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Biodiversity in India: An introduction

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Introduction

The biological diversity studies have begun since the time of Darwin (Darwin 1859) by recording the species wherever they were noticed mostly in accessible locations. Later, the naturalist from Europe started traveling inaccessible areas to explore new flora and fauna and published monographs for a specialized location. Further, biodiversity documentation began along gradient (Daubenmire 1943). The concept of biological diversity was introduced by Lovejoy (1980) to express the number of species present in a community. Norse and McManus (1980) have emphasized about the genetic diversity and ecological diversity.

The word 'biodiversity' has been coined from 'biological diversity' for the first time by Walter G. Rosen in 1985 (Heywood and Watson 1995) and came into force after the formulation of the United Nations Convention on Biological Diversity (UNCBD) during the United Nations Conference on Environment and Development (UNCED) at Rio de Janeiro in June 1992. It has been defined as '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 part; that includes diversity within species, between species and of ecosystems' (CBD 1992). Forest ecosystem biodiversity can be defined as the variability of life present in all its form i.e. from bacteria to higher plants/animals and at all of its level of organization i.e. from gene to ecosystem including structure, functioning and ecological processes at all these levels of organization (Chapin et al. III 2001, Norberg et al. 2001). Thus, biodiversity has multidimensional aspect, for instance, compositional, structural and functional diversity (Roy et al. 2004, Roy and Srivastava 2012), and includes diversity within species, between species and of ecosystems (Norse et al. 1986). The distribution and magnitude of the biodiversity that exists today

has evolved over 3.5 billion years as a result of speciation, migration, extinction and more recently human influences that can be described at many hierarchical levels. Further, it can be extended to the diversity of genes, species and ecosystem at three fundamental and hierarchical levels of biological organization (WCMC 1992).

The adverse effects of human impacts on biodiversity are increasing dramatically and threatening the foundation of sustainable development. The major problems associated with the biodiversity loss are the habitat fragmentation, due to human activities followed by the climate change, nitrogen loading and biotic exchanges (Sala et al. 2000). The predictions suggest that the land-use pattern will further change the biodiversity drastically because of increasing population, especially in tropical regions. Loss of biodiversity resources threatens our food supply chain, sources of wood, medicine and energy etc. Thus systematic biodiversity conservation efforts would be required to preserve the global biodiversity, with special attention in tropical regions. These efforts would require a critical monitoring and base line information in quantitative terms at each level of biodiversity organization at different scales ranging from region to the globe.

India encompasses a variety of climatic conditions (like tropical, subtropical, temperate, alpine etc.) due to wide variations in temperature and precipitation. Climatic variations make the country rich in flora and fauna making it a 'mega biodiversity country' in the world. Geographically, India has about 2.4% of the total land area of the world but it accounts for ~8% in terms of total number of species found over the world. The majority of the species are occurring in certain biologically rich zones of tropical forests. Accelerated increase in clearing of tropical forest areas and decline in their plant diversity across the world has necessitated identifying biodiversity hotspots locations and *in situ* conservation of biodiversity by mapping the distribution of vegetation diversity across different habitats and landscapes and monitoring rates of their change over time. Hotspots are identified on the basis of the number of endemic species and the degree of threat to the ecosystem for *in situ* conservation of biodiversity. Out of 35 hotspots identified to date over the world, 4 occur in India namely, Western Ghats, Himalaya, Indo-Burma and Sundaland. Because of the rich biodiversity wealth of the country, critical biodiversity assessment and its conservation strategies is important task ahead among the ecologists and the environmentalists.

Significance of biodiversity

The human population has started realizing the significance of biodiversity after the formulation of UNCBD during the UNCED at Rio de Janeiro in June 1992, which was aimed to conserve biological diversity, promote sustainable use of its components, and encourage suitable sharing of the benefits arising from the utilization of genetic resources. The CBD obliges signatory nations to undertake an inventory of their biodiversity to provide basic information about its distribution and abundance. India was one of the first signatory's nations to CBD.

Natural ecosystems are the store houses of biodiversity and they are being regulated by the variety of species present there (Ribas et al. 2003). As the genomics is important for the health of the human, biodiversity is equally important for the health of the ecosystems because every ecosystem need certain threshold level of biodiversity below which the ecosystem may not sustain their normal functioning. Biodiversity is the basis for ecosystem services, which constitute the life support system for humans. Human societies derive many essential goods (i.e. food, fodder, fuel, timber, pharmaceutics and energy) and services (i.e. air and water, decomposition of wastes, recycling of carbon and nutrients, regulation of climate, regeneration of soil fertility, and maintenance of biodiversity) from natural ecosystems (Costanza et al. 1997, MEA 2005, http://tinyurl.com/oee799). In fact, the backbone of the world economy is based on the ecosystem goods and services. Davidson (2000) has clearly mentioned in his book 'You can't eat GNP' that our economic well-being depends on the health of the ecosystems and warns if the ecosystems are not carefully managed our economic system will fail. He has rightly argued the drawbacks of economic calculations for providing more value to the product than the source. For example, consumer products like bread hold higher value than the flour and much higher than wheat, and virtually very less value to the soil from where wheat is grown. Therefore, this economic calculation needs to reverse to manage the health of the ecosystem that sustains our economy. Further, much emphasis is given for valuing the goods but very less for the fundamental ecosystem services which are the product of biodiversity. To overcome with the problem proper integration of the economy with that of ecology is needed.

First attempt was made to calculate the value of total ecosystem services played by biodiversity of the world. This was estimated to be ~US $ 33 trillion which was more than the world economy during 1995 (Costanza et al. 1997). N-supplying cost of soil alone would cost US $ 17

trillion per year if it had to be replaced by industrially fixed N (Costanza et al. 1997). The calculation of these costs are still underway and are refined that may change during the course of time. The cost of these services are perhaps still underestimated, for example, the process of soil formation are worth many trillions of dollars annually if it needs to be manufactured in the laboratory or industry. Therefore, there is a need to critically identify and monitor the role of ecosystem services at local and global levels, and to account the value of these services in temporal scale so that provision can be made in the economy to pay cost for the sustainability of these ecosystems. United Nations Framework Convention on Climate Change (UNFCCC, 2007) estimated total climate change adaptation cost of US$ 49-171 billion by 2030 which is considerably underestimated mainly because of lack of accountability on key sectors like ecosystems, energy and tourism (Parry et. al. 2009). India's submission to (UNFCCC) in 2009 has pointed out climate change as a major challenge for economic growth and social development of the country, and emphasized the need to reduce deforestation and enhance forest conservation and forest carbon stock through sustainable forestry management (Anonymous 2009). The data on economic valuation of Indian forests is scanty and on the way.

Biodiversity of Indian forests

India is located between 08º 04' -37º 06' N lat. and 68º 07' - 97º 25' E long. The total geographical area of the country is ~329 million ha, of which major part is dominated by tropical and subtropical climate where the vegetation growth is mainly regulated by temperature and the precipitation. These two abiotic factors in combination with the range of topography are responsible for variety of macro and micro climates that has resulted into a rich biodiversity in the country. On the basis of biota and environmental realms, Rodgers and Panwar (1988) have divided the country into 10 bio-geographic regions with their shared area, for example, Trans Himalaya (5.6%), Himalaya (6.4%), Desert (6.4%), Semi-arid (16.6%), Western Ghats (4.4%), Deccan Peninsula (42%), Gangetic plain (10.8%), Coasts (2.5%), Northeast (5.2%), Islands (0.3%). Besides, the country has all the representative ecological zones of south Asia, for instance; (i) tropical rainforest, (ii) tropical moist deciduous forest, (iii) tropical dry forest, (iv) tropical shrubland, (v) tropical desert, (vi) tropical mountain, (vii) subtropical mountain, and (viii) temperate mountain (FAO 2001). Of these, tropical shrubland, tropical dry forest and tropical moist forest are covering the largest area of the country. According to Champion and Seth (1968), the forest of India has been classified into five major groups, 16 type groups and 221 forest types on the basis of physiognomy and climatic conditions.

Of the total Indian forests, tropical moist and dry deciduous forest represent 65.6 percent followed by sub-tropical (9.5%), tropical wet evergreen (8%), temperate (7%), tropical semi-evergreen (4%) and the remaining miscellaneous types (Lal 1989).

India is a mega-biodiversity country accounting around 47000 species of plants and fungi and 89 000 animal species (Khoshoo 1995, 1996, MoEF 1999). The majority of the terrestrial biodiversity resides in forests, as many other terrestrial habitats have lost their natural status; therefore, conservation of forests is synonymous with conservation of biodiversity (Singh and Kushwaha 2008). Though information about the biodiversity in Indian forest is scanty, one estimate suggest that the India has 16 500 species of flowering plants, 390 species of mammals, 2 546 species of fishes, 68 000 species of insects, 17 000 species of fungi and bacteria, 6 500 species of algae, 2 850 species of bryophytes, 1 100 species of pteridophytes, 68 000 species of insects, 5 000 species of mollusks, 8 000 species of invertebrates, 200 species of amphibians and 1 200 species of birds (Cited by Singh and Kushwaha 2008). Interestingly, of the total reported plant species in forest about 33% are endemic to India. Roughly about 10 percent of India's recorded wild flora and possibly more of its wild fauna are under threatened categories and many species are at the verge of extinction because of about 50% reduction in forest area. It is assumed that thousands of species might have disappeared for which we do not have information.

India encompasses a variety of climatic conditions (i.e. tropical, subtropical, temperate, alpine etc.) and harbours enormous floral and faunal wealth, which are facing challenges due to anthropogenic disturbances and climate change. Most of the biodiversity hotspots of the country are located in the tropical and sub-tropical regions and their endemic species are facing high degree of threats. Very little is known about the biodiversity status and conservation measures in these regions, so critical biodiversity assessment, monitoring and conservation of important endemic species from tropical parts of the country would be important. North eastern part of the India, represents moist tropical forest belt, shares about 8% of the land area and harbours approximately 50% of the Country's angiosperms out of which 30% are endemic to the place. This part consists of diverse tribal populations practicing age old shifting cultivation that has transformed majority of the pristine forests into different stages of degradation and leads to the significant loss of biodiversity of the region. The area is under developed with hilly terrains and thus the biodiversity studies are limited.

About the book

The purpose of this book is to present an overview on current state of biodiversity in different Indian natural and modified ecosystems with an emphasis on underrepresented tropical and subtropical regions. Chapter 1 introduces the biodiversity in India, its significance and about the book. Chapter 2 describes present status and future scope of biodiversity in India. Chapters 3-8 describe floristic diversity of Nagaland, rapid plant diversity assessment in Uttarakhand, decadal change in liana diversity in evergreen forests and changes in plant composition, biomass structure and allocation patterns along disturbance gradient in different tropical ecosystems in India. Chapters 9-12 describe diversity of pollen morphology, leaf deciduousness, reproductive parts and regeneration in bamboo following gregarious flowering. Chapters 13-15 describe diversity of plant utilization in different parts of the country. Chapters 16-19 describe diversity of soil and litter microbes in northeast India. Chapters 20-25 describe conservation issues of ecosystem, plants and traditional practices in different ecosystems. Finally, Chapter 26 is a synthesis of information on biodiversity in India.

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Biodiversity information in India: Status and future scope

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Abstract

India being one of the mega biodiversity countries is also one of the most densely populated regions of the world. The country harbours two of the biodiversity hotspots out of the 35 global biodiversity hotspots: the Indo-Malayan which includes the eastern Himalayas, north-east India and Andaman Islands, and the Western Ghats. These regions harbour some of the important gene-pool of medicinal plants, wild varieties of cultivable crops and other species of economic importance as well as innumerable endemic and RET plant species. Conservation of this national wealth is of paramount importance in face of increasing pressure on the plant diversity in the form of land use and land cover change, invasive species, global warming, nutrient deposition and climate change.

Keywords: Biodiversity, information system, GIS, landscape modelling, vegetation map

Introduction

Biological diversity is a vital source for technological development in agriculture, pharmaceuticals and other technological innovations (Hall and Ferro 2013). The loss of biological diversity reduces our ability to adapt to the change (SCBD 2009). This loss is compounded by the loss of knowledge of biodiversity especially among people with close relationship with the natural ecosystem. Presently in all the biodiversity rich tropical and sub-tropical regions with special reference to India, spatially represented ecological database is almost non-existent. The existing database on the

species present with organizations like BSI and detailed ecological and edaphic database of some selected study sites present with selected schools of ecology in the country are not linked spatially (Roy et al. 2012). In addition absence of quantization of diverse ecosystems up-scaling of the database to regional level is not possible. Absence of adequate and authentic spatially linked database on population structure, population dynamics, edaphic and limiting factors makes it difficult for characterization, monitoring and required conservation of the species. Recent improvements in Remote Sensing and GIS has enabled us to categorize and spatially map species congregation and stratify the vegetation types based on ecological gradients and environmental drivers.

Quantification of the biodiversity is one of the major challenges in the biodiversity conservation. Until recently spatial ecological database in India was almost non-existent. The existing database on floristic and detailed ecological and edaphic database of some selected study areas (point database) are not linked spatially. In addition, up-scaling of the database to regional level is presently not possible in absence of quantization of diverse ecosystems. A new concept was put forwarded by Noss (1990) that since any robust quantifiable definition of the biodiversity was not in the offing in the recent future, so an operational measure of the biodiversity would be "characterization" of biodiversity. With the current technological capability, it is very certain that the present species extinction rate will overtake the biodiversity inventorization and characterization. So it would be worthwhile to identify areas rich in biodiversity and to carry out their intensive quantification in inventorization of biodiversity. Recent improvements in Remote Sensing technology and Geographic Information System have enabled us to categorize, spatially map species congregation and stratify the vegetation types based on ecological gradients and environmental drivers (Roy and Roy 2010).

Today the landscape has been shaped by powerful ever-present forces for anthropogenic origin that has dwarfed the evolutionary and geological changes (Roy et al. 2012). In pre-industrialized era landscape evolution was mainly influenced by the natural changes, but in recent years more specifically in the last three centuries, forces of anthropogenic origin have caused more profound changes to occur in much less time (MEA 2005). Anthropogenic forces in most cases were detrimental to the ecosystem processes (both structure and functioning), which are commonly known as disturbance and are of universal occurrence globally. There is scarcely any part of the habitable earth that is not under some or other disturbance. A landscape may be thought of as a heterogeneous assemblage

or mosaic of internally uniform elements or patches, such as blocks of forest, agricultural fields, and urban/rural settlements etc., which interact with each other (McIntre 2007). Factors that lead to the development of a landscape pattern include a combination of human and non-human agents. The geology of a region, including the topography and soils along with the regional climate, is strongly linked to the distribution of surface water and the types of vegetation that can exist on a site.

Remote Sensing techniques have been used extensively in the past few decades to provide digital mosaic of the spatial arrangement of land cover and vegetation types amenable to computer processing (Coulson et al.1990, Chuvieco 1999). Biophysical spectral modeling techniques allow stratifying vegetation types based on the canopy closure (Roy et al. 1996). Such an approach allows mapping and monitoring the forest condition and degradation processes. Mapping the distributions of vegetation types and land use provides critical information for managing landscapes to sustain their biodiversity and the structure and function of their ecosystems (Helmer et al. 2002). Satellite remote sensing along with Geographic Information System (GIS) provides a cost and time effective solution to collect process and integrate database in an effective manner. With the increasing technology availability both in spatial and spectral sensors it is much more robust in identifying areas for conservation.

The satellite remote sensing based vegetation type assessment in the Indian tropical conditions is dependent on the spatial scale as well as the seasonal repetitivity of the satellite data. Finer spatial resolution in the satellite data enables the finer delineation of the various tones and textures of the major vegetation types in relation to the bio-geographic, topographic and geomorphologic conditions in the region (Champion and Seth 1968). The forests of India especially the deciduous forests which constitute the majority of the forest cover in the country, shows distinct phenological characteristics and can be effectively used for their type classification.

Threats to tropical forest and associated biodiversity

Tropical Forests are home to about three fourth of the world's biodiversity and is estimated to harbor not less than three million species, although it can be 10 times higher than the figure mentioned. However only about half a million species from the tropical forests has been scientifically catalogued. It implies that another 2.5 to 25 million species which are thought to exist in these forests are unrecorded and are going to disappear in near future without being even identified if the current trends of habitat loss continue.

Indian context

India is one of the twelve-mega-biodiversity countries of the world. With only 2.4 per cent of the land area, India already accounts for 7 per cent to 8 per cent of the recorded species of the world. Over 47,000 species of plants and 81,000 species of animals have been recorded by the Botanical Survey of India and the Zoological Survey of India, respectively. India is also one of the twelve primary centers of origin of cultivated plants and is rich in agricultural biodiversity. India is equally rich in traditional and indigenous knowledge, both coded and informal on the use and importance of the biodiversity in the country. For generations, thousands of human communities have lived in the midst of this rich biodiversity and evolved sustainable lifestyles, of a symbiotic nature with the natural bounty around them. In the last two centuries, these equations have been radically challenged and threatened by various factors. Among them are a social and political mandate that favours maximum extraction of natural resources to achieve a certain paradigm of 'development' and a top-down model of conservation that ignores and threatens the very existence of the first allies of conservation – local people whose lives are deeply entwined with that of their surrounding for their physical, social, emotional and moral sustenance, in fact their very livelihood.

Table 1. Comparative statement of recorded number of threatened species in India and world (are also shown endemic species in India)

Taxa	India			World	% of India to the World
		Endemic	Threatened		
	Species	Species	Species		
Protista	2577			31259	8.24
Mollusca	5070	967		66535	7.62
Arthropoda	68389	16214 (Insects)		987949	6.9
Other Invertebrates	8329		22	87121	9.56
Protochordata	119			2106	5.65
Pisces	2546		4	21723	11.72
Amphibia	209	110	3	5150	4.06
Reptilia	456	214	16	5817	7.84
Aves	1232	69	73	9026	13.66
Mamalia	390	38	75	4629	8.42

Source: MoEF 1999.

With the current trend of globalization and Intellectual Property Rights (IPR) regimes there is an urgent need for proper and scientific quantification and documentation of the biodiversity and associated knowledge base especially in the developing nations in the tropics (IIED 2006). Traditional systems of knowledge sharing have not necessarily always been open and have been restricted based on hierarchy, community, caste and class. Since most of the information is not documented so it is probable that the information of the varied utilities and uses of the biodiversity in the tropical developing nations may be lost or privatized by some multinational companies ultimately taking away the source and sustenance from the poor.

The challenge for the 21st century is developing – for the first time – a working knowledge of the nation's biological diversity in all its complexity so as to preserve and use these resources sustainably. This knowledge is critical to science and society—for maintaining the nation's natural resources, for growing its economy, for sustaining human health and agriculture, and for improving the quality of human life. We urgently require this knowledge as the daily conversion of natural systems to human-managed systems accelerates the decline of biological diversity and its habitats.

Role of plant community in biodiversity assessment

Biodiversity is intricately related to the plant community. The plant community or association determines the biological diversity of the ecosystem. Plant community intricately modifies the ecosystem functioning essential for the survival of the species. Plant community heterogeneity is an important indicator of biodiversity assessment covering large areas (Hansen et al. 2001). So for fast and effective biodiversity assessment community characteristics should be analyzed. Furthermore plant species generally exists in association with a select species and any change in the species composition leads to a change in the plant community and hence the biodiversity of the region or ecosystem changes. The change in the biodiversity of the ecosystems is due to three basic ecological processes: 1) Invasion of exotic plants; 2) Progressive succession as a part of the ecological process and 3) retrogressive succession due to natural and anthropogenic pressures on the ecosystems. Assessment of the changes in the biodiversity or the state of the biodiversity is evident from the presence of indicator species and the distribution and the abundance of the keystone species.

