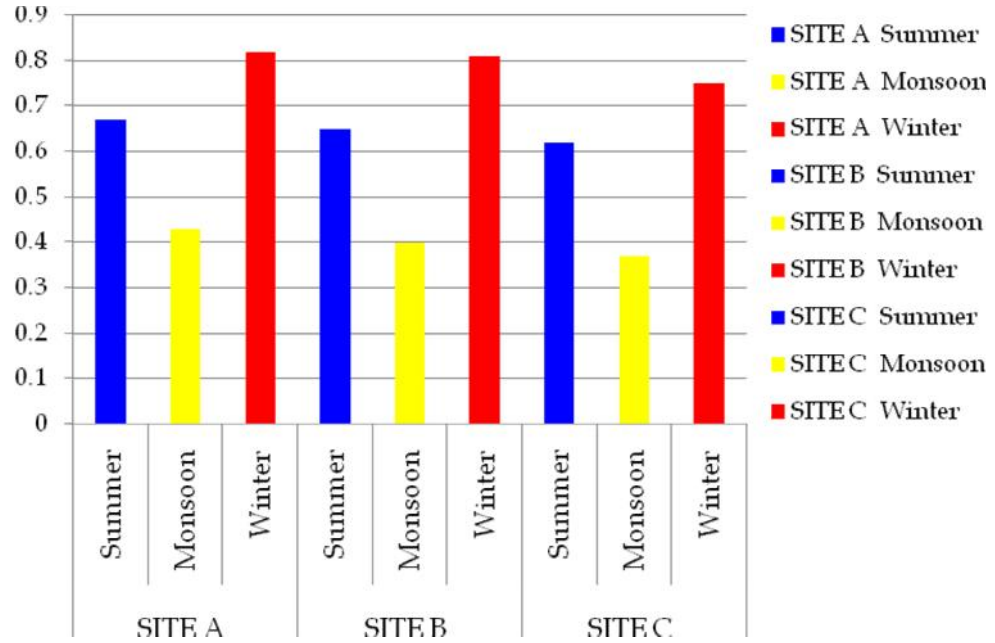


**Fig. 13.** Soil Bulk Density (2007-2008) of the Study Area

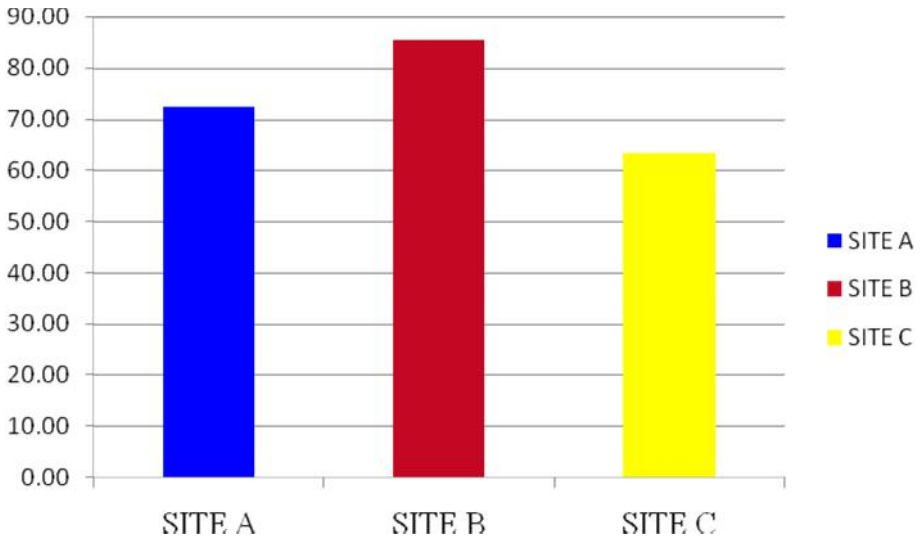


**Fig. 14.** Water Holding Capacity (%) (2007-2008) of the Study Area.

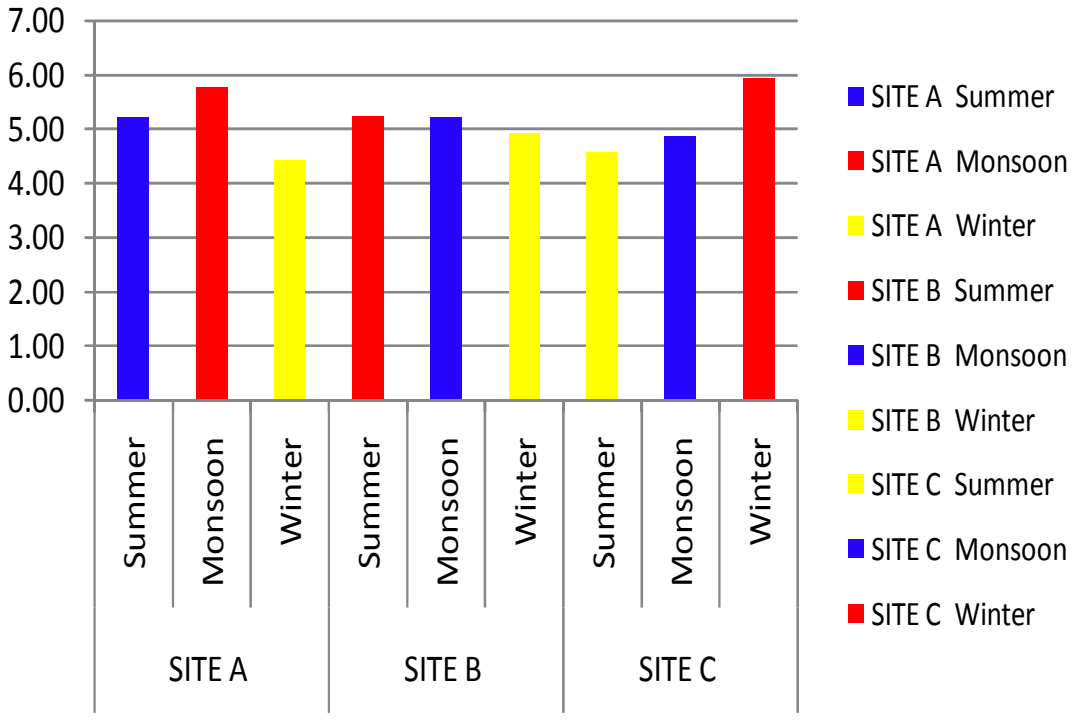


**Fig. 15.** Soil pH (2007-2008) of the Study Area

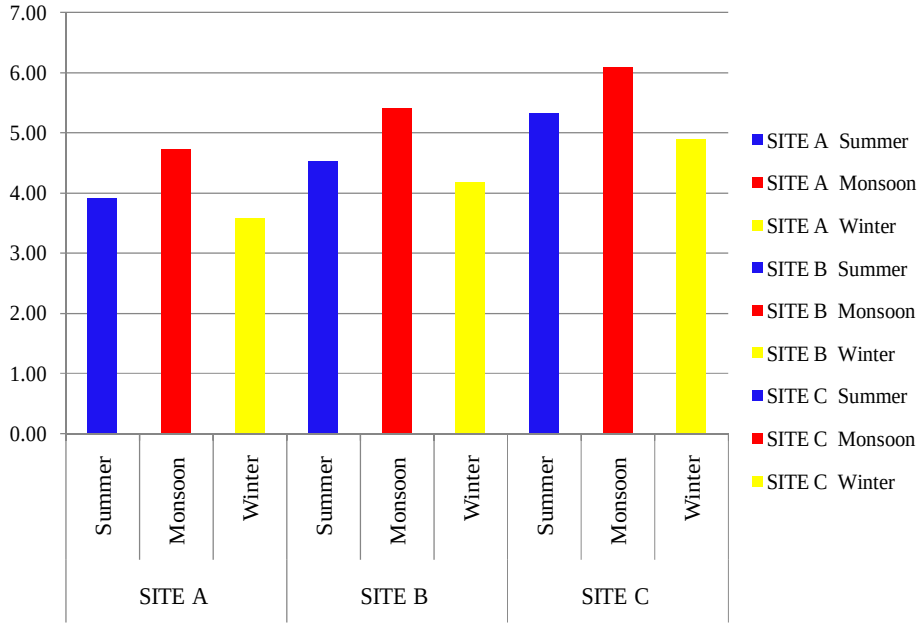


**Fig. 16.** Soil Organic Carbon (%) (2007-2008) of the Study Area

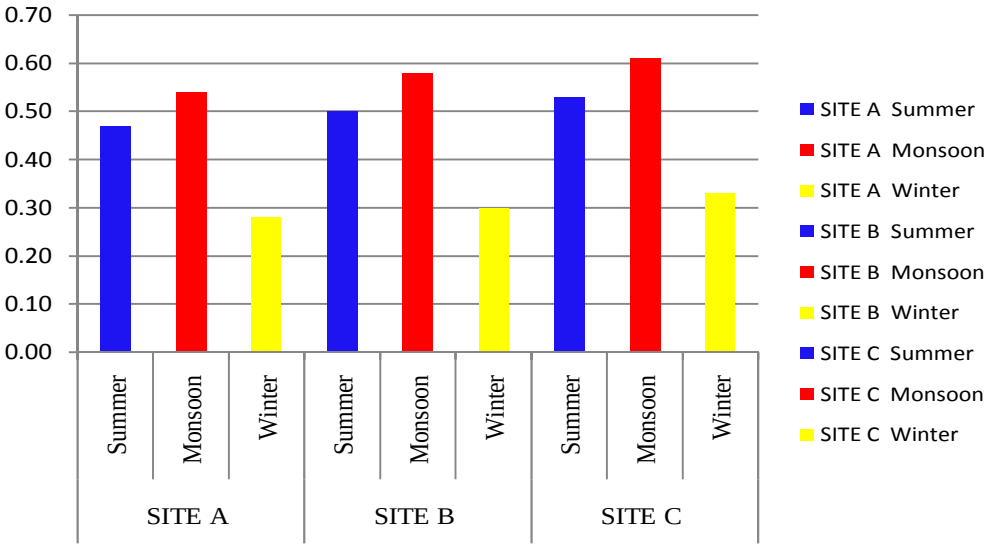


**Fig. 17.** Soil Total Nitrogen (%) (2007-2008) of the Study Area

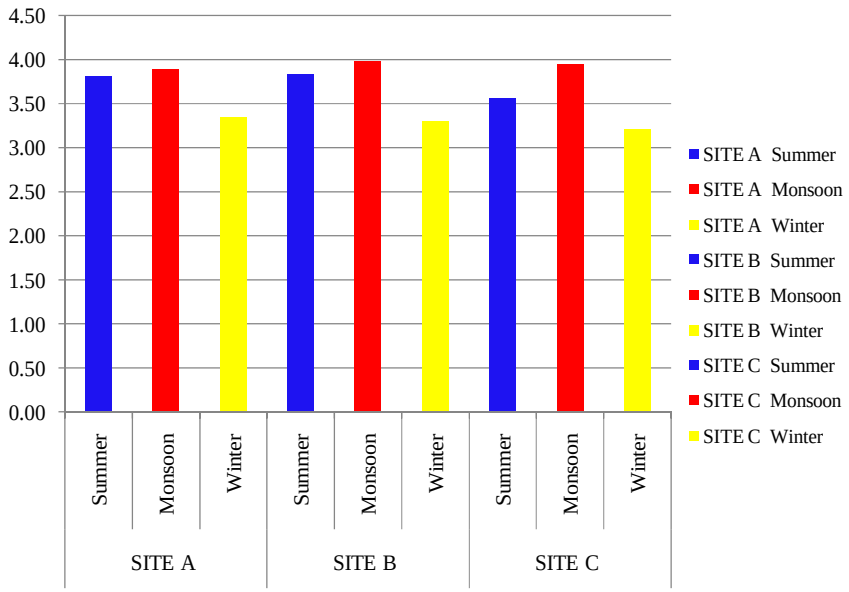


**Fig. 18.** Soil Available Phosphorus (µg/g) (2007-2008) of the Study Area

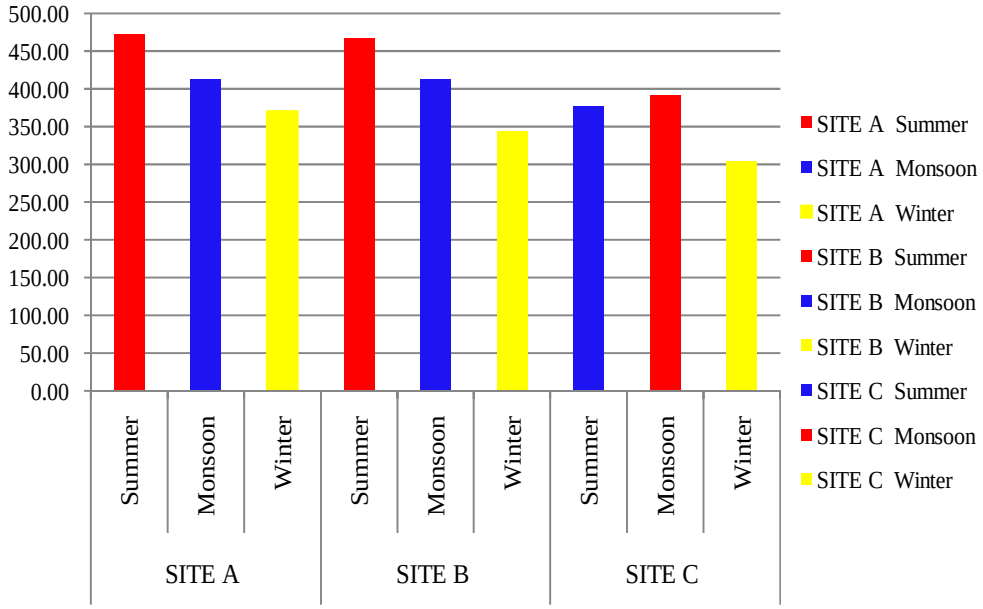


**Fig. 19.** Soil Exchangeable Potassium (kg/ha) (2007-2008) of the Study Area

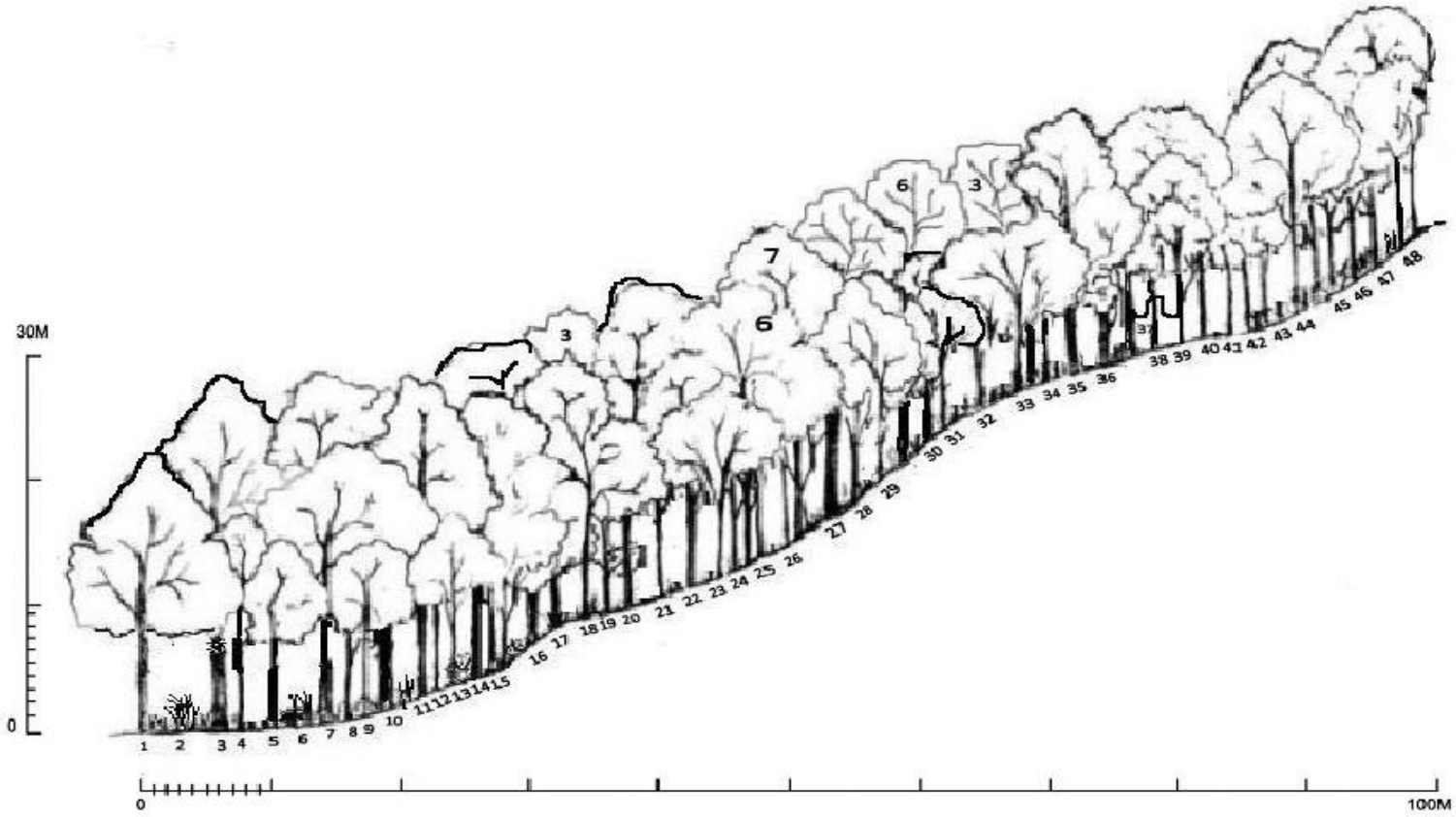


**Fig.20(a) Profile diagram of Site A:** *(1=Duabanga grandiflora, 2=Ammomum dealbatum, 3=Engelhardtia spicata, 4=Wandlandia grandis, 5=Quercus dealbata, 6=Helicia erratica, 7=Castanopsis tribuloides, 8=Cinnamomum verum, 9=Macaranga indica, 10=Mallotus macrostachyus, 11=Antidesma bumis, 12= Albizzia chinensis, 13=Castanopsis tribuloides 14= Quercus lanceaefolia, 15=Chukrasia velotina, 16=Vitex peduncularis, 17= Olia salicifolia 18=Sapium baccatum, 19=Litsea semicarpifolia, 20=Prunus jenkinsii, 21=Quercus leucotrichophora, 22=Derris robusta, 23=Styrax serrulatum, 24=Schima wallichii, 25=Rhus semialata, 26=Litsea cubeba, 27=Syzygium cumini, 28=Drimycarpus racemosus, 29=Saurauia punduana, 30=Eleocarpus tectorius, 31=Ostades paniculata, 32=Quercus helferiana, 33=Kydia calycina, 34=Zizyphus incurva, 35=Ficus religiosa, 36=Euria japonica, 37=Entada pursaetha, 38=Pithecolobium bigeminum, 39=Pithecolobium heterophyllum, 40=Debregeasia velutina, 41=Myrica esculenta, 42=Ailanthus integrifolia, 43=Arundinella khasiana, 44=Eleocarpus aristatus, 45=Dysixylum binecteriferum, 46=Glochidion velutinum, 47=Ficus rigida, 48=Aphanantha cuspida.*