Role of indicator species and keystone species in biodiversity assessment

Indicator species can play a major role in quick assessment of the biodiversity status of a region. For example invertebrate richness in the soil and plant litter is a good indicator of the presence rich diversity in the ecosystem (Weaver 1995). Recent studies by Mac Nally and Fleishman (2004) have shown that identification and analysis of the behavior of few indicator species in a community can predict the variation in 89% of the species in the community. Keystone species on the other hand is responsible for the sustenance of the community in the present form and any change in the abundance and distribution of the keystone species will lead to irreversible change in the ecosystem structure in terms of species composition hence affecting biodiversity. Assessment and Identification of keystone species and keystone groups of species in a community is also important for conservation and maintenance of biodiversity in an ecosystem as their removal will lead to permanent damage to the ecosystem. One of the possible ways of characterizing keystone species in the forest ecosystem is through the competitiveness of the species along the successional gradient and focusing on their role, which supports or contributes towards maintaining an existing type of vegetation (Tripathi and Law 2006).

Assessment of biodiversity

Spatial organization of biodiversity on the earth co-evolves with the physical environment of the region, in general and the local biotic influences in particular. It is also understood that ecological systems do not exist as discrete units but represent a continuum on an environmental gradient consisting of different land cover patches in the form of landscapes. Landscapes represent a mosaic of interacting ecosystems in relatively large to very large areas consisting of patches of different land use and land covers. Patch dynamics in the landscapes, one of the key ecological processes, is best understood and explained by analyzing the size, shape and arrangement of the patches in time and space. These patches are repositories of past and present environmental events and conditions including societal interactions. The landscape processes have significant bearing on the diversity at landscape level and thus becomes an important characterizing parameter of a landscape.

Collections of taxa might form an accurate representation of some biological distributions where well-designed and well-resourced surveys have been used to collect the data. Taxa collections may also be used with some reliability at coarse scales (for example, grid cells of 50 km or 250

km), but usually become less reliable at the scale of individual reserves. On the other hand, museum and herbarium data on the locations of taxa are biased, having been collected for a different purpose (systematic), and often in an opportunistic manner, from the places that collectors expected to find what they were looking for or that were conveniently accessible.

Various methods viz, empirical, statistical and computational are now available for modeling wider spatial distribution patterns from the point records that field samples represent, but their reliability is also at least partly a function of the degree of spatial bias. New systematic field surveys to fill gaps are the best solution but they can be expensive and time consuming. A limitation of the field based data lies in extending the insights from the data to regional or global scales. Methods to reduce the amount of time spent collecting data are therefore of interest (Innes and Koch 1998).

Hierarchy in biodiversity assessment

Wilson et al. (1996) identified attributes of biodiversity that can be assessed at each level of ecological organization. At the landscape level, attributes that could be monitored include the identity, distribution, and proportions of each type of habitat, and the distribution of species within those habitats. At the ecosystem level, richness, evenness, and diversity of species, guilds, and communities are important. At the species level, abundance, density, and biomass of each population may be of interest. And, at the genetic level, genetic diversity of individual organisms within a population is important. It is best to assess and interpret biodiversity across all these levels of organization by using various approaches at several spatial and temporal scales (Noss 1990, Noss and Cooperrider 1994).

Due to these reasons, the understanding of the priorities of biodiversity conservation and management has resulted in a policy shift from conservation of single species to habitats through interactive network of species at landscape level. In this ‘top-down’ approach biodiversity can first be characterized at landscape level and a subsequently detailed inventory can be performed for the prioritized areas. This ‘top-down’ approach allows extrapolation to large landscapes and involves the development of a spatial environmental database and systematic monitoring.

Because of the complexity of biodiversity, surrogates such as sub-sets of species, species assemblages and habitat types have to be used as measures of biodiversity, and the locations of these surrogates within areas have to be plotted so that similarities or differences among areas can be

estimated. In most parts of the world, the only spatially consistent information available is on higher-order surrogates such as vegetation types and environmental classes. A map of vegetation types (communities or habitat types) and/or environmental classes provides spatial consistency across wide areas. Higher levels in the biological hierarchy, such as species assemblages, habitat types and ecosystems lose biological precision, but have other advantages. They can integrate more of the ecological processes that contribute to the maintenance of ecosystem function and the relevant data are more widely and consistently available (Fig 1).

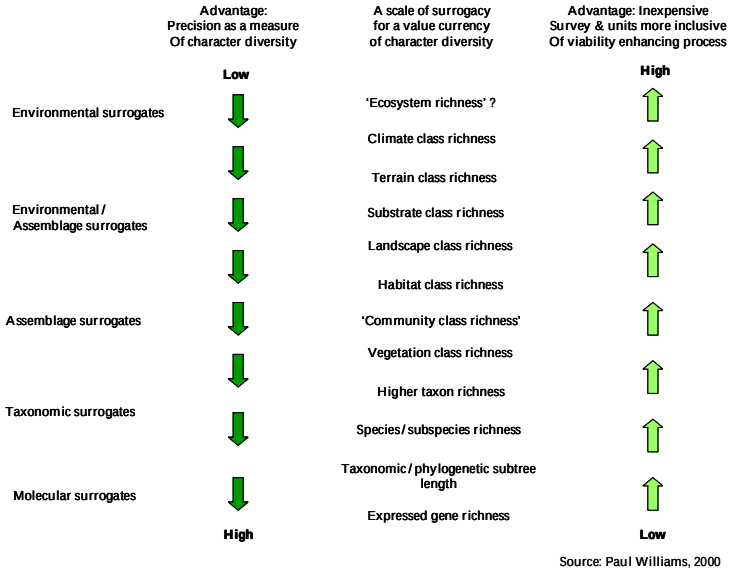

Fig 1. Surrogates in biodiversity assessment

Biodiversity assessment at landscape level

Ecosystems are units in space composed of group of different organizations having varying influence in the system structurally as well as functionally, with exchange of energy and individuals within the system as well as with other neighboring ecosystems. Studying the ecosystem dynamics and biodiversity change at patch level seems an appealing ecological basis for understanding these processes (Wu and Loucks 1996), but landscape ecology seeks to understand the ecological functions of larger areas and hypothesize the spatial arrangement of ecosystems, habitats or communities that have ecological implications in biological richness distribution (Romme and Knight 1982, Turner 1989, Gottlli 2002). In landscape ecology, biodiversity is considered an integral part of the broader concept of landscape heterogeneity for management and conservation.

Therefore, to characterize a landscape, diversity plays an important role; it acts as insurance for the system by increasing its ability to withstand change. In an effort to save biodiversity, several protected areas (Biosphere Reserves, National Parks and Wildlife Sanctuaries) have been earmarked. Even though these areas are protected, however they are not free from various degrees of human interference. Therefore, it is essential to study landscape elements for their status, interactions and importance.

The holistic understanding of the complex mechanisms that control biodiversity, as well as their spatial and temporal dynamics, requires synergetic adoption of measurement approaches, sampling designs and technologies. The data requirements include data of both spatial and non-spatial nature and also of various time scales. In view of this, the combination of satellite remote sensing, Global Positioning System (GPS), and integrative tools (such as GIS and Information Systems) is an important complimentary system to ground-based studies. It has been well explained by Murthy et al. (2003) that these technologies together form the basis for Geoinformatics. The various parameters required for biodiversity assessment and their amenability for measurements by different techniques is given in Table 2.

Table 2: Components of biodiversity assessment and measurement tools (Murthy et al. 2003)

No	Parameters	Remote sensing	Ground Measurement / GPS	GIS Based (Derived/ Integrated Spatial layer)
A	**Human interventions**	✓	✓	✓
1	Logging / Grazing	✓	✓	✓
2	Fire	✓	✓	✓
3	NTFP resources extraction	✓	✓	✓
4	Trampling	✓	✓	✓
5	Plantation	✓	✓	✓
6	Agriculture	✓	✓	✓
7	Encroachment/ Clearances	✓	✓	✓
8	Infrastructure	✓	✓	✓
B	**Natural Processes**	✓	✓	
10	Climate	✓	✓	✓
11	Erosion	✓	✓	✓

12	Topography / Soil	✓	✓	✓
C	**Structure and Function**		✓	
14	Vertical structure	✓	✓	✓
15	Size class distribution		✓	
16	Relative abundance		✓	
17	Gap frequency	✓	✓	✓
18	Canopy openness	✓	✓	✓
19	Standing and fallen dead wood		✓	✓
20	Trophic dynamics		✓	✓
21	Other structural elements		✓	
D	**Landscape level**			
22	Vegetation type and extent	✓		✓
23	Landscape diversity	✓		✓
24	Species diversity	✓	✓	✓
25	Number of patches per unit area	✓		✓
26	Neighbourhood	✓		✓
27	Patch shape	✓		✓
28	Core-edge ratio	✓		✓
E	**Habitat level**			
29	Species assemblages / Communities	✓	✓	✓
30	Species diversity	✓	✓	✓
31	Interior to exterior habitat	✓	✓	✓
32	Regeneration	✓	✓	✓
33	Habitat extinction	✓	✓	✓
F	**Species level**			
34	Reproduction		✓	
36	Dispersal / Migration		✓	
37	Regeneration		✓	
38	Location extinction		✓	

Scale and biodiversity

The concept of scale is critical to study of ecology (Allen and Hoekstra 1992, Peterson and Parker 1998), especially when talking about multi-dimensional and hierarchical concepts such as biodiversity. Biodiversity indicators as information tools summarizing biodiversity status and trend have to cope with different levels of biodiversity at different scales. Genes, species and ecosystems can be differently scaled in time and space. Spatial scale is critical for the sampling design of a monitoring programme that is the prerequisite for indicator construction. Biodiversity assessment is sensitive to sample size and area surveyed. Whitaker proposed three aspects of biological diversity for measuring diversity across scales (Whitaker 1977). Alpha diversity refers to the diversity within a particular area or ecosystem, and is usually expressed by the number of species (i.e., species richness) in that ecosystem; Beta diversity is used to examine the change in species diversity between ecosystems and Gamma diversity is a measure of the overall diversity for the different ecosystems within a region. Hunter (2002) defines gamma diversity as "geographic-scale species diversity".

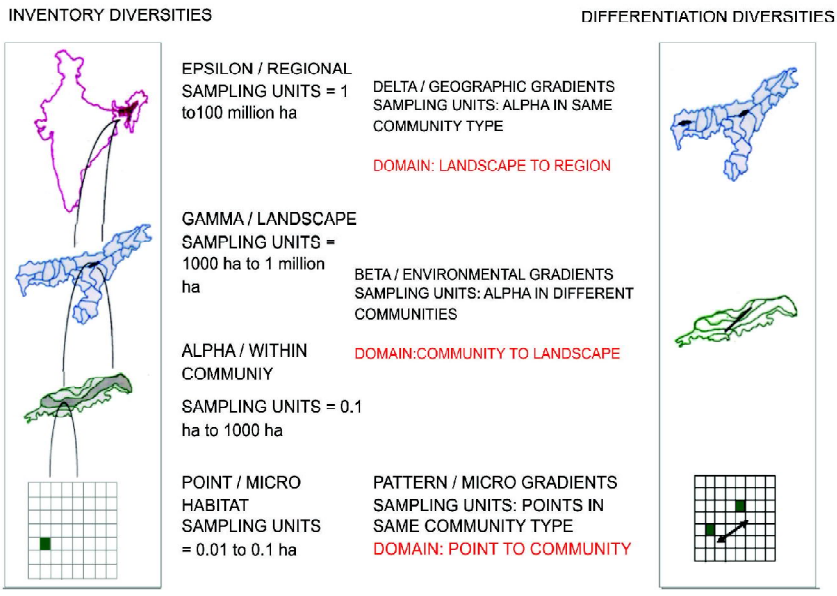

Fig 2. Levels of species diversity (Whittaker 1977)

Landscape composition can be measured in ways analogous to measurements of species composition (Romme and Knight 1982). The most straightforward approach is landscape richness i.e. the number of different

patch types in a landscape. Another approach includes the relative abundance or dominance of different patch types along with richness. Measurements of landscape diversity are analogous to common measurements of species diversity (Whittaker 1960, 1972 and 1977) (Fig 2). Different patch types provide different habitats and species composition, thus one might expect that the total number of species in a landscape would increase as landscape richness increases (Burnett et al. 1998).

Biodiversity assessment and quantification: Indian context

In this context biodiversity characterization at landscape level using satellite remote sensing (RS) and Geographical Information System (GIS) has been undertaken by the Department of Biotechnology (DBT) and the Department of Space (DOS) as an important initiative to develop baseline database of important landscapes of India (Roy et al. 2012).

The study hypothesizes to identify biodiversity conservation priority zones at landscape level interlaced with environmental complexity, disturbance index and habitats. Ecosystems are units in space composed of group of different organizations having varying influence in the system structurally as well as functionally, with exchange of energy and individuals within the system as well as with other neighboring ecosystems. In landscape ecology, biodiversity is considered an integral part of the broader concept of landscape heterogeneity for management and conservation. Therefore, to characterize a landscape, diversity plays an important role; it acts as insurance for the system by increasing its ability to withstand change. In an effort to save biodiversity, several protected areas (Biosphere Reserves, National Parks and Wildlife Sanctuaries) have been earmarked. Even though these areas are protected, however they are not free from various degrees of human interference. Therefore, it is essential to study landscape elements for their status, interactions and importance.

Impact on biodiversity due to fragmentation of ecological units has been well documented at the landscape level-using patch number, size, shape, abundance and forest matrix characteristics (Forman and Godron 1986, Skole and Tucker 1993, Roy and Tomar 2000). Ecosystem degradation and patch characteristics are associated with a degree of fragmentation (Mertens and Lambin 1997, Roy et al. 1997). Fragmentation apart from creating niches for the invasive species also isolates the endemic gene pools leading to loss of the genetic diversity and in long run loss of species.

Disturbance is a discrete event along the passage of time that modifies landscape, ecosystems, community and population structure (White

and Pickett 1985). The disturbance leads to processes like fragmentation, migration, local and regional extinction. At landscape level, disturbance is related to patch structure and spatial arrangement and determines the fate of patches, their size and duration. Severe disturbance generally has depressing effect on biodiversity, but intermediate disturbance has been reported to enhance diversity in a system. But disturbance of any intensity will always have a deleterious effect on the biological diversity of a region. Human activity has widespread impact on biodiversity, affecting ecological entities from species to whole communities and ecosystems, though heterogeneity in the landscape can be due to moderate disturbance. The disturbance regimes can be measured by using different indices i.e., degree of fragmentation, fractal dimension, contagion, juxtaposition, evenness and patchiness (Li and Reynolds 1994).

Identifying regions having high biological richness or biologically rich areas under threat has an immense bearing on the prioritization and also helps in inventorization of endemic and threatened species. A top-down approach to biodiversity characterization from landscape to species can also use landscape modeling techniques for identification of potential sites for endangered and threatened species for *in situ* conservation of the species by protecting their habitats (Giriraj 2006). Furthermore, this technique is also helpful in identifying potential biodiversity rich areas for intensive exploration for improving the plant biodiversity inventory. The study has been conducted in India in three phases.

India lies to the north of the equator between 6°44' and 35°30' north latitude and 68°7' and 97°25' east longitude. India has a coastline of 7,517 km and covers a total geographical area of 32, 87, 590 km^2 with 20.75% total forest cover. Forests of the country have been characterized as major 16 forest type groups (Champion and Seth 1968) and are a home to estimated 1.2 million species.

The natural tropical ecosystems have the largest share of the world's vascular plant species (i.e., 45% of the total). India which is ranked as eleventh mega-biodiversity centre of the world and the third in Asia with a share of about 11% of the total floral resources has more than 17,000 species, of which 33% are endemic. The vast geographical expanse of the country has resulted in enormous ecological diversity, which is comparable to continental level diversity scales across the world. India is also recognized as one of the twelve Vavilovian centres of origin and diversification of cultivated plants (Vavilov 1951). About 320 species belonging to 116 genera and 48 families of wild relatives of crop plants are known to have originated

here.

India's unique geography and geology strongly influence its climate comprising of six major climatic subtypes, ranging from desert in the west, to alpine tundra and glaciers in the north, to humid tropical regions supporting rainforests in the southwest and the island territories.

Biodiversity Characterization

A total of 150 vegetation and land use class have been mapped using visual interpretation technique (Fig 3). Further, 86 forest classes have been delineated of which 20 are mixed natural formations, 29 are gregarious formations, 21 locale specific formations, 13 forest plantation classes, 6 degraded classes, 2 woodland classes, 15 scrub classes, 15 grassland classes. Among the land use classes 17 classes of orchards have been delineated. Among the other land use and land cover classes there are Agriculture, long fallow/Barren land, River bed, Water body, Wetlands, Settlement and Snow. In some areas due to persistent cloud cover the land cover could not be observed have been put under reject class. The various vegetation type and land use are distributed throughout the country and occur according to their bio-geographic preference. Forest which includes mixed natural formations, gregarious formations, locale specific formations, forest plantations and degraded classes and woodland covers around 19.5% of the total geographic area (TGA) of the country.

Fragmentation calculated as the number of patches of forest and non-forest in 500m x 500m grid has been graded into 3 classes (low medium and high) with the values ranging from 1-38 for the entire country (Fig 4a). The pixels having the fragmentation index values of 1 were categorized as low fragmentation, medium fragmentation have been assigned to pixels having value of 2. All the pixels having values from 3 - 38 have been categorized as high fragmentation areas. Analysis of fragmentation status in the Indian landscape has shown that considerable area around 50% of the forests is under low fragmentation. This indicates that most of the forested areas are under some protection as shown by low fragmentation in-spite of various pressures.

Being one of the most populated regions of the world, the entire country has a very high level of anthropogenic pressure although the extent of the pressure varies from region to region. The disturbance index map of the country shows that the disturbance in the vegetated areas of the country is maximum in the western Himalayas, followed by regions in the northeast where shifting cultivation is prevalent (Fig 4b). Although Western Ghats

have high amount of anthropogenic pressure, the disturbance is high only in some pockets due to prevalence of various plantations of coffee, aracanut, etc.

The Disturbance Index computed has a range of 0-72 for the entire country. The range have been categorized as low (11-18), medium (19-23), high (24-28) and very high (28-72). The mixed formations have the highest area under low disturbance and Scrub / Shrub land has the maximum area under high and very high disturbance (Fig 4b). Degradation formations as expected show a good amount of disturbance. Analysis of the disturbance index in Indian vegetated regions has shown that although the disturbance is mostly concentrated in the degraded areas and scrub/shrubland, most of the natural formations are relatively undisturbed. Since the natural mixed formations contribute mostly to the biodiversity of India, the mixed natural formations have been analysed in details as to the detailed distribution of the various vegetation types with respect to the disturbance regimes.

India due to its unique location and varied bio-geography has a rich biological diversity. Due to the high population pressure, most of the natural areas of India are under tremendous pressure as a result of resource exploitation, need for agricultural land and development (Fig 4c). In spite of the pressure India harbours two biodiversity hotspots in the world. The biological richness map computed has a biological richness values in the range of 17-90. The range have been categorized similar to the disturbance index as low (17-40), medium (41-54), high (55-70) and very high (71-90).