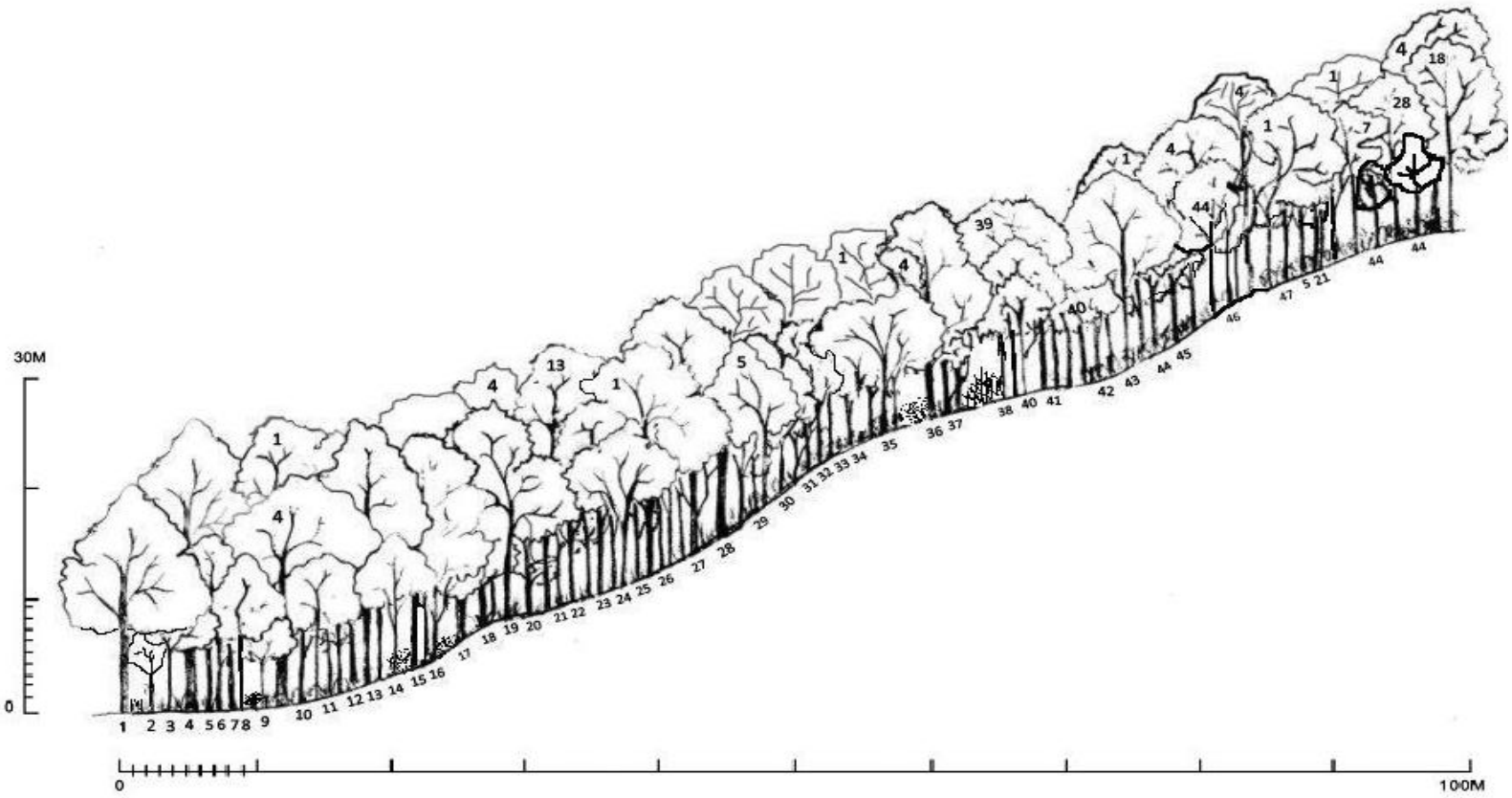


**Fig.20(b) Profile diagram of Site B:** *(1=Helicia erratica, 2=Euria japonica, 3=Litsea cubeba, 4=Engelhardtia spicata, 5=Myrica esculenta, 6=Prunus cerasoides, 7=Alseodaphne petiolaris, 8=Rhus semialata, 9=Schima wallichii, 10=Saurauia punduana, 11=Pithecolobium bigeminum, 12=Pithecolobium heterophyllum, 13=Castanopsis tribuloides 14=Albizzia chinensis, 15=Phoebe lanceolata, 16=Olia salicifolia, 17=Lasianthus biermanni,18=Quercus dilatata, 19=Quercus lanceaefolia, 20=Drimycarpus racemosus, 21=Glochidion velutinum, 22=Macaranga indica, 23=Castanopsis indica, 24=Lithocarpus elegans, 25=Mallotus macrostachyus, 26=Rhus succedanea, 27=Syzygium cumini, 28=Quercus leucotrichophora, 29=Olea dioica, 30=Ostades paniculata, 31=Ficus rigida, 32=Hetyeropanax fragrans, 33=Schima khasiana, 34=Quercus helferiana, 35=Litsea semicarpifolia, 36=Vitex peduncularis, 37= Aphanantha cuspida, 38=Schizostachyum capitatum 39=Sapium bacatum, 40=Kydia calycina, 41=Styrax serrulatum, 42=Dysoxylum binecteriferum, 43=Cinnamomum verum, 44=Rhododendron arboretum, 45=Macropanax undulatum, 46=Xantolis hookeri, 47=Curculigo crassifolia, 48=Artemesia nilagirica).*

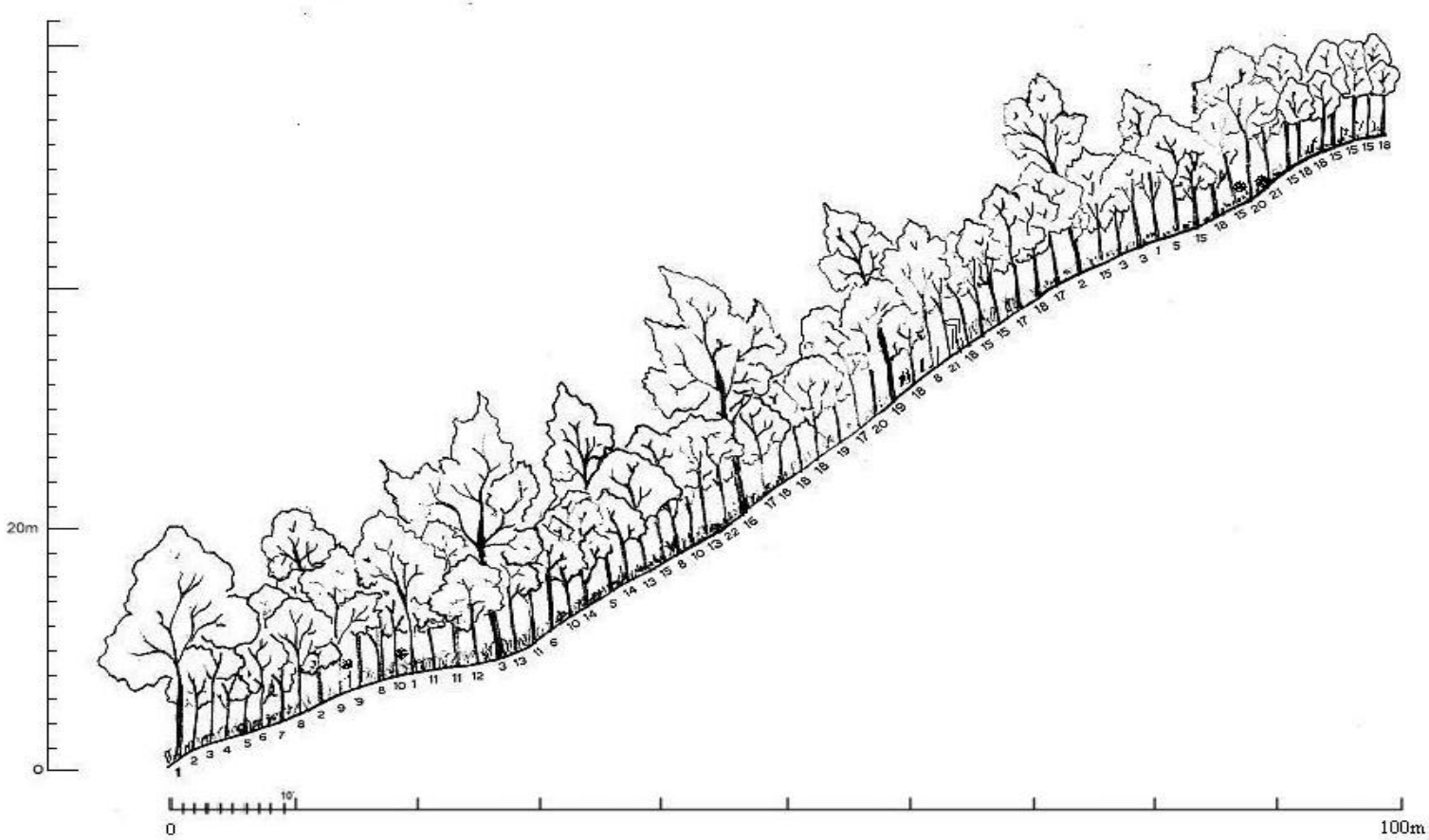


**Fig.20(c) Profile diagram of Site C:** *(1=Engelhardtia spicata, 2=Helicia erratica, 3=Castanopsis tribuloides, 4=Schima wallichii, 5=Quercus leucotrichophora, 6=Olia salicifolia, 7=Xantolis hookeri, 8=Rhus succedanea, 9=Eleocarpus tectorius, 10=Cinnamomum verum, 11=Ficus rigida, 12=Camelia kissi, 13=Syzygium cumini, 14=Lithocarpus elegans, 15=Quercus dilatata, 16=Alseodaphne petiolaris, 17=Euria japonica,18=Rhododnedron arboreum, 19=Phoebe lanceolata, 20=Hetyeropanax fragrans, 21=Schima khasiana, 22=Cinnamomum obtusifolium).*