It has been observed that the very high biological richness is present in North-east, Western Ghats, Andaman and Nicobar Islands and in some patches of Eastern Ghats especially Araku valley of Andhra Pradesh and Orissa border (Fig 4c). This is as expected as the North eastern India especially the Arunachal Pradesh and Andaman and Nicobar Islands is a part of Indo-Malayan biodiversity hotspot and the Western Ghats is another hotspot recognized by the CBD (Myers 1986).

The project has generated vegetation type maps, spatial disturbance regimes and biological richness maps using Remote Sensing and GIS based analysis. Around six thousand field sample points (based on stratified random sampling design) encompassing the different strata were inventoried for plant species and have been utilized for biological richness modeling. Location and abundance spatial database of more than 7500 species have been developed. Digital database on vegetation type distribution, the first of its kind of systematically organized databases developed in India, a

basic input for identifying the species habitats and would serve as benchmark for further biodiversity related ecological studies. Disturbance Regimes assessed across the landscape flag the 'stressed' eco-systems and may highlight the causative factors. Biological Richness maps (BR) lay emphasis on the areas, which should be treated on priority while formulating the strategies for conservation of biodiversity.

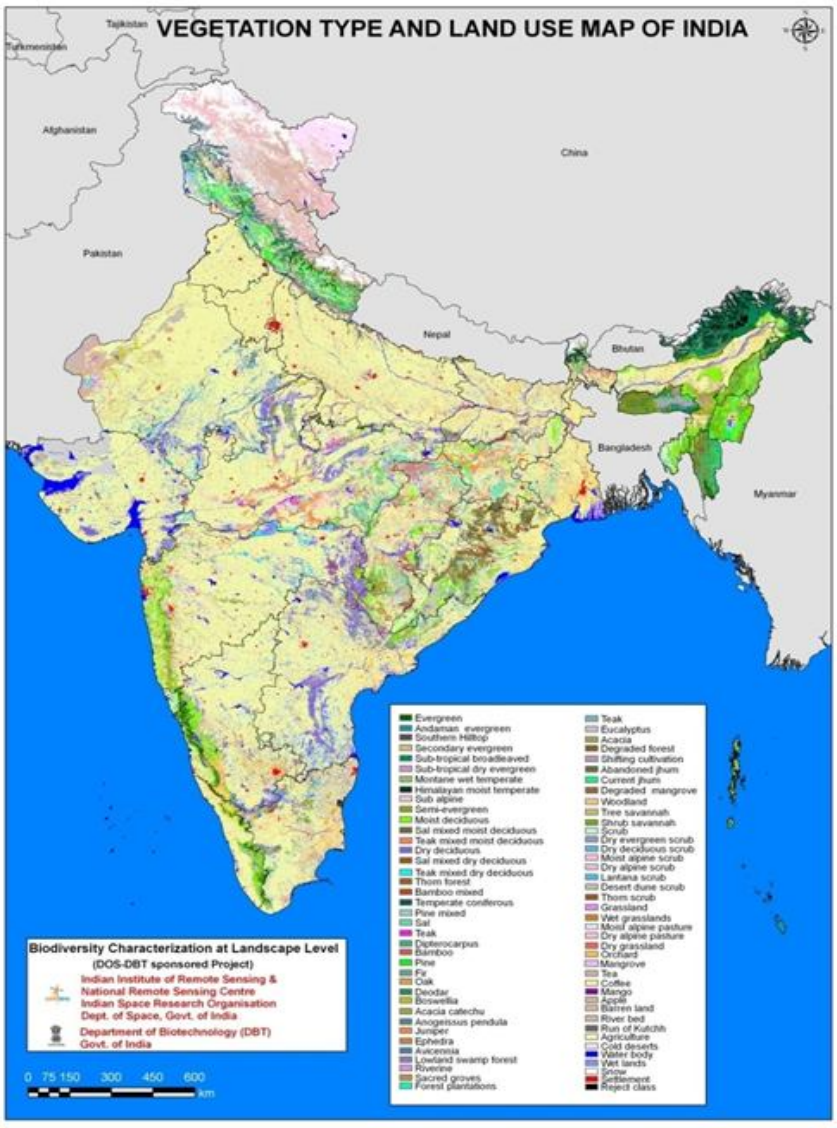

Fig 3. Vegetation type map of India

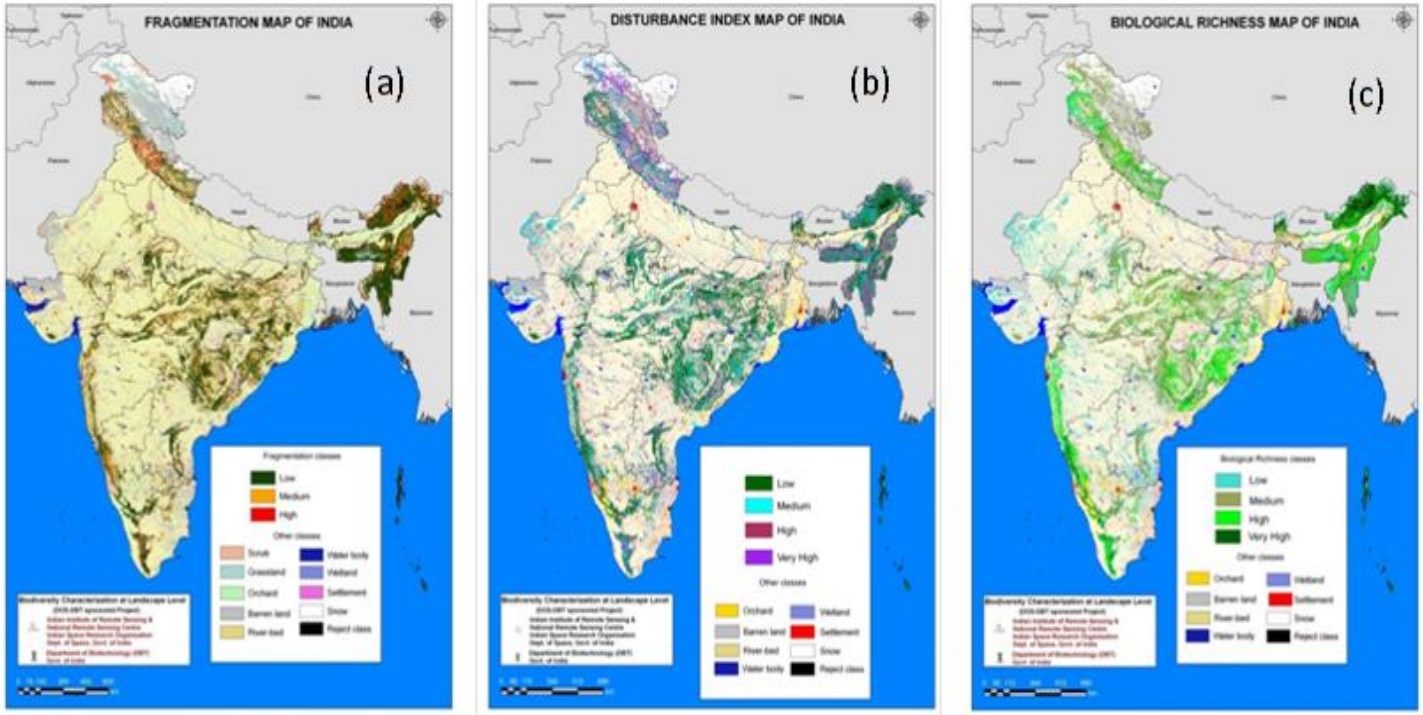

Fig 4. (a) Fragmentation map; (b) Disturnbance Index Map; (c) Biological Richness Map

Conclusion

Proper documentation of biological diversity is essential for conservation and sustainable use of this natural wealth for the benefit of mankind. The outcome of the nationwide project – "Biodiversity Characterization at Landscape Level" have been quite significant, particularly the wall to wall and holistic database on the key inputs describing the quality and quantity on the vegetation and biodiversity at different spatial levels. This database is a baseline database on vegetation types, fragmentation status and biological richness of Indian landscape which is the key to biodiversity conservation planning and developing future management strategies for conservation efforts. Wide dissemination and utilization of data has been achieved through development of Web GIS enabled information and data services to the range of users where the geo-spatial database has been organized as a central database repository and published into internet domain through Biodiversity Information System (BIS).

Using the spatially linked species database across the country in association with spatial ecological data, risk species and habitats under potential species loss risk can be identified using statistical modeling. This can form one of the databases for prioritization of ecosystem conservation. In the coming decades these information archived and disseminated by documentation of biodiversity and its associated knowledgebase will help in conservation and sustainable use of the biological resources for the benefit of mankind.

Monitoring of the biodiversity based on the baseline database need to be taken up. Appropriate methodologies need to be formulated for rapid assessment of the changes which have taken place. There is also need to identify the indicators of biodiversity changes amenable through satellite remote sensing for accurate monitoring of the changes. The databases also need to be regularly updated with the generation of new information and suitable mechanism need to be put in place.

There is an urgent need to bring the distributed information on biodiversity like the faunal data of Zoological Survey of India, historical plant species and distribution database of Botanical Survey of India, other biodiversity related database of various other universities and institutions, traditional knowledge mostly unwritten about the medicinal properties and other economic uses of the plants and animals in one common platform. To address this a web-portal is being mooted for data organization, services and dissemination wherein each data source of the parent institution will

act as a node for web portal in form of Indian Bio-resource Information Network (IBIN).

The database created will act as a surrogate for the conservation and sustainable management of the biological resources. The database will allow identification of gap areas, species/ habitat relationship and helps in biodiversity conservation planning by setting priority areas.

Acknowledgement

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Floristic diversity of Nagaland, Northeast India – An overview

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Abstract

Nagaland has the finest tropical and subtropical evergreen forests along with unique Broad Leaved Moist Temperate forests. The flora and fauna of the state represent the transition zone between Indo Malayan and Indo Chinese bio-geographic region. Patkai range of Nagaland is therefore acts as a bio-geographic gateway. The region is considered as a cradle of flowering plants due to occurrence of many ancient angiosperms and primitive flowering plants. The state harbours a total of 378 Orchids, 58 different bamboo species, 56 wild edible mushrooms, 428 lesser known edible fruits and vegetables, 656 medicinal plants, 74 indigenous crops in shifting cultivation system, 7 species of cane/rattans, 340 lichens, 280 ferns and many others species have been documented. In addition, Eastern Himalaya including Nagaland is one of the centers of origin of many agri-horticultural species like rice, citrus, chilly, maize and cucurbits. However, the rich biodiversity of this state is being impoverished disastrously along with the overall degradation of mountain environments due to human activities in last few decades. Further, loss of indigenous control over collection of valuable forest products is evidenced as a result of increasing local population and introduction of market linkages with the outside. Combination of the rich indigenous knowledge system together with scientific support should be applied to boost the forest management for sustainable agriculture, soil and water management which will surely ensure less pressure on forests, conserve forest resources and sound income generation for the rural people.

Keywords: Plant diversity, agri-diversity, subtropical evergreen forest, eastern Himalaya.

Introduction

State of Nagaland is situated in far north-eastern corner of India sharing border with states of Assam in south, Manipur in the west and Arunanchal

Pradesh in the north as well as with Burma in the east. State lies between 25°05' N and 27°10' N latitude and 93°28' E and 95°05' E longitude. Total geographical area of state is 16,527 Km^2, out of which 85.43% constitute variety of forests (dense forest - 5,137 Km^2; open forest - 9, 027 Km^2). Nagaland is particularly rich in biological species, genetic diversity with high degree of endemism and threat to the species. Thus, the State falls under (Indo-Burma hot spots) one of the biodiversity hot spots of the world with reference (Meyers 1988) that reflects the need for the conservation of the species. The state has about 3/4 of the area under forest cover as against national average of 19.5.%. About 80 % of the land and forests are owned and controlled by the village community, Clans/ Khels, and by the individuals.

Nagaland enjoys typical monsoon climate that differs from the plains of Assam. A year can be divided into four distinct seasons viz., winter (December to February), pre-monsoon (March-April), monsoon (May to September) and retreating monsoon (October to November). In winter, the night temperature comes down to an average of 2 - 4°C. In summer months it is not very hot but pleasant in the hills with maximum temperature of 25°C and up to 38°C in the foothills and plains. State experiences heavy rainfall and the annual rainfall vary from 100 cm to 300 cm. The monsoon season lasts for a period of five months from May to September while July and August experiencing the highest rainfall. The southern part of the state gets heavy rainfall in comparison to that of the northern part of the state. The rainy season is characterized by relatively high humidity with average relative humidity of 85% to 95% and as such it is rather damp during monsoon season and conducive for plant growth. The on-set of summer (Pre-monsoon) is marked by strong wind accompanied by thunder storms and hailstorm. During October to February cold wind blows bring down the temperature in the state. The temperature during the winter varies from 2° C to 17° C. The coldest months in Nagaland are December and January which are characterized by snow fall snow fall in higher range of Saramati range, Japfu range, and experience the frost falls in the ranges of Aghanato, Zenheboto, Longkhim, Pfutsero etc.

Nagaland has the finest tropical and subtropical evergreen forests and it has also a unique broad leaved Moist Temperate forests with its rich flora and fauna elements of different bio-geographic zones. The Nagaland being at the confluence point of two major bio-geographical realm of the world (i.e. Great Himalayan and South East Asia) support a rich biodiversity along with its several endemic species. Patkai and Barial ranges of Nagaland are the meeting place of Himalayan Mountains with that of Peninsular India and South-East Asia and the gateway of biological migration. The vegetation

represents the bio-geographic transition zone between the Indian, Indo Malayan and Indo Chinese and many ancient angiosperms and primitive flowering plants occurrence; as such Nagaland is considered under the cradle of flowering plants (Thakhtajan 1969, Rao 1994). Several groups of plants of Orchids, Rhododendrons, Ferns, Bamboos, Zingibers and Lichens have expressed their maximum diversity in this state. The state is also known to have a great treasure of medicinal plants, and also faunal elements. Eastern Himalayas including Nagaland is considered as one of the center of origin of rice and secondary origin of citrus, cucurbits, chilly and maize.

The biodiversity of the state is essentially due to its unique geographic location where the altitude varies gradient from flood plains (190 m) and the high hills of Mt. Saramati (3048 m) from the Mean Sea Level. A unique and rich terrestrial diversity of flora and fauna along the different gradient also prevailing a diverse agriculture practice systems conserving a huge indigenous germplasms by a diverse ethnic group. This rich agro biodiversity elements have evolved, over millenia, in intricate association with the communities distributed along the mountain and hill slopes. As this state is with a unique, functions and roles in context of biodiversity, the wide variety of plants and animals in the mountain ecosystem has supported human existence and contributed to our well being. The interactions between the tribal people and the natural system have helped in maintaining the richness of species, communities and genetic materials in both production systems and wild lands of the mountain environment. The traditional utilization of biologically resources in the region not only reflects a diverse resource use pattern, but also the way of maintaining biodiversity in mountain ecosystems by the people. Here the natural resource management systems are also localized systems, which form a basis for decision making for rural people, since the majority of farming systems and all productive systems in the region operate under indigenous knowledge systems. Indigenous tribal depend on plants and animals for their livelihood and collect their needs such as meat, fruits, vegetables, medicines, constructional materials, fibbers, etc., from their surrounding environment. Indigenous people have developed a highly complex and very specific knowledge of their local vegetation and many of them depends on vegetation resources for most of their foods and nearly all their material needs (Changkija 1996).

Vegetation and forest types

In Nagaland, 52.04% of the total geographical area are under various status of forest cover (Table 1) and the remaining lands are classified as agricultural land, miscellaneous tree crops and grooves, cultivable wasteland, cultivable non-forest area, etc.

Table: 1. **Status of Nagaland Forest.**

Legal Status	Forest Area (ha)	% of Total Forest Area	% of Total Geographical area
Reserved Forests	8583	1	0.5177
Purchased Forest	19247	2.2	1.1558
Protected Forests	50756	5.9	3.0615
Wildlife Sanctuary	22237	2.6	1.3413
Village Forests			
i) Virgin Forests	477827	55.4	28.8212
ii) Degraded/Jhumfallow	284280	32.9	17.1467
Total	862930	100	52.0442

(Dept.of Forests, Ecology, Environment and wildlife, Govt. Of Nagaland 31.01.2008)

The unique geographical location and wide range of physiographic terrain coupled with climatic and altitudinal variation in Nagaland has resulted in luxuriant and diverse flora that a wide variety of forest types occurs in the state. Based on the classification of Champion and Seth (1968), the forest of Nagaland can be classified into following forest types:

(1) Tropical Forest:

(a) Tropical Wet Evergreen Forest

(b) Tropical Semi-Evergreen Forest

(c) Tropical Moist Deciduous Forest

(2) Sub-Tropical Forest:

(a) Sub-Tropical Broad Leaved Forest

(b) Sub-Tropical Pine Forest

(c) Degraded Bamboo Forests

(3) Montane Wet Temperate Forest

(a) Broad Leaved Wet Temperate Forest

(b) Sub-Alpine Forest

1. Tropical forest:

(a) Tropical Wet Evergreen Forest: This type of forests occurs in the Assam-Nagaland border in the foothills of Tuli in Mokokchung district,

Merapani in Whokha District, and once covered the Namsa-Tizit area but is now confined only to a small vestige in the Zankam area in Mon district. These forests are endowed with rich floristic diversity and multi-tiered forests. The dominant tree species in these forests are *Ailanthus integrifolia, Artocarpus, chaplasha, Artocarpus lakoocha, Dillenia indica, Dipterocarpus macrocarpus, Mesua ferrea, Alstonia scholaris, Pongamia pinnata, Michelia* sp., *Phoebe* sp., *Sapium baccatum, Shorea assamica* etc (Kanjilal et al. 1934-40). A characteristic feature of this type of forest is the abundance of climbers and lianas. Various bamboos, orchids, pteridophytes including tall tree ferns also occur among them.

(b) Tropical Semi-Evergreen Forest: These types of forest are found in the foothills of Nagaland in Mokokchung, Wokha, Longleng and Mon districts. Most of the plant species of Tropical Wet Evergreen Forest are found in these forests; however there are some species which are deciduous in nature like *Tetrameles nudiflora, Lagerstroemia speciosa, Stereospermum chelonoides, Bombax ciba Albizia procera, Altingia excelsa, Morus laevigata, Callicarpa arborea, Ficus sp*., etc. The dominant other species are *Alstonia scholaris, Pongamia pinata Aquilaria agallocha, Canarium resiniferum, Spondias mangifera, Garcinia sp.* (Kanjilal et al. 1934-40). Lianas of family Menispermaceae, Vitaceae and Papilionaceae are common.

(c) Tropical Moist Decidous Forest: These types of forest are found in adjacent to the rivers of Doyang, Dikhu, and also in the foothills of Assam-Nagaland border in Paren and Dimapur districts. *Tetrameles nudiflora, Morus lavigata, Lagerstroemia speciosa, Lagerstroemia, Albizia procera, Albizia lebbek, Albizia chinensis, Bombax ceiba, Canarium benalensis, Holorhena antidysendrica, Stereospermum chelenoides, Elaeocarpus lanceafolius, Spondias mangifera etc* (Kanjilal et al. 1934-40).