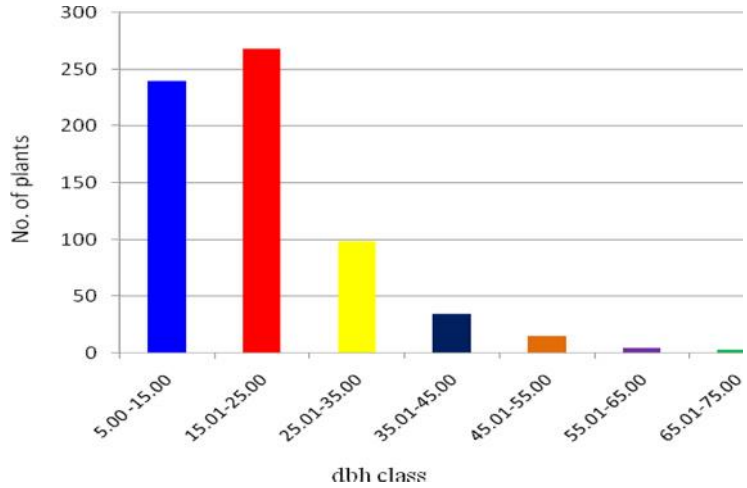


**Fig.21.** Diameter-class distribution of plant species in Site A.

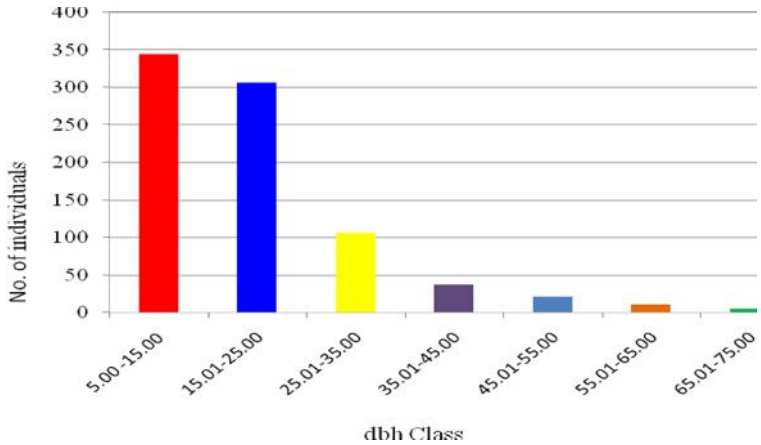


**Fig.22**. Diameter-class distribution of plant species in Site B.

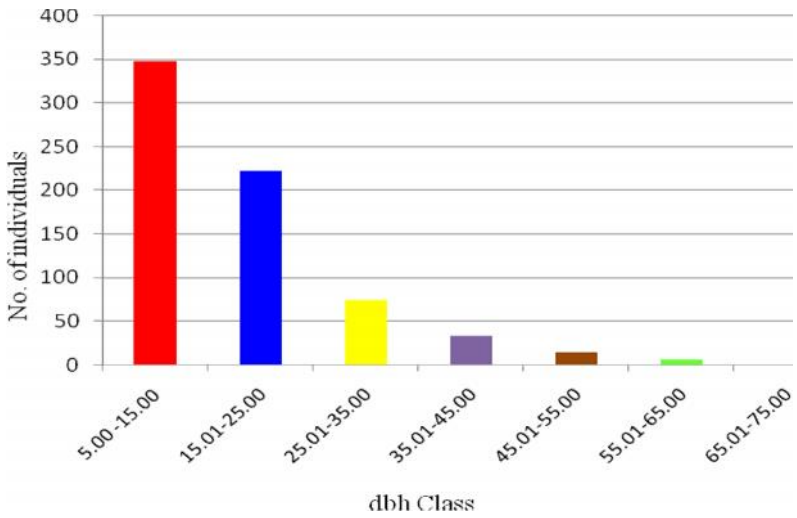


**Fig. 23**. Diameter-class distribution of plant species in Site B.


**Fig. 24**. Inverse J-curve Diameter-class distribution of plant species at Site A.

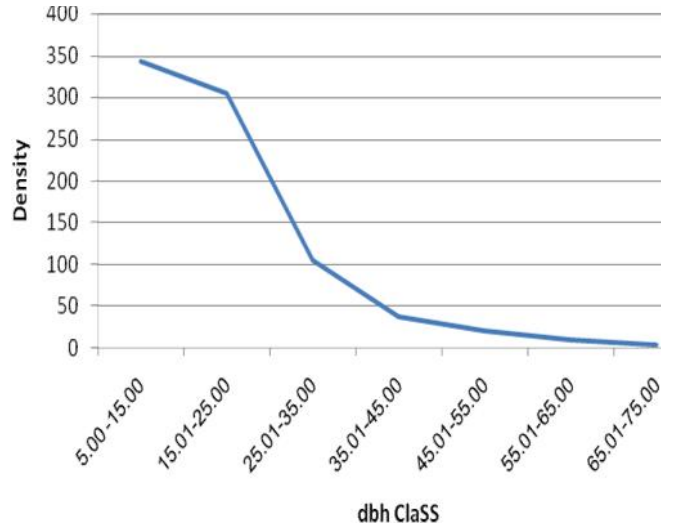


**Fig. 25**. Inverse J-curve Diameter-class distribution of plant species at Site B.

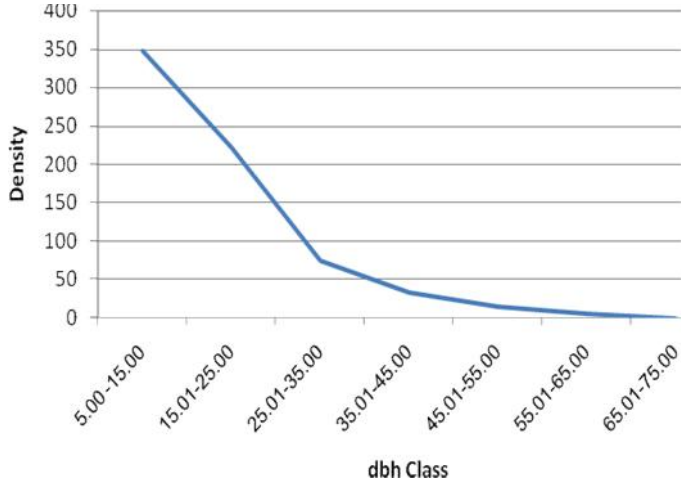


**Fig. 26**. Inverse J-curve Diameter-class distribution of plant species at Site C.

## PHOTO PLATE 1

**(a).** *Helicia erratica* (Roxb.) Blume

**(b).** *Engelhardtia spicata* Lechen *ex* Blume

**(c).** *Quercus dilatata* Lindl.

**(d).** *Rhododendron arboreum* Sm**.**

**(e).** *Myrica esculenta* Ham.

(f). *Macropanax undulatum* (Wallich *ex* G.Don.) Seem.

## PHOTO PLATE 2

**(a)**. *Eria lacei* Summerh

**(b).** *Rhododendron veitchianum* Hook.*f.*

**(c)**. *Mantisia spathulata* Schult.

**(d)**. *Mahonia borealis* Takeda

## PHOTO PLATE 3

**(a)**. *Dendrobium pygnostachyum* Lindl.

**(b).** *Bergenia ciliata* (Haw.) Sternb.*f.*

**(c).** *Dendrobium devonianum* Paxt.

**(d).** *Helicia robusta* (Roxb.) R.Br. *ex* Blume

## PHOTO PLATE 4

**(a)**. *Anoetochilus brevilabris* Lindl.

**(b).** *Zeuxine goodyeriodes* Lindl.

**(c)**. *Dendrobium peguanum* Lindl.

**(d)**. *Cephalotaxus griffithii* Hook. *f.*

**(e)**. *Xantolis hookeri* (C.B.Clarke) P. Royen

**(f)**. *Camelia kissi* Wallich

## PHOTO PLATE 5

**(a)**. *Sinarundinaria griffithiana* (Munro) Chao & Renvoize.

**(b)**. *Schizostachyum capitatum* (Munro) R. Majumdar

**(c)**. *Sinarundinaria falcata* (Nees.) Chao & Renvoize

**(d)**. *Dinochloa compactiflora* Kurz. Mc Clure

# PHOTO PLATE 6

**(a)**. *Disporum pullum* Sallish.

**(b)**. *Swertia cordata* Cl.

**(c)**. *Circium interpositum* Patrak.

**(d)**. *Isodon repens* (Wall.) Murata

**(e)**. *Arundinella khasiana* Nees. *ex* Steud. Stapf. *ex* Bor.

**(f)**. *Cymbopogon khasianus* (Hackel)

## PHOTO PLATE 7

**(a)**. Burned and dead *Sinarundinaria griffithiana* (Munro) Chao & Renvoize.

**(b)**. Burned and dead *Rhododendron veitchianum Hook.f*.

**(c)**. Cattle grazing inside the National Park.

## CONCLUSIONS

Phawngpui National Park is one of the most important protected areas in Mizoram which is situated at 330 km away from Aizawl in Lawngtlai District. It has an area of about 50 sq. km with Geographic Location of 93° 00' 41" E to 93° 04' 57" E and 22° 36' 37" N to 22° 41' 33" N. It lies under Sub-tropical Hill forest (Lalramnghinglova, 1997) and consists of a series of parallel hills running from North to South direction and includes the highest peak (2200 m asl) in the State called "Blue Mountain". The vegetation of this area has provided an ideal habitat for wildlife and is a home for the wild mountain goats-Serrow. It is said to be rich in biodiversity harbouring rare, endangered and endemic species but little is known about the biodiversity and no adequate and scientific research has been carried out except few field observations made by pioneer workers and recent workers (Ref: see Review of Literature). Due to these it has been selected to explore its status of plant diversity from ecological point of view. The physical and chemical properties of soil were also determined.

The field work and analysis of vegetation has been carried out during 2007 to 2010 at different altitudinal gradient and it was observed that species richness in Phawngpui National Park show a hump-shaped distribution pattern and is rich in plant diversity. The study recorded a total of 208 vascular plant species belonging to 150 genera and 71 families. Out of 208 plant species, 84 species of trees, 31 shrubs, 45 species of herbs, 33 climbers and epiphytes, 6 species of canes and palms, and 9 species of grasses and bamboos were enumerated excluding lower plant groups. Study on soil properties revealed that the study area has a fertile soil which is an important factor for plant growth but the most important factors governing the distribution of

plant species in mountains are temperature, resource availability, land area and human activities.

A detailed study of the socio economic status of the surrounding villages revealed that the socio-economic condition is poor. About 81% of the family still depends on traditional jhumming thereby depends much on forest for timber and NTFP's. Though their dependency on the forest and its products are high, they are not aware of the sustainable utilization and habitat destruction of wild species which could lead to biodiversity loss and extinction of valuable species of plants and animals. Therefore, there is a need to develop adequate strategy and action plan for the conservation and management of habitats, species, and communities, so that sustainable utilization of the species could be ensured.

Natural resource consumption rates and human population size exert tremendous pressure on the world's plants and animals. As revealed from the study it can be concluded that the national park has suffered various anthropogenic disturbances, over exploitation, habitat destruction, forest fragmentation, grazing and encroachments from the people living in the adjoining villages of the national park. It also suffered frequent forest fire through jhum burning from the surrounding villages which results in loss of valuable biodiversity. The loss of biodiversity has immediate and long-term effects on human survival. The majority of the world's population still depends on wild plants and animals for their daily food, medicine, housing and household, material, agriculture, fodder, fuel wood, spiritual sustenance, and intellectual stimulation (Agrawal, 2002). Therefore, methods must be developed to manage and conserve biological diversity; otherwise threatened species may not be

able to withstand the growing human population and anthropogenic pressures and may become extinct from their natural habitats.