(2) Sub-Tropical forest:

(a) Sub-Tropical Broad Leaved Forest: This category of forest occupies the hill areas between 500 m and 1800 m in all the districts of Nagaland. The vegetation is dense and the species that make up these forests are mostly (i) Evergreen, (ii) Semi-deciduous and (iii) Degraded bamboo forests. These categories of the forests are degraded mostly due to human interference as such Jhum cultivation and extraction of resources. Some important timber species found in these forests are *Albezia procera, Alstonia scholaris, Amoora wallichii, Mansonia dipikae, Bauhinia purpurea, Terminalia myriocarpa, Arctocarpus chaplasha, Artocarpus lakoocha, Morus laveigata, Garcinia sp, Stereospermum chelonoites, Duabanga grandifollia, Phoebe sp, Juglan regia, Canarium resiniferum, Phoebe*

lanceolata, Prunus napaulensis, Spondias mangifera, Spondias axilary, Elaeocarpus sp., Schima wallichii, various *ficus* species, *Magnolia rubra, Gmelina arborea, Betula alnoides, Mangifera sylvatica* (Kanjilal et al.1934-40, Nayak and Sastry 1987, 1988, 1990). The climatic condition of these forests is favourable for various bamboos, cane, wild banana (*Musasae and Ensete*), epiphytes like orchids, ferns, mushrooms, bryophytes, lichens and various medicinal shrubs and herbs etc. occurred abundantly.

(b) Sub-Tropical Pine Forest: These types of forest are found in hills with elevation of 1500 m to 2500 m in parts of Tuensang, Kiphire and Phek districts of Nagaland. The dominant species in these forests is *Pinus*. The pines are generally associated with species like *Alnus nepalensis*, *Bauhinia purpurea, Quercus* sp., *Schima wallichii, Prunus* sp., *Betula alnoides, Taxus baccata, Cephalotaxus griffithii, Rhododendron* spp., *Exbucklandia populnea, Ilex excelsa, Schima khasiana,* Dwarf shrubs and undershurbs like *Rubus, Hydrangia, Polygonum,* etc. (Kanjilal et al. 1934-40, Nayak and Sastry 1987, 1988, 1990) are abundant in these forests.

(c) Degraded Bamboo Forests: A total of 57 species of bamboo are growing in Nagaland forests. Bamboos are secondary succession species growing rapidly in the forest fallows of shifting cultivation areas in the state.

(3) Montane Wet Temperate Forest:

(a) Broad Leaved Wet Temperate Forests: These forests types occupy the tall mountain ranges like Saramati range in Kipheri district, Japfu range in Kohima district, Yakor and Hillipong ranges in Tuensang district, Aghanato range in Zunhepoto, (above 2200 m). The dominant species are *Rhododendron, Cryptomeria japonica, Ilex excelsa, Schima khasiana Magnolia campbelii, Exbucklandia populnea, Phoebe lanceolata Toona ciliata, Quercus sp, Lithocarpus sp, Acer sp., Birch and Juniperus spp* (Kanjilal et al. 1934-40, Nayak and Sastry 1987, 1988, 1990).

(b) Sub-Alpine Temperate Forest: The sub alpine forest or Alpine vegetation occurs mainly at high altitudes in the ridges of Saramati range and Japfu range. Saramati ranges the alpine vegetation such as only few annual short duration grasses and herbs are grown in the top hills and in lower area various *Rhododendron* spp., *Tsuga* sp. and *Junipers* sp. along with various shrubs and herbs are grown. The mountain ranges remains snow capped for major part of the year from October to April. The summers are very brief during which the snow melts and a few annuals, herbs and shrubs along with mosses can be seen growing there. Sub-alpine vegetation

gradually merges into alpine vegetation which comprises of high altitude grasses and dwarf *Rhododendron*. Herbs like *Primula, Anemone, Aconitum, Potentilla,* etc are common in the alpine forest.

FLORISTIC RESOURCES:

Table 2: **Floristic resource of Nagaland**

Sl. No.	Floristic diversity components	Number of documented spp.
1	Cultivated crops of Jhum fields	74
2	Wild edible fruits	248
3	Wild edible vegetables	128
4	Wild edible flowers	52
5	Wild edible mushrooms	58
6	Domesticated fruits	26
7	Edible roots and tubers	42
8	Edible seeds and nuts	54
9	Medicinal plants	658
10	Bamboo species	58
11	Orchid species	378
12	Cane species	7
13	Lichens	340
14	Ferns	280
15	Indigenous jhum crops	74
16	Indigenous local useful trees sp.	560
17	Commercial timber plants	147

(Source: Kanjilal et al. 1934-40, Nayak and Sastry 1987, 1988, 1990)

Table 3: **Germplasm diversity: different crops of Nagaland**

Sl. No.	Groups	Crops	Germplasm collected
1	Cereals	Paddy and Maize	372
2	Pseudo cereals	Sorghum, Amaranth, Chenopodium	15
3	Millets	Pennisetium, Eleusine, Setaria, Coix	88
4	Oilseeds	Brassica, Sesame, Perilla, Groundnut.	74
5	Legumes	Cowpea, Sembean, Soybean, Ricebean,	

		Frenchbean, French bean, Pea, Pigion pea, winged pea.	193
6	Tuber crops	Colocasia, Dioscoria, Sweet potato	64
7	Vegetables	Cucurbits, Momordica, Benincasa, Sachium, Luffa, Solanum, Tree tomato.	124
8	Spices and condiments	Okra, Onion, Garlic, Chillies, Ginger, Turmeric, Wild cardamom, Black pepper, Coriander, Leafy spices,	68
9	Beverages and narcotics	Tea, Coffee, Tobacco.	6
10	Fruits	Orange, Jackfruit, Banana, Guava, Papaya.	15
11	Others	Cotton, Sugarcane, and wild medicinal plants.	13
		Total Germplasm Collected:	**1014**

Source: Hore and Sharma (1993)

Economically important plants

The rich and diverse flora of Nagaland contains a large number of economically important plants such as medicinal, aromatic, ornamental, horticultural, wild edible vegetables and fruits, timber and fodder species (Table 2 and 3). Some important plants under various heads are as follows:

i) Medicinal Plants: The Nagas in rural areas are solely dependent on the floral resources for their health care and treatment of various ailments. The use of medicinal plants for treatment of various diseases has always been known to the Nagas. They have gained intimate knowledge of the uses of variety of medicinal plants which are passed from generation to generation through oral tradition. Many of the plants are used in traditional medicinal purposes and among some is also use as vegetables and fruits. Some of the important medicinal plants among the total of 658 species can be listed as follows: *Aconitum sp., Acorus calamus, Aquilaria agallocha, Asparacus racemosa, Adhatoda vasica, Bauhinia varigata, Berberis asiatica, Canarium resiniferum, Canabis sativa, Cassia alata, Catharanthus roseus, Centilla asiatica, Chloranthus officinalis, Cinnamomum zylanicum, Clerodendrum colebrookianum, Coix lachryma-jobi, Costus speciosus, Curculigo orchioides, Curcuma longam, Cyclea peltata, Emblica officinalis, Entada pursaetha, Eurya accuminata, Garcinia spp., Gonathanthus pumilus, Hibiscus sabtariffa, Hodgsonia macrocarpa, Holarrhena antidysendrica, Houttuynia cordata,*

Hydnocarpus kurzii, Hypericum japonicum, Lassia spinosa, Litsia citrata, Milletia auriculata, Mesua ferrea, Mucuna purerea, Osimum gratismum, Papaver sominiferum, Passiflora utilus, Phlogacanthus thyrsiflorus, Phyllanthus amarus, Plantogo majore, Panax gensing, Panax psuedo-gensing, Rhus semialata, Rubia sikkimensis, Smilax aspera, Solanum nigrum, Swertia chirayita, Terminalia arjuna, Terminalia chebula, Tinospora cordifolia, Withania somnifera, Xanthoxyllum acanthopodium, Zingiber officinalis, etc (Kanjilal et al. 1934-40, Nayak and Sastry 1987, 1988, 1990). Some of these plants among them are cultivated in house gardens and jhum fields, but about 80% of medicinal plant requirements are met through wild collection by the local tribe. The conservation and sustainable utilization of the medicinal plants is an urgent problem for which the assessment of the biodiversity of medicinal plant of the state is a pre-requisite.

ii). **Timber Yielding Plants**: Many valuable timber yielding species occur in these forests. Some such important ones which are being commercially exploited are as follows: *Ailanthus grandis, Albizia lucida, Albizia* procera, *Alstonia scholaris, Amoora wallichii, Anthocephalus chinensis, Artocarpus chaplasha, Artocarpus lakoocha, Altingia excelsa, Bombax ceiba, Bischofia javanica, Betula alnoides, Canarium bengalensis, Canarium resiniferum, Chukrasia tabularis, Castanopsis indica, Cedrela toona, Dysoxylum procerum, Dysoxylum hamiltonii, Dysoxylum binectariferum, Dillenia indica, Duabanga grandiflora, Echinocarpus assamicus, Elaeocarpus lanceofolium, Elaeocarpus chinensis, Eurya acuminata, Gmelina arborea, Gynocardia odorata, Holarrhena antidysenterica, Kydia calycina, Lagerstroemia speciosa, Litsea monopetala, Litsea polyantha, Magnolia hodgsonii, Mesua farea, Mesua assamica, Michelia champaca, Michelia oblonga, Michelia kisopa, Morus laevigata, Macaranga denticulata, Magnolia pterocarpa, Pterospermum acerifolium, Pterospermum lanceofolium, Phoebe goalparensis, Phoebe paniculata, Pinus khesea, pinus roxburghii, Quercus spp., Sterculia villosa, Sterculia coccinea, Stereospemum chelenoides, Schima walichii, Schima khasiana, Terminalia myriocarpa, Tetrameles nudiflora* etc (Kanjilal et al. 1934-40, Nayak and Sastry 1987, 1988, 1990).

iii). **Ornamental Plants**: A wide range of attractive wild ornamental plants occur in Nagaland.

a) Orchids: Orchids are among the most beautiful creation of nature and are well known for their attractive, colourful flowers which need no introduction. Many wild orchids found growing in the forests have great

potential for exploitation as horticultural species. Out of 378 species of orchids (Changkija et al. 1994), which occur in Nagaland, some of the important commercial and ornamental orchids including many rare, endangered and endemic species are as follows: *Acampe multiflora, Acampe regita, Aerides crassifolium, Aerides odoratum, Arachinis cathcartii, Ascocentrum ampullaceum, Ascocentrum miniatum, Bulbophyllum rothschildianum, Calanthe biloba, Calanthe masuca, Calanthe longifolia, Coelogyne barbata, Coelogyne corymbosa, Coelogyne critata, Coelogyne flaccida, Coelogyne occulatata, Cymbidium elegans, Cymbidium iridioides, Cymbidium lancifolium, Cymbidium longifolium, Cymbidium lowanium, Cymbidium mastersii, Cymbidium tigrinum, Dendrobium chrsanthum, Dendrobium chrysotoxum, Dendrobium densiflorum, Dendrobium devonianum, Dendrobium farmer, Dendrobium fimbriatum, Dendrobium formosum, Dendrobium heterocarpum, Dendrobium infundibulum, Dendrobium nobile, Dendrobium orchreatum, Dendrobium primulinum, Dendrobium wadianum, Eria coronaria, Galeola lindleyana, Gastrochilus calceolaris, Hygrochilus parishii, Paphiopedilum hirsutissimum, Papiopedilum insigne, Papiopedilum longicornu, Paplionanthe teres, Phaius flabus, Phaius tankervilliae, Pleione hookeriana, Pleione humilis, Pleione maculate, Pleione praecox, Rananthera imschoodiana, Rhynchhostylis retusa, Spathoglottis plicata, Thunia alba, Thunia marshalliana, Vanda albino, Vanda coerulea, Vanda cristata, Vanda tessellate,* etc. Highly ornamental, rare and endemic orchid species such as of Lady's slipper *Paphiopedilum hirsutissimum, Bulbophyllum rothschildianum* (Red chimney), *Ranenthera imschoodiana* (Dancing lady), *Penkhimia nagalandsis* (New genus reported from Nagaland 2008), *Cymbidium tigrinum, Arachinis cathcartii, Ascocentrum miniatum, Dendrobium wadianum, Galeola lindleyana, Hygrochilus parishii, Thunnia alba, Coelogyne spp.,etc.* are endemic sp. (Kanjilal et al. 1934-40, Nayak and Sastry 1987, 1988, 1990).

b) Rhododendrons: Rhododendrons are evergreen highly ornamental, flowering plants. Total of 18 species have been found grown in the state and which can be grown in the gardens in cooler regions. *Rhododendren macabeanum, R. anthopogon, R. maddenii, R. triflorum,* var. *bauhiniiflorum, R. johnstoneanum, R. arboreum, R. arboreum* subsp. *delavayi, R. campanulatum R. elliotii, R. fulgens, R. hodgsonii, R. thomsonii, R. vaccinoides, R. lepidotum, R. wattii, R. lepidotum.* Among those mentioned above *Rhododendron wattii* and *R. vaccinoides* are new species reported for the first time from Japfu hill ranges and *R. triflorum* var. *bauhiniiflorum* and *R. macabeanum* are rare and endemic and *R.*

johnstoneanum and *R. elliotii* are endangered and endemic. The tallest Rhododendron in the world is reported from the Japfu hills of Nagaland.

c) Hedychiums: Hedychiums are beautiful, fragrant flowering plants of Family Zingiberaceae, which are found growing abundantly all over the state. They are also used as cut flowers due to their aesthetic beauty and fragrance which are also used as room freshener by the local communities. Hedychiums are represented by 16 species- *Hedychium aurantiacum, H. aureum, H. coronarium, H. densiflorum, H. ellipticum, H. elwesii, H.gardnerianum, H. gracile, H. gratum, H. griffithianum, H. hookeri, H. luteum, H. marginatum, H. spicatum, H. stenopetalum, H. villosum.* Some common species like *Hedychium aurantiacum, H. densiflorum, H. ellipticum, H. gardnerianum* and *H. spicatum* are also cultivated as ornamental plants in gardens and pots.

d) Others: Apart from the above well known ornamental groups of plant, there are several other wild species available in these forests which have showy flowers and are easily cultivable. Some of such plants genera can be listed as follows: *Bauhinia, Ensete, Hibiscus, Mussaenda, Prunus, Pyrus, Tacca, Vaccinum* etc.

Wild edible plants

The people of Nagaland live very close to nature and have always been dependant on the rich diversity of locally available edible plant resources. Nagas are generally a traditional community and have intimate knowledge about the uses of the variety of wild plants. The natives mostly depend on the wild edible plants as source of vegetables, fruits, tubers, spices and condiment, etc. The knowledge of uses of wild plants as vegetables, fruits and medicinal are well preserved and practiced by the local communities. Many of these plants are now cultivated in house gardens/homesteads and jhum fields, but most of the wild edible vegetables and fruits are still collected from the wild. Some of the wild common edible vegetables, fruits, shoots, flowers, roots and tubers are sold in local markets and regarded as delicacies by the people. Some of the species can be listed as follows: the flowers/inflorescence of *Bauhinia vareigata, Phlogacanthus thyrsiflorus, Musae spp., Curcuma spp., Crotalaria quadrangularis, Moringa oleifera* are consumed as vegetable. *Clerodendrum colebrookianum, Gnetum gnemon, Huttuynia cordata, Lasia spinosa, Paedera foetida, Polygonum chinensis, Urtica dioica, Zanthoxylum* spp. And etc., are as leafy vegetables. A total of 56 wild edible mushrooms are also consumed as vegetable. Many species of bamboo shoots are also consumed as well as use for fermentation for consumption.

Endemic plants

Nagaland along with other states of North-East India is a major centre of endemism. Chatterjee (1940) observed that about 50% of the endemic taxa of India are confined to North-East (Eastern Himalaya). There are many species which are strictly confined to Nagaland. The geographical position along with climatic condition have created isolated geographical island and the high mountain ranges (Barail and Patkai) along the eastern side and the alluvial plains in the west may act as a barrier for migration of plants.

Some taxa exclusively confined to Nagaland are as follows: *Areca nagansis, Begonia wattii, Bulbophyllum rothschildianum, Capillipedium nagense, C. pteropechys, Chaerophyllum orientalis, Clematis meyeniana, C. Meyeniana var. insularis, Cocculus prainianus, Coelogyne hitendrae, Corydalis borii, Cotoneaster nagensis, Crotolaria meeboldii, Cyclea wattii, Deyeuxia borii, D. nagarum, Hedychium marginatum, Penkhimia nagalandsis, Pholidota imbricate, Pimpinella evgoluta, P. flaccida, Ranenthera imschoodiana, Rhododendron wattii, R. vaccinoides, R. johnstoneanum and R. elliotii, Silene vegans* etc.

Besides many species hitherto reported to be endemic to Assam, Manipur, Meghalaya and Arunachal Pradesh have been observed and collected in Nagaland. Some of these important species are *Antidesma acuminatum, Ardisia paniculata, Artemisia indica, Brassaiopsis mitis, Casearia kurzii, Castanopsis indica, Castanopsis tribuloides, Cinnamomum tamala, Cycas pectinata, Elaeocarpus acuminatus, Erythrina arborescens, Ficus elmeri, Gmelina oblongifolia, Leptodermis griffithii, Leucosceptrum canum, Lithocarpus dealbata, Lithocarpus pachyphylla, Litsea salicifolia, Macaranga Pustulata, Macropanax dispermus, Macropanax undulatum, Magnolia baillonii, michelia oblonga, Musa velutina, Phoebe goalparensis, Phoebe lanceolata, Pinus kesiya, Piper thomsonii, Psychotria monticola, Rhododendron arboretum, Rhus assamensis, Rubus lucens, Schima wallichii* var. *khasiana, Terminalia myriocarpa, Wendlandia grandis* (Hooker 1872-1890, Kanjilal et al. 1934-40, Jain and Sastry 1980, Nayak and Sastry 1987, 1988, 1990).

Endemic Species of Grasses: Nagaland do not have climax grasslands however, many species of grasses are endemic to the State. Endemic species of grasses are *Calamaagrostis nagensis, Andropogon munroi, Arundinaria hirsute, Arundinaria rolloana, Dendrocalamus giganteus, Dendrocalamus patellaris, Dendrocalamus sikkimensis, Dichanthium nagense, Dichanthium pteropechys, Calamaagrostis*

nagarum, Panicum incisum, Pseudostachyum polymorphum, Schizostachyum dullooa, Schizostachyum fuchsianum, Schizostachyum latifolium, Schizostachyum mannii, Schizostachyum pergracile, Sinobambusa elegans, Thamnocalamus prainii, Anthraxon breviaristatus, Coelorhachis striata var. pubescens, Hymenachne assamica, Isachne clarkei (Kanjilal et al. 1934-40, Nayak and Sastry 1987, 1988, 1990).

Needs for conservation

In the traditional agro ecosystems of Nagaland, the natural forest is an indispensable component. The peoples are engaged in agriculture, hunting and selected logging activities in the forests to supplement their needs and to earn cash income for their livelihood. On the other hand, foods and other human needs of plant origin collected in the forests include edible fruits, seeds, flowers, leaves, tubers, mushrooms, bamboo shoots, besides hundreds of medicinal plants, fibers and weaving materials and dying materials are gathered from the natural vegetations. There are varieties of minor forest products which are valuable for home consumption as well as for sale in local markets. On the other hand, as local population pressure increases and market linkages with the outside are introduced, loss of indigenous control over collection of valuable forest products ensues. Combination of the rich indigenous knowledge system and scientific support should be utilized to boost the management of the forests, agriculture, horticulture, soil and water management and etc. This will also should ensure less pressure on forests for longer jhum cycles, conserve forest resources and sound income generation for the rural people.