The study also revealed high species richness in the middle range of 1700 -1900 m which means greater effort should be made focused on conservation of biodiversity of Phawngpui National Park. Further, an in-depth analysis of the flora and fauna of the national park is necessary for effective management and conservation of biodiversity and hence the present study could serve as baseline information on the vegetation and floral diversity of Phawngpui National Park.

The scenic beauty of the Park, the enchanting 'Far Pak', the gentle breeze amidst the beautiful *Rhododendron arboretum* and *R. veitchianum* abode with beautiful orchids surrounding the Park and the uniqueness to harbor rare and endemic species, Zingiberaceae spp., medicinal plants and the wildlife – Serrow in the western cliff attracts tourists and other visitors. The sun-rise and the sun-set are clearly visible in the morning meadows and bright evenings amidst the chirping birds. It could be and have been an important Eco-tourism Centre in the State of Mizoram.

## SUGGESTIONS AND RECOMMENDATIONS FOR PHAWNGPUI NATIONAL PARK IN LAWNGTLAI DISTRICT OF MIZORAM

During the research work, the present researcher has encountered many things which are a threat to the forest and wildlife of the National Park. Some of the important threats and its remedial measures suggested and recommended are describe in detail below:

1) Phawngpui National Park has suffered from a great forest fire for a consecutive of three years (2007-2009) which shows that the National Park is prone to fire. This forest fire is due to the burning of jhumland around the National Park. This forest fire even reached upto 'Far Pak' which is *ca* 1900 m asl. Because of this surface fire, valuable biodiversity has been lost and wildlife are in jeopardize. Therefore, immediate steps should be taken to prevent the forest fire. The first and most important step which might prevent or reduce forest fire is to launch Awareness Campaign in every villages surrounding the National Park organized every year before the burning of jhumland. Secondly, making proper fire lines around and inside the National Park involving the local people, NGOs, Journalist and prominent citizens that would reduce and prevent forest fire.

2) The forest has suffered from encroachment and illegal collection of medicinal plants especially orchid –Dendrobium pygnostachyum Lindl. and Dendrobium devonianum Paxt. which are thought to have medicinal value. The collection of these plants not only reduce their population but also affect other species because they cut the branches of a tree where they grew with other species and even fell down the trees to collect these valuable plants. If this kind of encroachment and illegal collection of forest

resources continues valuable species will be lost and even led to extinction. Therefore, steps needs be taken effectively in these regards. To prevent this, proper forest check gate be maintained (though there is one Forest Check Gate at Thaltlang village, it needs to be strengthened) and duty detailment be made regularly. Also by punishing the encroacher under the Wildlife Protection Act (1972) Rules and Regulations and the State Biodiversity Act, 2010. At the same time, paying a handsome reward to those who help the official(s) in finding the illegal collector or defector. There needs to be a store-house infrastructure facility for the seized materials at Sangau and/or Bualpui (Ng).

3) Another important threat to the wildlife of the National Park is the entering of visitors' vehicle up to Far Pak during fair weather. The sound of the vehicles is more or less heard by the animals and move far away from it as their natural instinct helps them to distinguish different sound and movement. This might be the reason that the researcher does not come across a single wild animal even the wild mountain goat during the eight time visits to the National Park for consecutive four years (2006-2009) but it doesn't mean that the sorrows are totally absent. To let the wildlife live in a quiet and peace environment, entering of vehicles must be stopped up to the dropping zone or car park halfway up from Thaltlang village, and strictly prohibited beyond that. Moreover, a large amount of visitors at one time could also hinder the life of wildlife and also difficult to control. So, restrictions should be made in the number of visitors at a particular time.

4) The Park is managed by a Range Officer with headquarters at Sangau village and Beet Officers under the control of District Forest Officer (DFO), Lawngtlai. For better

management of the National Park, it is highly recommended that District Forest Office be set up at Sangau, which is far more nearer to the National Park than the existing DFO Office at Lawngtlai. In future, Southern Circle may be set up at lawngtlai to monitor Phawngpui National Park and Ngengpui Wildlife Sanctuary, respectively.

5) It is also observed that wild animals move from Phawngpui National Park to the adjacent forest in the Myanmar border and *vice versa.* Identification of animal corridors would be helpful in conservation of wild animals and that they move freely with the least disturbances.

6) The research workers also seen that some villagers of the surrounding villages move freely inside the National Park and used as a shortcut to travel from one village to another. This is very difficult to stop or control but could be lessened only when there is a better (all weathered) road connecting the surrounding villages through Eco-development or Border Area Development Programme or Eco-tourism Programme.

7) Most of the approach roads of the surrounding villages of the National Park is only fair weathered road which cause various problems during unfavourable conditions and also lowered down their economic status. Maintenance and construction of all weathered roads to the surrounding villages is a major issue for the growth and development of the socio-economic condition of this rural area.

8) Though the surrounding villages of the National Park have LPG connections, they face problems in refilling due to high rate of LPG and due to road poor conditions. Therefore, their dependency on forest for fuel wood did not reduce at all. It is, therefore, recommended that construction and maintenance of all weathered roads and

supply of LPG at a lower price that they can be afforded by the local people. Hence, collection of fuel wood from the forest might be lessened.

9) Cattle grazing inside the National Park was also seen which could lead to ecological imbalance at the ground level affecting disturbance of vegetation, biodiversity loss, compaction of soil and environmental degradation. Appropriate animal fencing should be done.

10) The present research work is the pioneer work in this field and therefore, an indepth study, analysis and biodiversity exploration is highly recommended to have a clear picture of the flora and fauna of the National Park and to enhance eco-development and nature conservation measures.

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