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Rapid plant diversity assessment in Uttarakhand

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Abstract

Spatial database on the plant diversity is one of the important assets in conservation prioritization. The landscape level rapid plant richness assessment in Uttarakhand, carried out as part of a nationwide plant assessment at landscape level, gives a new perspective in plant diversity assessment in the state. The spatial extent of the forest/vegetation types, forest fragmentation, disturbance and the plant richness worked out in this study gives critical information about the distribution of the species including economic and medicinal species in the state. We found that Uttarakhand has 55% of its area under forests which are relatively less disturbed. These forests harbour various endemic, medicinal, and other economically important plants providing invaluable ecosystem services to the people of Uttarakhand. Proper conservation of the species is the need of the hour. It is expected that spatial database on the plant diversity, created in this study of Uttarakhand will be a crucial input for formulating the conservation and management plan.

Key words: Plant diversity, remote sensing, GIS, forest fragmentation, disturbance.

Introduction

Uttarakhand is among the few states in India that has more than 60% of its geographical area under forest cover (FSI 2011). The topography of the state is undulating with ridges and furrows ranging from 300 to 6000m above m.s.l. This wide variation in the topography has resulted in immense diverse ecosystems supporting large taxonomic variability in flora and fauna. The region also has some of the unique biodiversity heritage areas such as Valley of Flowers. The social fabric of the State, elucidating respect for the forests and the mountains, the region enjoys considerable

social conservation (Negi 2010). In this scenario, the status of the biological diversity especially in the plant diversity needs to be assessed. An effort in this regard has been made at national level by Department of Space and Department of Biotechnology, Govt of India through the multi-institutional project on Biodiversity Characterization at Landscape Level.

Biodiversity per se is not simply the number of genes, species or ecosystems as is normally perceived. Biodiversity encompasses both structural as well as functional aspect of the system (Chapin et al. 2000). Hence it becomes difficult to define biodiversity which is responsive to the real life management and regulatory questions. So for any operational purpose, "Characterization of Biodiversity" that identifies the major components at several levels of organization is more useful (Noss 1990). Biodiversity plays an important role in maintaining the structure and functioning of the mountain ecosystems, especially in Uttarakhand. The innumerable ecosystem services provided by the natural landscape in the state are to some extent dependent on the biological diversity of the region. In this scenario identification of the biological rich areas and their spatial extent is critical to formulation of the conservation and prioritization of the biodiversity in the state.

Landscape comprises the visible features of an area of land including the physical and human elements. Landscape ecology deals with the spatial distribution of the different ecosystems, their dynamism over time and space and their interaction (Turner et al. 2001). The shaping of a landscape is influenced by the dynamic landscape mosaics, bio-complexity, adaptive cycles, resilience and threshold. In the present study we have characterised the status of the biological diversity of Uttarakhand at landscape level with respect to the plant diversity. Since the phyto-diversity provides the habitat of the fauna, so in a sense the phyto-diversity can be considered as a surrogate for the biodiversity in a region if we are considering the landscape as a unit.

Study area

The study was conducted in Uttarakhand province. The region lies between 28°43' N to 31°27' N latitude and 77°34' E to 81°02' E longitude. Uttarakhand has a total area of 51, 125 km², of which 93% is mountainous and 64% is covered by forest. Uttarakhand is surrounded by Nepal in the East, China in the North, Himachal Pradesh in the west and Uttar Pradesh in the South. Uttarakhand province has a very loafty Mountains and rugged terrain with the altitude range between 300-6000 m above m.s.l. The average rainfall of the province is 1523mm. Mostly, the higher peaks of the province

is covered by snow and glaciers, while foothills are covered by deciduous forest.

The climate and vegetation vary with elevation, for example, highest elevations are covered with permanent snow and the lower elevations with deciduous forest. Broadly the Uttarakhand is divided into five major forest/vegetation types *viz*., above 4500m the Uttarakhand province is covered by ice, glaciers and permanent rock. The western Himalayan alpine shrub and meadows lies between 3000 and 4500m. The temperate western Himalayan subalpine conifer forests ranges between 2,600 to 3,000m and form a tree line. Below 2600 to 1500m the temperate western Himalayan broadleaf forests occur. The Himalayan sub-tropical pine forests lie between 900-1500m. The lower Himalayas or Upper Gangetic plains are covered by dry and moist deciduous forests. Dry Terai-Duar savanna and grasslands cover the lowlands along the Uttar Pradesh which are also called as Bhabhar.

Materials and Methods

Data

Cloud free IRS P-6 satellite data for wet (Oct-Dec) and dry (Feb-April) seasons of 2005-06 were used for vegetation type mapping. Topographic maps and management/stock maps were also used as ancillary data.

Vegetation type mapping

Digital interpretation was used for Forest/vegetation type mapping. Forest/vegetation types were classified according to their separability on the satellite imagery along with information on climate and topography. This facilitated interpretation, delineation and mapping of classes, climatic and physiognomy based forest type classification that broadly fits into the existing Champion and Seth's Classification scheme (Champion and Seth 1968). Where ever necessary field knowledge have been used to delineate the local specific types of ecological significance.

Forest/vegetation sampling

Probability proportionate sampling (PPS) procedure was adopted for forest/vegetation sampling. A total of 425 sample plots of 20m x 20m size were laid for this purpose. Within each sample plot the trees were enumerated. A plot size of 5m x 5m and four quadrat of 1m x 1m were laid within the 20 m x 20m plot for enumeration of shrubs and herbs respectively.

Landscape Modeling

Fragmentation

Fragmentation has been computed as a function of forest and non-forest units in a unit area. This was executed by using a moving window of a user grid of n (n=500m in this case) which is convolved with the spatial layer with a criterion of delivering the number of forest patches within the grid cell. The iteration is repeated by moving the grid cell through the entire spatial layer. An output layer with patch number in the 500 m grid is derived and a lookup table (LUT) is generated to normalize the data in the range from 0-10 (Roy et al. 2012).

$$Frag = f(n_F, n_{NF}) \quad \text{(Eq. 1)}$$

where *Frag* = fragmentation; *n* = number of patches; *F* = forest patches; *NF* = non-forest patches.

A *patch* is been defined as a non-linear surface area differing in appearance from its surroundings (Forman and Godron 1986).

Disturbance Index

Disturbance is a manifestation of the impact of anthropogenic activities and natural disturbance on the landscape change. The disturbance is manifested in the spatial extent and distribution of the vegetation cover as well as species composition. In this model for generation of disturbance surface, as a first step, Cumulative landscape metric surface is prepared as a combination of different landscape metrics *viz.*, fragmentation, Juxtaposition, Interspersion, Patchiness, Porosity, Fractal Dimension, contagion etc. In the next step biodiversity driver surface, which reflect the spatial distribution of the anthropogenic/natural forces on the landscape is prepared using disturbance generating factors *viz.*, proximity to roads, villages, fire intensity, mines and disturbance indicator parameters (diversity, invasive species, regeneration potential etc.) using ground based sampling data. Using these two surfaces, we run the model to generate the disturbance surface. A user grid cell of n×n (e.g. n=500 m) is convolved with the spatial data layer with a criterion of deriving a specific landscape metric value within the grid cell. The iteration is repeated by moving the grid cell through the entire spatial layer. An output layer with the specific landscape metric value of a parameter is derived and associated to this a look- up table (LUT) is generated which keeps the normalized data of the landscape metric values per cell in the range of 0 to 10 (Roy et al. 2012).

$$DI = \sum_{i=1}^{n}\left(Frag_i \times Wt_{i1} + Por_{ji} \times Wt_{i2} + Int_i \times Wt_{i3} + Pat_i \times Wt_{i4} + Jux_i \times Wt_{i5}\right) \quad \text{(Eq. 2)}$$

where DI = Disturbance Index; *Frag* = fragmentation, *Por* = porosity; *Int* = interspersion; *Pat*= patchiness, *Jux* = juxtaposition; *Wt* = weights.

The final spatial data were rescaled to a range of 0-100 for the preparing the final map.

Biological richness surface

Biological richness surface is generated from a combination of the outputs of the different sub-models in an iterative process calculated cell by cell across the spatial domain of the model extent. The spatial layers involved in preparation of biological rich regions are – i) Disturbance, ii) Terrain and the non-spatial layers are i) Ecosystem uniqueness, ii) Species richness and iii) Biodiversity value. The gradients of disturbance identified are weighted with ecosystem uniqueness, species diversity and biodiversity value, terrain complexity to identify biologically rich regions. Terrain complexity was calculated based on slope or elevation variance in a given cell of defined size. Ecosystem uniqueness of given forest type is weighted based on number of endemic species, protected areas and composition of IUCN category of species (Roy et al. 2012).

$$BR = \sum_{i=1}^{n}\left(DI_i \times Wt_{i1} + TC_{ji} \times Wt_{i2} + SR_i \times Wt_{i3} + BV_i \times Wt_{i4} + EU_i \times Wt_{i5}\right) \quad \text{(Eq. 2.3)}$$

where *BR* = biological richness, *DI* = Disturbance Index, TR= terrain complexity, *SR* = species richness, *BV* = biodiversity value, *EU* = ecosystem uniqueness, and *Wt* = weights.

Results and Discussion

Vegetation Type

Uttarakhand is rich in forest cover and has around 55% of the area is under natural vegetation (Fig. 1). Of the 55% of the total geographic area, 16.75% is under mixed natural formations most dominated by Himalayan moist temperate forest followed by sal mixed moist deciduous, temperate conifer and dry deciduous forest (Table 1). The other prominent vegetation types found in the region are sub-alpine, and pine mixed temperate forest. Among the gregarious formations, Pine forest dominates in the state with about 11.26% of the TGA followed by sal (3.22%) and oak (2.54%). Around 2.27% is degraded forests. Among the grasslands, the moist alpine pasture has a considerable cover constituting around 4.82%, followed by Wet grasslands (3.31%).

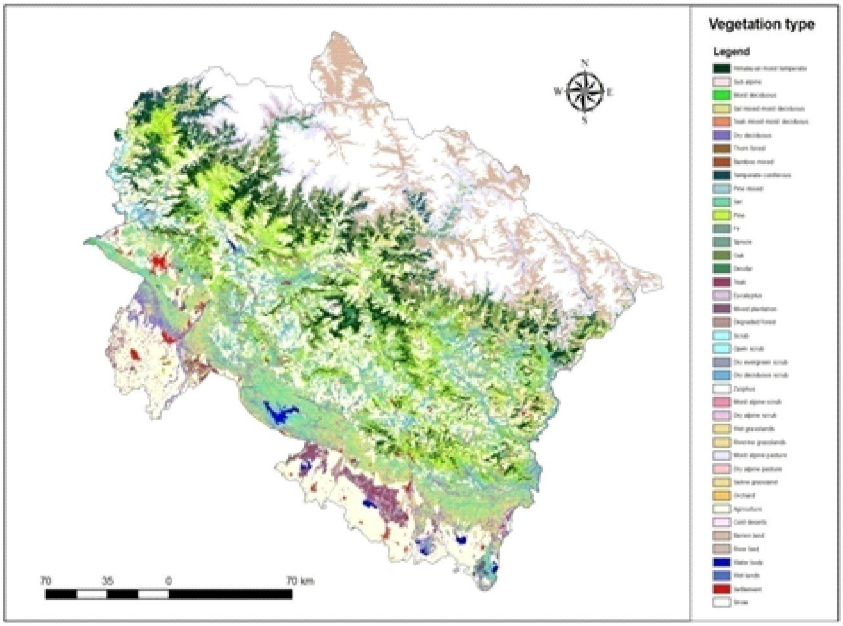

Fig. 1. Vegetation types.

Table 1. Area under different forest/vegetation type and land use in Uttarakhand

Vegetation type	Area (km^2)	% of TGA
Mixed Natural formations		
Himalayan moist temperate	3469.49	6.79
Sub alpine	835.32	1.63
Moist deciduous	6.00	0.01
Sal mixed moist deciduous	2265.33	4.43
Teak mixed moist deciduous	0.03	0.00
Dry deciduous	843.31	1.65
Bamboo mixed	0.03	0.00
Temperate coniferous	1142.96	2.24
Pine mixed	2.58	0.01
Total	8565.04	16.75
Gregarious formations		
Sal	1648.59	3.22
Pine	5756.49	11.26

Fir	101.66	0.20
Oak	1300.93	2.54
Deodar	363.82	0.71
Teak	158.77	0.31
Eucalyptus	97.10	0.19
Total	9427.37	18.44
Forest Plantation		
Mixed plantation	609.91	1.19
Total	609.91	1.19
Degraded Formations		
Degraded forest	1161.96	2.27
Total	1161.96	2.27
Scub/Shrubland		
Scrub	60.93	0.12
Open scrub	0.02	0.00
Dry evergreen scrub	200.97	0.39
Dry deciduous scrub	3444.44	6.74
Ziziphus	71.65	0.14
Dry alpine scrub	99.56	0.19
Total	3877.57	7.58
Grassland		
Wet grasslands	1690.38	3.31
Riverine grasslands	316.04	0.62
Moist alpine pasture	2466.03	4.82
Dry alpine pasture	6.35	0.01
Total	4478.81	8.76
Manmade Ecosystems		
Orchard	0.18	0.00
Agriculture	11084.94	21.68
Other land cover classes		
Barren land	3310.48	6.48

River bed	607.87	1.19
Water body	489.35	0.96
Settlement	300.08	0.59
Snow	7211.46	14.11
Total	23004.35	45.00
Grand Total	51125.00	100.00

Fragmentation

Analysis of the vegetation fragmentation in the state shows that most of the forest areas are relatively intact which accounts for 62.8% of the forested areas (Table 2). Furthermore the low fragmentation areas in the state accounts for 28.67% of the forest area. This is really commendable and reflects the fact that the forests of Uttarakhand are relatively protected against degradation. Only 4.45% and 4.08% of the forest are under moderate and high fragmentation in the state. A fragmentation map of Uttarakhand is given as figure 2. The forest type which has most of the areas relatively intact is the Pine forests followed by the Himalayan moist temperate forests (Table 2). The presence of such vast tracts of intact forests has a lot of opportunities for conservation and prioritization (Potapov et al. 2008).

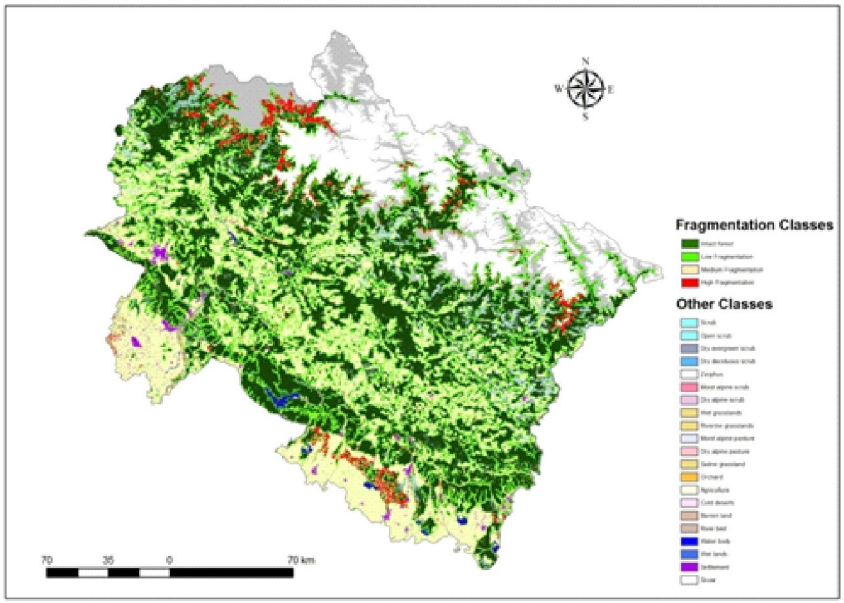

Fig. 2. Forest Fragmentation.

Table 2. Fragmentation in different vegetation type (values in % of Total forest area)

Vegetation type	Intact	Low	Medium	High
Himalayan moist temperate	13.02	3.98	0.36	0.03
Sub alpine	1.57	0.87	0.36	1.38
Moist deciduous	0.03	0.00	0.00	0.00
Sal mixed moist deciduous	7.60	3.47	0.46	0.11
Dry deciduous	2.23	1.25	0.19	0.05
Temperate coniferous	3.77	1.17	0.25	0.35
Pine mixed	0.01	0.00	0.00	0.00
Sal	6.00	2.01	0.28	0.05
Pine	17.26	10.72	1.22	0.16
Fir	0.37	0.09	0.03	0.06
Oak	5.17	1.19	0.24	0.40
Deodar	1.14	0.44	0.11	0.15
Teak	0.31	0.20	0.09	0.15
Eucalyptus	0.12	0.13	0.08	0.16
Mixed plantation	0.87	0.87	0.40	0.89
Degraded forest	3.34	2.27	0.38	0.15
Total	62.80	28.67	4.45	4.08

Disturbance Index

The level of disturbance in the region is quite high with around 64% of the natural area under medium and high disturbance (Fig 3). A considerable portion of the natural landscape is under very high disturbance (Table 3). The disturbance is very high in the Pine and sub-alpine forest as they are prone to exploitation during the harsh winter in the high elevation of the state. Studies reveal that most of the natural ecosystems which occur in relatively accessible terrain like Pine, Sal mixed moist deciduous, Himalayan moist temperate, Oak, Plantation and Sal have high disturbance (Fraterrigo and Rusak 2008).

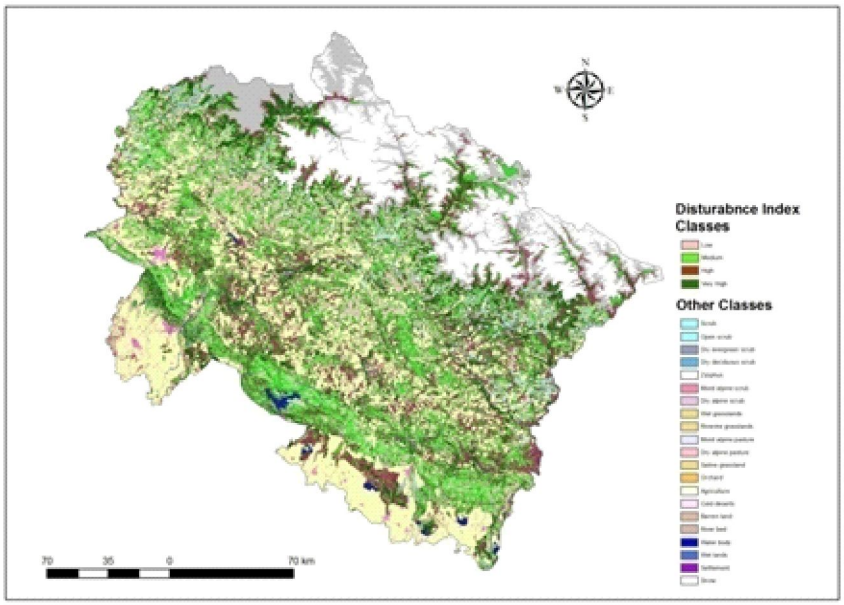

Fig. 3. Disturbance regimes.

Table 3. Disturbance regimes in different vegetation types (% of total forest area)

Vegetation type	Low	Medium	High	Very high
Himalayan moist temperate	5.06	5.84	2.89	0.90
Sub alpine	0.38	0.71	0.89	1.55
Moist deciduous	0.01	0.01	0.00	0.00
Sal mixed moist deciduous	2.46	4.23	2.09	1.06
Dry deciduous	0.36	0.88	1.02	0.88
Temperate coniferous	1.47	1.56	0.92	0.72
Pine mixed	0.00	0.00	0.00	0.00
Sal	2.02	3.19	1.26	0.59
Pine	4.36	9.58	7.63	3.24
Fir	0.15	0.14	0.09	0.08
Oak	1.97	1.95	1.08	0.90
Deodar	0.53	0.58	0.28	0.17
Teak	0.00	0.01	0.36	0.25
Eucalyptus	0.00	0.01	0.23	0.17

Mixed plantation	0.00	0.20	1.57	0.78
Degraded forest	0.01	0.51	3.43	1.25
Scrub	0.00	0.08	0.16	0.02
Dry evergreen scrub	0.00	0.10	0.56	0.15
Dry deciduous scrub	0.09	1.17	8.35	4.16
Ziziphus	0.00	0.07	0.20	0.03
Dry alpine scrub	0.00	0.00	0.07	0.31
Total	18.86	30.82	33.08	17.23

Biological Richness

The Biological Richness in the region (Fig 4) is quite high with around 68% of the natural area under high and very high Biological Richness (BR) (Table 4). The Biological Richness is very high in the temperate conifer and the sub-alpine forest as they have unique vegetation of high altitude ecosystems and also contain many medicinal and economic important plants. Studies reveal that most of the natural ecosystems are relatively high disturbance which include gregarious pine forests, Himalayan moist temperate, Sal mixed moist deciduous forest, Oak and

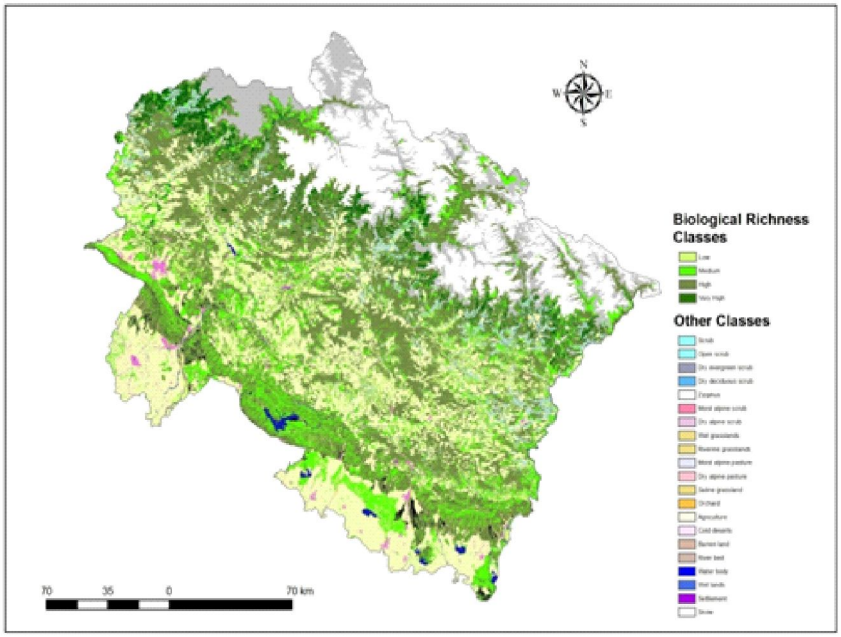

Fig. 4. Biological richness.

deodar to name a few. In-fact around 97% of the Himalayan moist temperate and 88% of the gregarious pine forest, the two dominant forests in the region have considerable area under high biological richness. The high biological richness in the region in spite of the considerable disturbance in the region can be attributed to the sustainable use of the forest resources by the local population (Negi 2010). Furthermore the intermediate disturbance hypothesis (Connell 1978) also suggests that moderate level of disturbance leads to higher species richness.

Table 4. Plant biological richness in different vegetation types (% of total forest area)

Vegetation type	Low	Medium	High	Very high
Himalayan moist temperate	0.07	0.07	14.28	0.27
Sub alpine	0.06	0.30	1.02	2.15
Moist deciduous	0.00	0.00	0.03	0.00
Sal mixed moist deciduous	0.03	1.03	8.77	0.00
Dry deciduous	0.02	0.21	2.91	0.00
Temperate coniferous	0.02	0.04	0.96	3.66
Pine mixed	0.00	0.00	0.01	0.00
Sal	0.02	5.67	1.36	0.00
Pine	1.77	1.07	21.85	0.11
Fir	0.00	0.00	0.45	0.01
Oak	0.04	0.07	5.29	0.50
Deodar	0.01	0.01	1.50	0.03
Teak	0.05	0.55	0.03	0.00
Eucalyptus	0.35	0.05	0.01	0.00
Mixed plantation	0.06	2.43	0.06	0.01
Degraded forest	0.10	4.90	0.18	0.01
Scrub	0.00	0.26	0.00	0.00
Dry evergreen scrub	0.01	0.78	0.02	0.00
Dry deciduous scrub	8.29	3.23	2.21	0.04
Ziziphus	0.29	0.00	0.00	0.00
Dry alpine scrub	0.00	0.24	0.11	0.03
Total	11.19	20.93	61.05	6.83

Phytosociological observation:

A total of 287 unique species have been recorded during the field sampling in Uttarakhand, of which 123 species were herbs, 90 shrubs, and 74 trees. During field sampling, sapling and seedling of 70 tree species were observed indicating that the regeneration potential of the tree species in Uttarakhand was good. The highest number of herb species was observed in the pine forests followed by Himalayan moist temperate forests. The highest number of shrub species was observed in the gregarious sal forests followed by sal mixed moist deciduous and pine forests. The highest number of tree species was observed in the pine forests followed by sal mixed moist deciduous and Himalayan moist temperate forests (Table 5)

Table 5. Number of species sampled in each vegetation type

Vegetation Type	Herbs	Shrubs	Trees	Seedling/ sapling
Himalayan moist temperate	81	34	33	34
Sub alpine	5	1	2	2
Sal mixed moist deciduous	45	37	35	31
Dry deciduous	8	14	16	11
Temperate coniferous	6	2	3	4
Sal	37	42	26	27
Pine	97	35	42	38
Deodar	16	9	12	9
Teak	4	2	3	1
Mixed plantation	6	7	11	11
Degraded forest	35	11	14	11
Dry evergreen scrub	3	2	3	3
Dry deciduous scrub	62	17	21	16
Wet grasslands	18	4	5	4
Riverine grasslands	16	7	17	14

Conclusions

It is observed that Uttarakhand is rich in natural resources and has considerable area under natural vegetation. The region has varied vegetation

types ranging from moist deciduous forests to alpine meadows harbouring rich floral diversity. Although there is considerable disturbance both anthropogenic as well as natural/topography and climate induced, the state has considerable biologically rich areas. The state boasts of some of the most unique natural ecosystems in the world such as Valley of Flowers which are important natural heritage sites (UNESCO 2013). But the increasing anthropogenic pressures associated with the climate change are leading to the degradation of the natural ecosystems in the region. This is expected to affect the ecosystem goods and services necessary for the sustenance of the local population. For effective conservation of the natural ecosystems in Uttarakhand, it is necessary that the spatial locations of the biological rich areas identified are prioritised for the conservation measures. The study will help in effective management and planning of conservation measures.

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Changes in Liana diversity over a decade in Indian tropical dry evergreen forests

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Abstract

Lianas or woody climbers contribute considerably to biodiversity, leaf production and biomass of tropical forests. Lianas persist in mature tropical forests with little structural disturbance and their abundances have increased in recent years, possibly due to increase in atmospheric CO_2. Further, with increase in global temperatures due to climate change, it has been anticipated that the growth rates of lianas, may increase further. The present study was conducted to investigate the changes in liana species richness and abundance in two Indian tropical dry evergreen forest sites. Two 1-hectare permanent plots, one each at Oorani (OR) and Puthupet (PP), established a decade ago, were re-inventoried for liana diversity in December 2011. All rooted lianas $\geq$ 1cm diameter were measured at 1.3m from the rooting point. A total of 2199 liana individuals representing 32 species, 27 genera, and 22 families were inventoried in the present study. Over a decade (2001–2011) liana species richness decreased as a whole but there was an overall increase in liana abundance and basal area in both the sites. The increase was greater in small diameter lianas. Evidently, with increasing human disturbance, there is an increase in liana abundance, which is in agreement with results of other studies.

Key Words: Decadal changes, Forest disturbance, Liana diversity, Species density, Tropical dry evergreen forest.

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Introduction

Lianas are an important component of most tropical forests, comprising 10–45% of the woody species, and typically reaching peak abundance in highly seasonal forests (Gentry 1991, Schnitzer 2005, DeWalt et al. 2010). Lianas play an important role at the ecosystem level by contributing to the carbon budget of tropical forests, as they represent 10% of fresh aboveground biomass (Putz1984). Lianas are reported to play a vital role in many aspects of forest dynamics, including suppressing tree regeneration, increasing tree mortality, providing a food source for animals and physically linking trees together, thereby providing canopy-to-canopy access for arboreal animals (Putz and Mooney 1991, Gentry et al. 1983, Schnitzer and Bongers 2002).

Liana abundance varies with several key abiotic factors, including total rainfall, seasonality of rainfall, soil fertility and disturbance (Schnitzer and Bongers 2002). Liana abundance, diversity and biomass have been shown to be significantly higher in disturbed areas than in undisturbed areas (Schnitzer and Carson 2001, 2010, Schnitzer et al. 2004). In addition, liana basal area was reported to have increased rapidly following forest disturbance (Allen et al. 2007, Rutishauser 2011). The leading hypotheses to explain liana increases include increasing forest disturbance, increasing duration and severity of seasonal drought, and elevated atmospheric $CO_{2,}$ all of which may be operating simultaneously and synergistically (Schnitzer and Bongers 2011). Increasing forest disturbance would favor lianas relative to trees by creating more edge and gap habitat, where lianas proliferate (Putz 1984, Schnitzer et al. 2000, Schnitzer and Carson 2010). Stronger seasonal drought may benefit lianas because they suffer less water stress and grow more than trees during dry periods (Schnitzer 2005, Cai et al. 2009), presumably increasing their fecundity, abundance, and biomass relative to trees. Stronger seasonal drought has been linked to decreases in tree density and increases in liana density in both tropical dry and moist forests (Ingwell et al. 2010), as well as decreases in tree growth in tropical wet forests (Clark et al. 2010).

The tropical dry evergreen forests are found on the eastern Coromandel Coast of India (Parthasarathy and Sethi 1997), extending inland about 50km (Mani and Parthasarathy 2005) and in northeastern Sri Lanka (Blasco and Legris 1973, Perera 1975, Dittus 1985), northeastern Thailand (Bunyavejchewin1999), southwest China (Liu et al. 2002), and the south coast of Jamaica (Loveless and Asprey 1957, Kelly et al. 1988) and Bahamas (Smith and Vankat 1992). The remnant patches of Indian tropical dry

evergreen forests are mostly the sacred groves or temple forests, which vary in their areal extent from 0.5 ha to about 30 ha. Sacred groves are patches of natural climax forests preserved on the basis of religious belief of the local people (Parthasarathy and Sethi 1997).

Quantitative floristic inventories provide a context for planning and interpreting long-term ecological research (Phillips et al. 2002), supplying information on the species, communities, and ecosystem structure (Venkateswaran and Parthasarathy 2003). Continuous monitoring of forest stand on a long-term basis is needed to document vegetation dynamics satisfactorily (Proctor et al. 1983, Swaine et al. 1987, Sukumar et al. 1992, 1998). Although the study of lianas has increased dramatically in recent years (Gentry 1992, Phillips and Gentry 1994, DeWalt et al. 2000, Schnitzer et al. 2000, Laurance et al. 2001, Nabe-Nielsen 2001, Perez-Salicrup et al. 2001, Schnitzer and Carson 2001, Schnitzer and Bongers 2002), a recensus of inventoried sites for lianas has not been carried out on the Coromandel Coast of peninsular India. Hence, considering the significant role lianas play in tropical forest functional ecology, the present study was undertaken with an aim to investigate decadal changes (2001-2011) in liana species richness and abundance in two Indian tropical dry evergreen forests on the Coromandel Coast, India, in the face of increased forest disturbance over the decade.

Materials and Methods

Study sites

The present liana re-inventory was conducted in two tropical dry evergreen forest (TDEF) sites: Oorani (OR: lat. 12° 11' N and long. 79° 5' E) and Puthupet (PP: lat. 12° 4' N and long. 79° 53' E) on the Coromandel Coast of peninsular India (Figure 1). OR and PP are located 15 km and 28 km north of Puducherry town, respectively. Both sites are sacred groves. OR houses a temple of Goddess Selliamman, and PP houses God Ayyannar temple. OR is ~ 200m from human habitation, while site PP is closer to human habitation. Both sites are subjected to anthropogenic disturbance such as site encroachment, impact from temple visitors, and resource removal.

The vegetation of the study sites is described as tropical dry evergreen forest (type 7/CI of Champion and Seth 1968, Parthasarathy et al. 2008, Venkateswaran and Parthasarathy 2003). OR covers an area of about 1.5 ha. and PP covers about 5 ha. The forests are 8m tall on an average. A tropical dissymmetrical climate prevails in the study sites, with

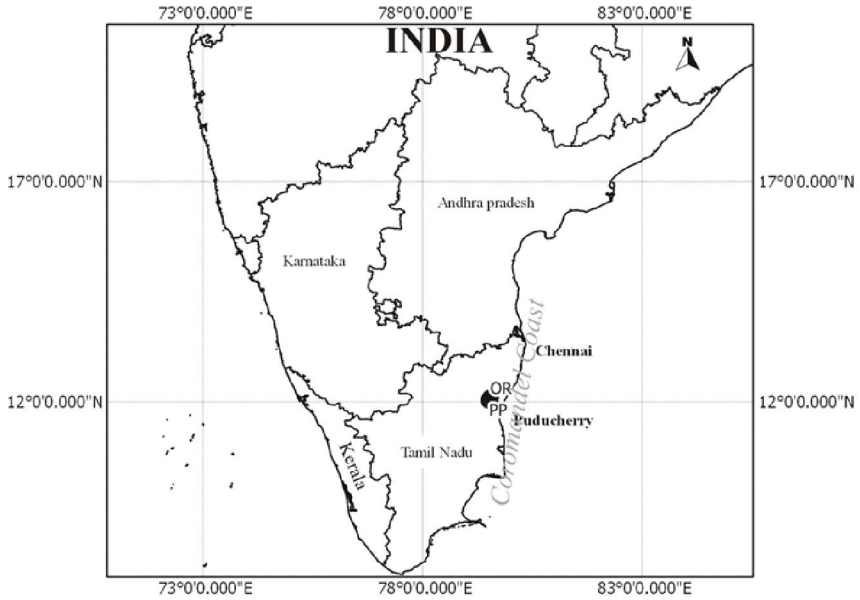

Fig. 1 Map indicating the location of two study sites Oorani (OR) and Puthupet (PP) on the Coromandel Coast of peninsular India.

most rainfall received during the north-west monsoon, and some quantity during the south-west monsoon. The amount of rainfall varies due to the atmospheric depression in the Bay of Bengal. Another source of moisture, from October to March, is dew (Parthasarathy and Karthikeyan 1997).

Climate data for the sites, available for twenty years (1990–2010) from the nearest station, in Puducherry reveal a mean annual temperature of 29.5°C and mean annual rainfall of 1,141 mm in during a mean number of 55.5 rainy days. The mean monthly temperature ranges from 25°C to 34°C for the same period (Anbarashan and Parthasarathy 2013). Soils of site OR are a granular coastal sandy soil with little humus content, contrasting with alluvial soils of PP, probably overlying the Miocene Cuddalore sandstone formation, and are sandy in texture with greater humus and moisture content (Parthasarathy and Sethi 1997). Human disturbance increased in both study sites over the decade. In OR, the frequency of people visitation has increased leading to new road construction and wood removal. In PP, the frequency of people visitation has increased and portions of forest cleared for vehicle parking, cooking and recreation activities. Comparison of forest disturbance in the two sites over the decade revealed that PP is subjected to greater disturbance than OR (Table 1).

Liana census

Two 1-hectare permanent plots, one each at OR and PP, established a decade ago (Reddy and Parthasarathy 2003), were re-inventoried for liana diversity in December 2011. At OR two 200 m × 25 m transects located one on either side of the centrally dividing mud road was marked and sub-divided into forty 10 m × 10 m and twenty 5 m × 10 m quadrats in each sub-plot. At PP one plot of 50 m × 200 m dimension was marked and sub-divided into one-hundred 10 m × 10 m quadrats and re-inventoried. All lianas $\geq$ 1cm diameter and rooted in the plots were measured at 1.3m from the rooting point. Plant specimens were identified using regional floras (Gamble and Fischer 1915–1935, Matthew 1991), confirmed with collections deposited in the Department of Ecology and Environmental Sciences, Pondicherry University. Decadal changes in liana species richness and density were calculated by comparing the 2011 and 2001 censuses. Liana species richness was determined by noting the number of species in each plot. The Shannon-Wiener index (H'), Simpson index (D) and Fisher's α diversity were computed by Magurran (2004). The Wilcoxon signed rank test was performed to check for any significant change in liana stem density between two inventories. Chi-square test was carried out (SPSS ver. 8.5) to determine any significant change in liana stem density by different climbing modes. According to Putz (1984) lianas were classified into stem twiners, scrambler-armed, scrambler-unarmed, hook climber, root climber, and tendril climber. Fruit types of liana species were categorised based on regional flora and from the field observations. The disturbance scores were derived based on the intensity of human activities on both sites and qualitatively assessed, ranking from "0" score for none to "4" score for very high disturbance (Table 1).

Table 1 Various forest disturbance operative in two tropical dry evergreen forest sites (Oorani and Puthupet) on the Coromandel Coast of peninsular India

Study site attributes	Study site			
	OR		PP	
	2001	2011	2001	2011
Site encroachment (land use within the forest)				
Construction of temple structure	1	1	1	3
Forest clearance for shops	0	0	1	2
Bridle path	1	2	2	4
Temple visitors' impact: area used for				

Vehicle parking	0	1	2	4
Cooking inside the forest	0	0	2	4
Festive occasion use - get-together, recreation etc.	0	1	2	4
Waste dump (plastic, polythene, rexin, glass etc.)	0	0	2	4
Grazing (cattle/goat)	0	0	1	1
Cultural attachment of people (those resulting in negative impacts)	1	2	2	4
Resource removal				
"Stem cut" for firewood	1	2	2	3
Soil removal	0	1	1	2
Others: Collection of medicinal plants, edible fruits, etc.	1	2	2	2
Total score	**5**	**12**	**20**	**37**

Results

Changes in liana species richness and density

The liana flora community in 2011 in OR and PP combined, inventoried a decade later in tropical dry evergreen forest (TDEF) sites of peninsular India, yielded 2199 individuals, consisting of 32 species in 27 genera and 22 families (Table 2 and 3). Capparaceae constituted the most speciose family in our study sites (Table 2). At OR a net total of four species were lost, while one species was added at PP, in decadal interval. Over a decade two genera and one family were lost at OR, whereas one genus and one family were lost in PP. Overall, 552 liana stems (33%) has increased in both sites in ten-year interval; OR has minimal (55%) and PP very minimal (13%) increment of stem density (Table 2). The Wilcoxon signed rank test reveals that site OR shows a negative mean rank (7) which is less than the positive mean rank (16), suggesting that the liana stem density is much greater in 2011 than 2001 ($P = 0.017 \leq 0.05$). But in site PP the negative mean rank (18) is more than the positive mean rank (16), suggesting that the liana stem density has not increased much between the two periods ($P = 0.758 \geq 0.05$). Altogether, the increase in basal area over a decade in the two sites was 65.8%. At OR site, basal area increased about two fold, while there was a one-and-a-half fold increase at PP. At OR the Simpson index increased over the decade, whereas the Shannon-Wiener and Fisher's α values decreased; while at PP Shannon-Wiener index decreased and the Simpson and Fisher's α indices increased (Table 2).

Table 2 Decadal changes (2001-2011) in liana diversity of two tropical dry evergreen forest sites (Oorani and Puthupet) on the Coromandel Coast of peninsular India

Variable	Study site					
	Oorani		Changes	Puthupet		Changes
	2001	2011		2001	2011	
Number of species	24	20	-4	28	29	1
Number of genera	20	18	-2	25	24	-1
Number of family	18	17	-1	22	20	-2
Stem density	812	1259	447	835	940	105
Basal area ($m^2 ha^{-1}$)	1.85	3.31	1.46	0.99	1.4	0.41
Diversity indices:						
Shannon (H')	2.34	2.07	-0.27	2.69	2.47	-0.22
Simpson (D)	0.127	0.194	0.067	0.099	0.145	0.046
Fisher's α	4.642	3.376	-1.266	5.584	5.667	0.083

Rarefaction curves

Rarefaction curves show the original inventory and re-inventory curves of two tropical dry evergreen forest did not reach an asymptote, except the recent inventory on site Oorani at a point of 1259 individuals (Figure 2). The species richness reached maximum of 28.97 species at Puthupet in 2011, followed by Puthupet-2001 (27.99 species), Oorani-2001 (24 species) and Oorani-2011 (20 species).

Changes in species density of lianas

Over the decade the species density of many lianas changed considerably; it ranged from an increase of 320 stems for the predominant species *Strychnos lenticellata* at OR to a loss of 45 stems for *Gymnema sylvestre* at PP (Table 3). At OR the density gain was greatest for *Strychnos lenticellata*, *Combretum albidum* (+36 stems) and *Grewia rhamnifolia* (+21 stems), while stem density decreased for *Carissa spinarum* (-8 stems), *Asparagus racemosus* (-7 stems) and *Cissus vitiginea* (-6 stems). For 13 species (65%) the density addition ranged from one to 20 stems, for three species (15%) the loss was one to five stems and for one species (*Cansjera rheedii*) the net change was none (Table 3). At PP the stem density increase was high for *Strychnos lenticellata* (+143 stems), followed by *Ichnocarpus frutescens* (+48 stems), *Jasminum angustifolium* (+32 stems) and *Pachygone ovata* (+22 stems). For 11 species (31%) the density addition

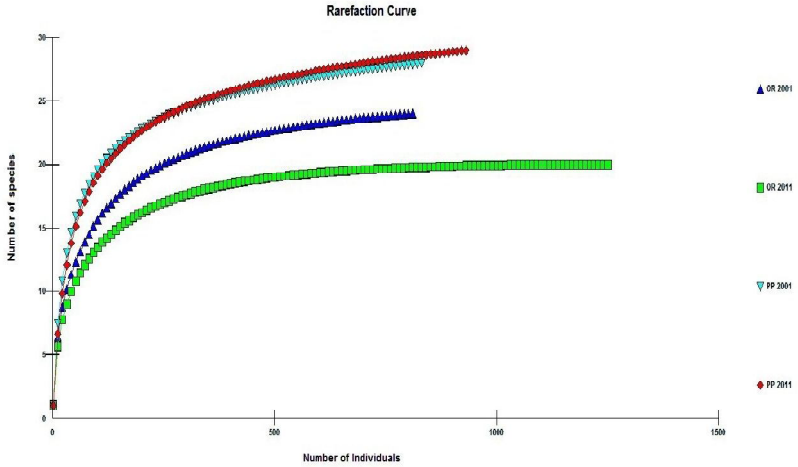

Fig. 2 Rarefaction curve of species and abundance changes at two study sites OR and PP on the Coromandel Coast of peninsular India.

ranged from one to 20 stems; while for 18 species (51%) there was a loss of one to 45 stems, and there was no net change for *Ziziphus oenoplia*.

Table 3 Decadal changes in species density of lianas along with details on family and climber type in Oorani and Puthupet sites on the Coromandel Coast of India

Sl. no.	Species and Family	CM*	Density in Oorani		Net change	Density in Puthupet		Net change
			2001	2011		2001	2011	
1	*Aristolochia indica* L. (Aristolochiaceae)	ST	0	0	-	0	1	+1
2	*Abrus precatorius* L. (Papilionaceae)	ST	0	0	0	7	0	-7
3	*Acacia caesia* (L) Willd. (Mimosaceae)	Scr-A	1	3	+2	11	12	+1
4	*Adenia wightiana* (Wall.ex Wight and Arn.) Engler (Passifloraceae)	TC	0	0	-	0	9	+9
5	*Asparagus racemosus* Willd. (Liliaceae)	Scr-A	7	0	-7	2	3	+1
6	*Cansjera rheedii* Gmel. (Opiliaceae)	Scr-A	7	7	0	4	8	+4
7	*Capparis brevispina* DC. (Capparaceae)	Scr -A	7	21	+14	46	31	-15

8	*Capparis rotundifolia* Rottl. (Capparaceae)	Scr-A	25	30	+5	0	1	+1
9	*Capparis sepiaria* L. (Capparaceae)	Scr-A	1	0	-1	10	2	-8
10	*Capparis zeylanica* L. (Capparaceae)	Scr-A	4	8	+4	18	8	-10
11	*Carissa spinarum* L. (Apocynaceae)	Scr-A	11	3	-8	65	46	-19
12	*Cayratia pedata* (Lam.) Juss. ex Gagnep. (Vitaceae)	TC	7	8	+1	0	0	-
13	*Cissus quadrangularis* L. (Vitaceae)	TC	2	0	-2	19	0	-19
14	*Cissus vitiginea* L. (Vitaceae)	TC	6	0	-6	5	2	-3
15	*Coccinia grandis* (L.) Voigt (Cucurbitaceae)	TC	2	4	+2	12	6	-6
16	*Combretum albidum* G. Don (Combretaceae)	ST	125	161	+36	20	31	+11
17	*Derris ovalifolia* (Wight and Arn.) Benth. (Papilionaceae)	ST	113	131	+18	1	0	-1
18	*Grewia disperma* Rottl. (Tiliaceae)	Scr-UA	0	0	-	0	20	20
19	*Grewia rhamnifolia* Heyne ex Roth (Tiliaceae)	Scr-UA	47	68	+21	72	36	-36
20	*Gymnema sylvestre* (Retz.) R. Br. ex Schultes (Asclepiadaceae)	ST	0	0	-	73	28	-45
21	*Hugonia mystax* L. (Linaceae)	HC	22	30	+8	57	41	-16
22	*Ichnocarpus frutescens* (L.) R.Br. (Apocynaceae)	ST	0	0	-	0	48	+48
23	*Jasminum angustifolium* (L.) Willd. (Oleaceae)	ST	81	98	+17	130	162	+32
24	*Jasminum auriculatum* Vahl (Oleaceae)	ST	0	0	-	0	2	+2
25	*Olax scandens* Roxb. (Oleacaceae)	Scr-UA	0	0	-	5	6	+1
26	*Pachygone ovata* (Poir.) Miers ex Hook. (Menispermaceae)	ST	6	11	+5	24	46	+22

27	*Plecospermum spinosum* Trecul (Moraceae)	Scr-A	3	2	-1	11	3	-8
28	*Premna corymbosa* (Burm.f.) Rottl. and Willd. (Verbenaceae)	ST	16	12	-4	42	54	+12
29	*Pyrenacantha volubilis* Wight (Icacinaceae)	ST	0	0	0	2	0	-2
30	*Reissantia indica* (Willd.) Halle (Celastraceae)	Scr-UA	152	166	+14	18	9	-9
31	*Rivea hypocrateriformis* (Desr.) Choisy (Convolvulaceae)	ST	2	8	+6	1	0	-1
32	*Salacia chinensis* L. (Celastraceae)	ST	0	0	0	2	0	-2
33	*Strychnos lenticellata* Hill (Loganiaceae)	TC	150	470	+320	151	294	+143
34	*Tinospora cordifolia* (Willd.) Hook. f. and Thoms. (Menispermaceae)	ST	15	18	+3	0	11	+11
35	*Ventilago maderaspatana* Gaertn. (Rhamnaceae)	ST	0	0	-	26	19	-7
36	*Ziziphus oenoplia* (L.) Mill. (Rhamnaceae)	Scr-A	0	0	-	1	1	0
	Total		812	1259		835	940	

CM* - climbing mode: HC – hook climber; SCr-A – scrambler- armed; SCr-UA – scrambler-unarmed; TC – tendril climber; ST – stem twiner

Changes in species richness and density by diameter class

The liana species richness over a decade increased in the lower diameter class (1–10 cm) in both study sites (Table 4). At OR, out of the total stem density increase of 447 stems, 95% was contributed by the lower diameter classes, and just three stems were added to the larger diameter class, (25–35 cm). At PP, the changes in stem density was minimal in all diameter classes except for 6–10 diameter class (Table 4).

Table 4 Changes in diameter class distribution of liana species richness and stem density over a decade in Oorani and Puthupet tropical dry evergreen forest sites

Diameterclass (cm)	Oorani				Puthupet			
	2001		2011		2001		2011	
	Species richness	Density	Species richness	Density	Species richness	Density	Species richness	Density
1-3	22	397	20	660	24	580	22	582
3-6	14	264	16	377	23	202	20	244
6-10	10	113	9	161	11	38	18	100
10-15	8	30	8	51	6	12	6	14
15-20	2	3	4	6	2	3	0	0
20-25	3	5	1	1	0	0	0	0
25-30	0	0	1	1	0	0	0	0
30-35	0	0	2	2	0	0	0	0
Total	24	812	20	1259	28	835	29	940

Changes at family level over a decade

The recensus data revealed an increase in stem density in most of the families, recording a total change of 0.55% at OR (Figure 3a). Loganiaceae showed a steep increase in stem density followed by five other families. Similarly, at PP, Loganiaceae contributed the most to stem density addition followed by five other families. Three families (Aristolochiaceae, Liliaceae and Mimosaceae) recorded a marginal increase and for eight families the stem density decreased (Figure 3b).

Changes in liana species richness and density by climbing mode

Among the five climbing modes recognised in our study sites, the species richness of tendril climbers and armed scramblers decreased in the ten-year interval, but there was no change in species richness of other three climbing modes at OR. At PP, liana species richness decreased for stem twiners, increased for scramblers, but remained unchanged for tendril and hook climbers. Over the ten-year interval the liana density increased in all climbing modes at the OR. At PP, stem density decreased in hook climber and scramblers but, not for twiners and tendril climbers (Table 5). The Chi-square analysis between the two study sites and inventory periods reveals that the proportion of climbing mode is not significant (P = 0.131, 0.720 for sites OR and PP respectively) at 95% confidence level.

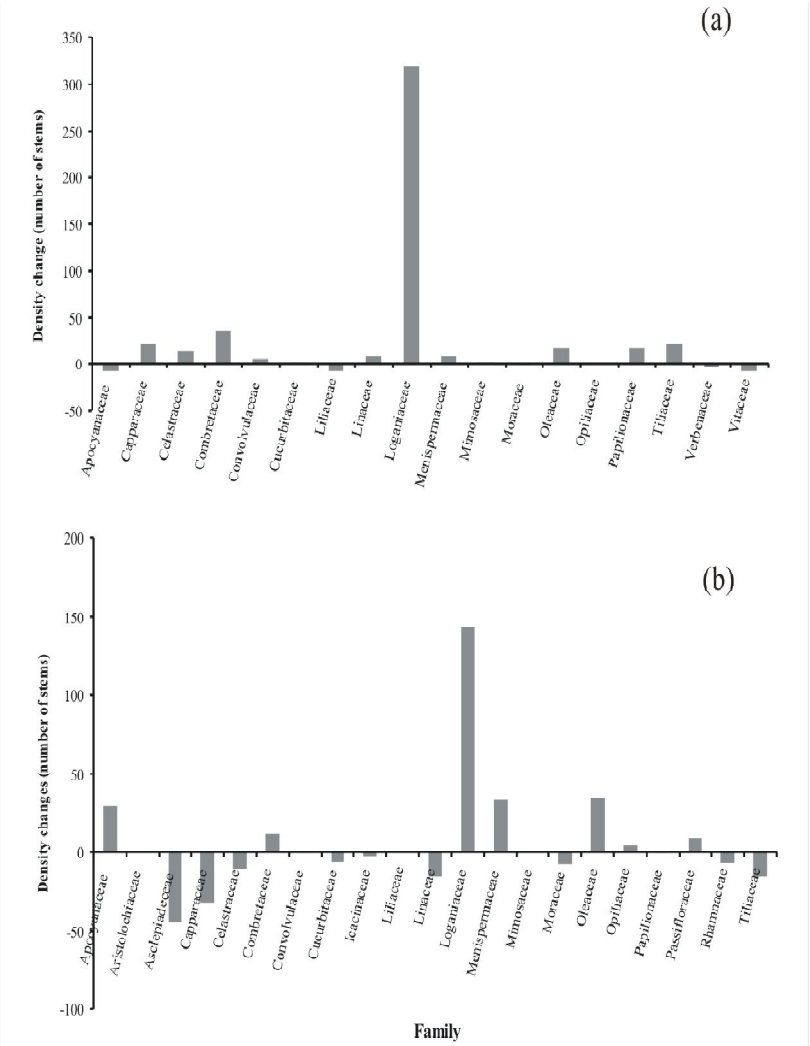

Fig. 3 Family-wise changes in liana density over a decade (2001-2011) in Oorani (a) and Puthupet (b) tropical dry evergreen forest sites.

Discussion

The dataset available on changes in liana diversity and abundance are few, and furthermore, the variation in the objectives pursued, methodology employed, spatial scale of inventory, plot dimension, diameter threshold considered, and so on render comparison across sites difficult. Yet, an attempt has been made to compare re-inventory studies on lianas in tropical forests. The present liana recensus in two Indian tropical dry evergreen forest sites Oorani (OR) and Puthupet (PP) recorded an overall

loss of four species and a gain of one species over a decade in both the sites combined is less when compared to a loss of 15 species and gain of 9 species in 13-years in a Gabonese rainforest (Caballe and Martin 2001). Contrary to the general trend that liana abundance increases with forest disturbance, at PP it has not increased (13%) much revealing that liana abundance may decrease in highly disturbed forests, if the disturbance reduces host tree species abundance (Allen et al. 2005, Addo-Fordjour et al. 2008, 2009). At OR, the liana stem density increased by 55% in the ten-year period which could be explained by a moderate level of anthropogenic impact. Whereas Chave et al. (2008) reported that liana abundance increased by just 1.8% at Nouragues Biological Research Station in French Guiana in a decade.

According to Putz (1984) and Schnitzer et al. (2000) any undisturbed site has a high likelihood of becoming disturbed over a 20-year period, which would result in higher liana abundance, diversity, and biomass from lianas recruiting in as seedlings or, more importantly, falling from the canopy and re-rooting in the newly disturbed understory. Yet other studies have reported that favourable light conditions and suitable trellises in gaps made by logging could increase liana diversity and abundance (Gerwing and Uhl 2002, Schnitzer et al. 2004) and in our sites the result seems to be a cumulative effect of the above cited reports. In mixed tropical lowland rain forest, Ituri, Congo Basin, Ewango (2010) found that the density of a predominant species in his study site decreased by 97% over 13-years, which contrasts with our results in which density of the predominant species *Strychnos lenticellata* drastically increased over a decade. The current rate of increasing evapotranspirative demand in many tropical forests is likely to favour liana proliferation (Schnitzer and Bongers 2011), and this may be a possible reason for the greater liana abundance for both our study sites. Similar to our findings the liana abundance has increased in a study conducted in sub-tropical floodplain forest in South Carolina, Amazonia, Northwest South America, and Central America (Phillips et al. 2002, Allen et al. 2007).

Studies at La Selva Biological Station in Costa Rica by Rutishauser (2011) revealed a 20% increase in mean liana basal area which is closer to the basal area increment of 29% at PP. At Oorani site, the basal area increased by 44% which could be due to comparatively less disturbed condition of the site and this is conformity with the result of Phillips et al. (2002) in Amazonia, northwest South America, and Central America wherein basal area increased by 4.6% per year. According to DeWalt et al. (2000) as forest successional age increases the abundance and basal area

of very large lianas also tend to increase.

Out of the total stem density increase of 447 stems, 95% was contributed by lower diameter classes (Table 4); as such greater abundance of lianas in small diameter class is attributed to their extremely slow diameter increment by an inverse resource allocation as against trees which pump for radial growth (Bazzaz and Pickett 1980, Gentry 1983, Putz 1983), while Mascaro et al. (2004) reported high mortality in smaller size class in Costa Rican forest.

In most of the studies on lianas conducted in different tropical forests, stem twining constituted the predominant climbing mechanism and stem twining lianas composed the largest proportion of species richness and abundance and these results are consistent with other studies on lianas in different tropical forests (Putz and Chai 1987, DeWalt et al. 2000, Muthuramkumar and Parthasarathy 2000, Chittibabu and Parthasarathy 2001, Senbeta et al. 2005, Cai 2009, Muthumperumal and Parthasarathy 2010). In line with earlier findings, in our study also the species richness of stem twiners was highest among the climbing modes, but stem density was greatest for *Strychnos lenticellata*, which makes use of both tendrils and twining. At OR, the liana species with special climbing devices declined from 13 to 11species; and their contrasts the results of a Gabonese rain forest where it increased by one species in thirteen years (Caballe and Martin 2001). Liana species without special support organs (passive climbers) declined from 11 to 9 species in our sites as against 43 to 36 species in the Gabonese forest (Table 5). At PP species richness of lianas with no special organs increased by one in the 10-year interval, which contrasts with the results in the Gabonese rain forest; whereas liana species

Table 5 Changes in liana species richness and density by climbing mode in Oorani and Puthupet tropical dry evergreen forest sites

Climbing mode	Oorani				Puthupet			
	Species richness		Stem density		Species richness		Stem density	
	2001	2011	2001	2011	2001	2011	2001	2011
Stem twiner	7	7	358	439	11	10	328	402
Tendril climber	5	3	167	482	4	4	187	311
Hook climber	1	1	22	30	1	1	57	41
Scrambler - armed	9	7	66	74	9	10	168	115
Scrambler - unarmed	2	2	199	234	3	4	95	71

with special organs increased by one in our site, similar to the findings of Gabonese study.

There has been a considerable change in liana species richness, density and basal area over a decade in two (Oorani and Puthupet) Indian tropical dry evergreen forest sites on the Coromandel Coast. Forest fragments such as our present study sites contribute substantially to conservation of biodiversity by providing habitat for plants, food for animals, and seed sources for the expansion of forests in the future (Schelhas and Greenberg 1996), and by maintaining regional biodiversity of the natural ecosystem (Muthumperumal and Parthasarathy 2010). These re-inventoried data on permanent plots will be useful for further research on the role of lianas in forest structure and functioning, particularly reproductive ecology of lianas and resource use by faunal communities. In our study of decadal changes, a one-and a half-fold increase in liana density indicate that in line with other tropical forests of the world, liana abundance is increasing in at least one tropical dry evergreen forest.

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Changes in plant diversity along disturbance gradient in a dry tropical region, India

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Abstract

Peri-urban ecosystems are considered highly dynamic both ecologically and economically. Yet, the ecological information on the vegetation structure in these ecosystems is considerably inadequate, particularly in Indian dry tropics. The present study across diverse anthropo-ecosystems in the dry tropical peri-urban Bulandshahr-Khurja region in the vicinity of Delhi, aimed at understanding vegetation structure, organization, and soil seed banks in relation to soil and site characteristics. Phytosociological analysis (quadrat method, n=360) and DCA ordination of twelve diverse anthropic sites in three seasons were carried out. A total of 404 angiospermic flora (43 trees, 35 shrubs and 326 herbs) distributed over 89 families and 270 genera were recorded. The largest families were Poaceae (66), Fabaceae (36) and Asteraceae (31). DCA results delineated five different herb communities: (i) *Cynodon-Parthenium*, (ii) mixed-weed, (iii) *Chenopodium-Achyranthes*, (iv) grass-weed and (v) crop-weed. The dominants changed with site and season. The herb communities had wide structural variability. The herb communities separated distinguishably along two environmental variables mean soil organic carbon (0.11%-1.15%) and mid-day soil temperature (29.5°C-43.7°C). However, substantial overlap of communities indicated grading tendency of these communities. Most diverse in term of species richness index was *Chenopodium-Achyranthes* community and the least diverse was crop-weed, whereas in terms of information statistic index (Shannon) mixed-weed was most diverse. Mixed-weed and grass-weed communities had higher species evenness. Seedling density, although variable with the passage of time on account of mortality, competition etc., showed better and denser colonization potential of soils under

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grass-weed and *Cynodon-Parthenium* communities. The mixed-weed and crop-weed communities at pottery site in Khurja indicated significant impact of anthropogenic pressure here. Thus, the investigated anthropic peri-urban vegetation is a mosaic of patches that correspond to different landuses and habitat conditions. They are structurally heterogeneous, variable, dynamic and susceptible to larger weed intrusions. The soils are relatively nutrient-poor, with variable regenerative potential.

Keywords: Anthropogenic disturbance; DCA; Diversity; Land-uses

Introduction

Analyses of changes in species number and composition at the city level are highly important for a better understanding of biodiversity responses to urbanization as they are frequently used as value-connoted biodiversity indicators (Heink and Kowarik 2010). A major ecological concern arising out of human impact is the rise in urbanization at differing scales, associated with the rapid growth of the world's population and the consequent transformation of rural and natural landscapes (Keles et al. 2008). Such alteration of landscapes across the world due to human activities is well recognized since the second half of the 20th century (EEA 2006). Although urban landscapes occupy only approximately 4% of the earth's surface (UN 2008), urban growth has imposed major challenges to biodiversity conservation as it has already induced a profound transformation at the landscape level and is regarded as a major threat to biodiversity (Antrop 2004, Hansen et al. 2005). These urban areas are reportedly complex ecological systems, affected by human practices that have increasingly altered biogeochemical cycles and contributed to the deterioration of natural habitats and loss of biodiversity by promoting the replacement of native species with non-native counterparts, leading to the extinction of some species and to biotic homogenization (Barrico et al. 2012, Chapin et al. 2000, Kowarik 2011, Mckinney 2006). Such areas are highly heterogeneous (Kowarik 2011) and the flora here is dominated by a mix of early successional and disturbance tolerant species from various geographic origins (Tredici 2010).

Biodiversity is an important component of any ecological system that promotes functional diversity and improves ecological stability by influencing the resistance and resilience to environmental change (Chapin et al. 2000, Peterson et al. 1998) and is therefore crucial to the over-all quality of life. Understanding, assessing, and enhancing urban and peri-urban biodiversity is often considered to be of paramount importance, from both conservation and social perspectives (Kowarik 2011). Soil seed banks

are potentially major propagule sources that have a significant input to vegetation community structures (Li 2008, Warr et al. 1993). In anthoropo-ecosystems, recovery from the soil seed bank has long been recognized as important to community processes since it plays a role in sustaining local plant populations after disturbance (Navarra and Quintana-Ascencio 2012, Thompson and Grime 1979). If mortality results from the disturbance event, the seed bank is particularly vital for species that have limited dispersal distance and rely on seeds for recruitment (Noble and Slatyer 1980). For vegetation study across degraded ecosystems facing persistent disturbance, it is always suggested that before the commencement of a vegetation improvement project (Bossuyt and Hermy 2003) or adjusting management for poor vegetation, it is essential to understand soil seed bank characteristics and to assess community dynamics, relevant regeneration potential and possible development direction of extant vegetation (Bakker and Berendse 1999, Schmidt et al. 2009, Tracy and Sanderson 2000). Characteristics of seed banks viz. seed density and species composition have been reported to vary across vegetation, climate, soil, elevation and fluvial processes (James et al. 2007, Lohengrin and Mary 2001), and successional stages (Cavieres and Arroyo 2001, Coulson et al. 2001, Eycott et al. 2006, Schmidt et al. 2009, Yu et al. 2008). Such studies are generally lacking in dry tropics (Li et al. 2011).

Across the world is seen a mosaic of urban settlements spreading across the rural landscape in a seemingly irreversible manner. The scale of urban development in India is quite alarming. Here, the urban growth in the decade 1991-2001 was 2.1% (Asgher 2004). About 70% of the urban population lives in small and medium sized cities. The studies on ecological impacts of development and settlement pressure in such cities on the plant communities are few. Most of the vegetation studies that exist on natural ecosystems pertain to forest, grasslands etc. Comparable quantitative studies on vegetation existing in the midst of cities corresponding to mosaic of land-uses and habitat conditions are generally lacking in India.

The present study carried out in Bulandshahr-Khurja region that stands in the midst of urbanizing landscape in the National Capital Region (NCR), has witnessed a range of environmental degradation activities in last 5-6 decades. This peri-urban region has catered to the developmental needs of larger urban centres in vicinity *viz*. Delhi, Gurgaon, Aligarh, NOIDA, Ghaziabad and Meerut in U.P. The poor railway network and basically rural character of the present study area, offers important ecological opportunity for investigation of its floristic diversity, the existing vegetation structure and its organization. Moreover, there has been little

authentic quantitative ecological information on vegetation-soil aspects and existing soil seed bank in this region.

The present ecological work was designed at medium spatial scale on herb diversity in Bulandshahr-Khurja region to accomplish the following objectives: (i) to study the vegetation structure and its dynamics in relation to soil and site characteristics, across a variety of land-uses/ habitat conditions, (ii) to estimate the levels of diversity and understand its relationship with the environment, and (iii) to understand soil seed bank relations with site conditions.

Study Area

Location of the study sites

In the present study, two major study sites were located at Bulandshahr (28º 24´ N lat. and 77º 51´ E long.) (72 km from Delhi) and Khurja (28º 15´ N lat. and 77º 15´ 12´´ E long.) (17 km from Bulandshahr) in the state of Uttar Pradesh of India. Twelve vegetation sampling sites were established, eight at Bulandshahr proper and four at Khurja, representing a range of diverse landuses and differing habitat conditions. These were:

(A) Bulandshahr: (i) Grazing land (near Parag dairy), (ii) IMCL (Indian Maize and Chemicals Ltd.) (abandoned land), (iii) Brick kiln area (iv) Dairy complex area, (v)Animal slaughter centre, (vi) Agriculture land, (vii) Kalinadi bank, and (viii) Gang-Nahar bank.

(B) Khurja: (i) Suman India Pottery, (ii) Agriculture land, (iii) Animal slaughter centre, and (iv) Hindustan Pottery.

Climate

The climate is semi-arid and the year is divisible into three seasons: winter (November - February), summer (March - June) and rainy (July - October). Annual mean temperature was 28.9ºC. The monthly average maximum temperature ranged from 15.6ºC (January) to 37.2ºC (May). Annual mean rainfall was 554.2 mm, of which about 88 % occurred in rainy season. July, August and September were the wet months, which experienced nearly 86% of total annual rainfall.

Materials and Methods

Vegetation sampling and analysis

The floristic composition of the study area was recorded during

survey visits to the sites in different seasons. A total of 360 plots (each 25 cm x 25 cm) were sampled for phytosociological analysis. The vegetation of Bulandshahr (across eight stands) and Khurja (across four stands) was seasonally sampled through 240 and 120 plots respectively. The species in quadrats were identified and their individuals counted. Every emergent tiller was considered as one individual for density estimation of grasses. The quadrat data were quantitatively analyzed for density, frequency and abundance.

The 36 herb species data sets (12 stands in three seasons) were subjected to Detrended Correspondence Analysis (DCA) using CANOCO 4.5 package (ter Braak and Šmilauer 2002). On the basis of DCA ordination results, deciphered groups were analyzed for community delineation.

Dominance diversity curves were prepared by plotting relative density of species against the species sequence according to Whittaker (1975).

Species diversity

Diversity indices reflecting either species richness or proportional abundance of species (Information statistic indices and Dominance measures) were calculated as described (by Magurran 1988) below:

Species richness index

Species count (Number of species/area, in this study the number of species occurred in quadrats)

Information statistic indices

Shannon-index (H') (Shannon and Weaver 1949) $= -\Sigma\, pi \ln pi$

Evenness (Pielou 1966) $= \dfrac{H'}{\ln S}$

Dominance measures

Simpson index (Simpson 1949) $= \Sigma pi^2$

Where S = total number of species, N = total sum of dominance attribute of all species, pi = proportional dominance of i^{th} species (ni/N) and ni = number of dominance attribute of each species.

Soil analysis

Four surface soil samples were collected from each of the twelve research sites in the month of April and were analyzed for soil organic carbon (Walkley and Black method) according to Piper (1944). Mid-day surface soil temperature (5 cm depth) was measured with the help of four thermometers in May between 1200-1330 hrs for six consecutive days.

Soil seed bank

Three surface soil samples (20 cm x 20 cm x 5 cm) were collected from all study sites in the month of April. The soils were air dried and sieved (2 mm). The soil samples were spread uniformly in round earthen pots, gently watered regularly. The seedling emergents were recorded every day up to three weeks. The density of the emergent individuals was noted, and the plants, which survived and matured, were identified.

Results and Discussion

A total of 404 angiospermic plant species were recorded, which included 43 tree, 35 shrub and 326 herb species spread over 89 families and 270 genera (Table 1) reflecting a relatively large diversity potential in this dry tropical region. A total of more than 36% of species reported by Sharma (1980) for the whole of Bulandshahr district was recorded in this selected area of study, and these flora at family level were spread over more than 65% of the families reported for the entire district. The largest three families observed in the present study viz. Poaceae, Leguminosae and Asteraceae compared well with the dominant families reported by Goel (2005) for tropical herb vegetation at Sikandrabad, and Narayan (1992) for sal-bearing dry tropical forests in the Vindhyan region.

Table 1. Angiospermic plant flora of peri-urban vegetation in Bulandshahr-Khurja region, by family and life forms.

S. No.	Family	Genus	Species			
			Herbs	Shrubs	Trees	Total
1	Poaceae	37	65	1	-	66
2	Fabaceae	20	30	3	3	36
3	Asteraceae	24	30	1	-	31
4	Cyperaceae	4	22	-	-	22
5	Lamiaceae	7	12	-	-	12
6	Malvaceae	6	10	2	-	12

7	Euphorbiaceae	7	9	3	-	12
8	Amaranthaceae	8	10	-	-	10
9	Mimosaceae	7	-	1	8	9
10	Acanthaceae	7	8	-	-	8
11	Convolvulaceae	3	8	-	-	8
12	Solanaceae	6	7	1	-	8
13	Moraceae	4	1	3	4	8
14	Brassicaceae	6	6	-	-	6
15	Rubiaceae	4	5	-	1	6
16	Verbenaceae	5	3	3	-	6
17	Apocynaceae	6	1	2	3	6
18	Caryophyllaceae	5	5	-	-	5
19	Cucurbitaceae	5	5	-	-	5
20	Scrophulariaceae	5	5	-	-	5
21	Polygonaceae	3	5	-	-	5
22	Boraginaceae	2	5	-	-	5
23	Commelinaceae	2	5	-	-	5
24	Tiliaceae	3	4	1	-	5
25	Lemnaceae	2	4	-	-	4
26	Portulacacea	1	4	-	0	4
27	Capparaceae	3	1	2	1	4
28	Rutaceae	3	-	-	4	4
29	Onagraceae	3	3	-	-	3
30	Molluginaceae	2	3	-	-	3
31	Caesalpiniaceae	1	3	-	-	3
32	Chenopodiaceae	1	3	-	-	3
33	Asclepediaceae	3	2	1	-	3
34	Liliaceae	3	2	-	1	3
35	Sterculiaceae	3	1	1	1	3
36	Myrtaceae	3	-	-	3	3
37	Apiaceae	2	2	-	-	2

38	Hydrocharitaceae	2	2	-	-	2
39	Papaveraceae	1	2	-	-	2
40	Oxalidaceae	1	2	-	-	2
41	Cuscutaceae	1	2	-	-	2
42	Nyctaginaceae	1	2	-	-	2
43	Typhaceae	1	2	-	-	2
44	Bignoniaceae	2	-	2	-	2
45	Rhamnaceae	1	-	1	1	2
46	Combretaceae	1	-	-	2	2
	Other families (43)	43	25	7	11	43
	Total	270	326	35	43	404

The detrended correspondence analysis of 36 vegetation data sets representing 12 diverse stands/sub-sites in three different seasons (summer, rainy and winter) yielded cluster of stands whose pooled data analysis resulted into recognition of five different herb communities in this study (Fig. 1). These were: (i) *Chenopodium-Achyranthes* community (cluster of four stands in Bulandshahr- dairy complex, brick kiln area, animal slaughter area and agriculture land), (ii) *Cynodon-Parthenium* community (cluster of three stands in Bulandshahr- kalinadi banks, grazing land and abandoned land of IMCL), (iii) mixed-weed community (cluster of two stands in Khurja- Suman India Pottery and Hindustan Pottery), (iv) crop-weed community (cluster of two stands in Khurja- agriculture land and animal slaughter area), and (v) grass-weed community formed by isolated stand along nahar bank in Bulandshahr. The scatter of points in a group is indicative of the intra group variability in terms of species composition and the degree of a species dominance exercised in a particular stand and season (Fig. 1). The overall vegetational heterogeneity including the temporal one is implicit from the relatively larger spread and scattering of different herbaceous stands. Disturbances may be considered to be the major environmental drivers causing creation of spatial and temporal heterogeneity in such ecosystems (Denslow 1985). Habitat heterogeneity is often suggested to be the major structuring agent of ecological assemblages that promotes beta diversity and ultimately contributing to overall higher global diversity (McClain and Barry 2010). Relatively higher diversity in this area, deserves attention in the light of the fact that the peri-urban region of Bulandshahr, has witnessed immense developmental activities and settlement pressure in the last few decades. The land use

patterns have undergone transformation, albeit this process of transformation appears slow, may be due to the lack of massive, large-scale intensive developmental activities undertaken here.

Several workers have opined that the disturbances including the grazing-induced heterogeneity (Marion et al. 2010) allow maintenance of species richness by creating a mosaic of patches (Connell 1978, Pickett

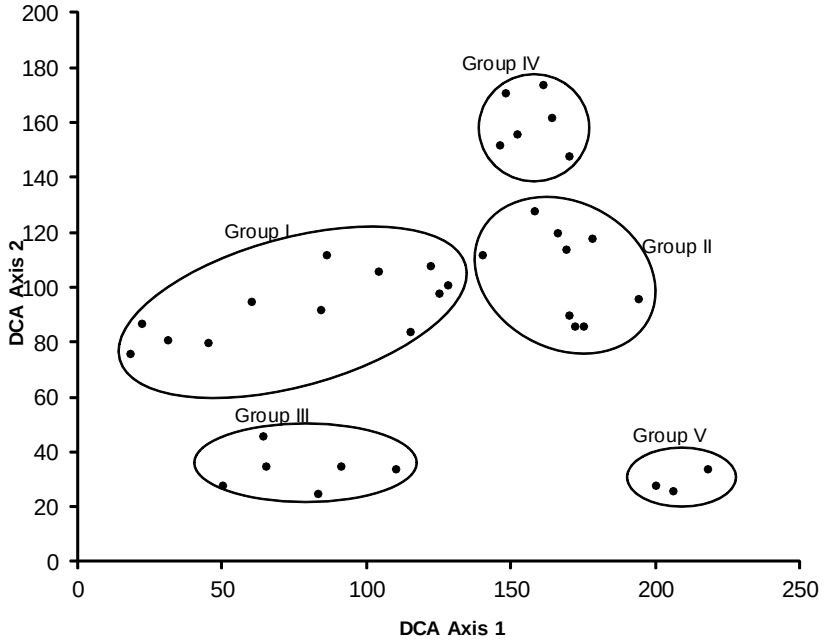

Fig. 1. DCA ordination results of the herb vegetation stands in Bulandshahr-Khurja region. Group I. *Chenopodium-Achyranthes* community; Group II. *Cynodon-Parthenium* community; Group III. Mixed-weed community; Group IV. Crop-weed community; Group V. Grass-weed community.

and White 1985). This is comparable to the mosaic of communities recognized in the present study. These disturbances are more frequent and intense in tropics and sub-tropics, which have been recognized as sensitive environment witnessing enhanced rate of loss of biodiversity (Sagar and Singh 2005). The disturbances in this study area could be visualized in terms of brick dust and debris accumulation (in brick kiln areas), accumulation of animal organic wastes (around animal slaughter centers), discharge and accumulation of pottery dump materials (in Khurja pottery town), flooding effect or rise and fall of water level in kalinadi particularly after rains etc. Such disturbances have been recognized by several workers e.g. disturbances causing specific edaphic conditions related to the

variability of flooding frequency and duration reported by Hartman (1988), and grazing effect causing strain on the ecosystem by Watkinson and Davy (1985). Plant communities along rivers respond differently to anthropogenic stresses and can serve as reliable indicators of ecological condition of these habitats (Miller et al. 2006) as compared to use of individual plant species as an ecological indicator.

Based on phytosociological analysis of pooled vegetation data across different DCA groups, the structure of the herb communities was evaluated in terms of species density and frequency. The dominants generally changed with change in site and season. The seasonal dynamics was evident in inter-stand (within community) dominance studies (Table. 2). The top three dominant species in terms of density (D, individuals/m^2) and % frequency (F) in the five communities were:- (i) ***Chenopodium-Achyranthes*****:** *Chenopodium murale* (D 56, F 33), *Achyranthes aspera* (D 34, F 30), *Cynodon dactylon* (D 19, F 26) ; (ii) ***Cynodon-Parthenium***: *Cynodon dactylon* (D116, F 76), *Parthenium hysterophorus* (D 43, F 40), *Cyperus rotundus* (D 28, F 61); (iii) **mixed-weed:** *Cannabis sativa* (D 29, F 38), *Croton bonplandianum* (D 25, F 42), *Malvastrum tricuspedatum* (D 25, F 23); (iv) **grass-weed:** *Saccharum munja* (D 18, F 60), *Achranthes aspera* (D 14, F 31), *Abutilon indicum* (D 12, F 43); (v) **crop-weed:** *Zea mays* (D 14, F 30), *Trianthema portulacastrum* (D 9, F 24), *Parthenium hysterophorus* (D 2, F 30). Here, the disturbances appear to affect the distribution of plants (Ager et al. 2010, Gupta and Narayan 2006) by allowing establishment of species usually annuals, as found predominant at most of the study sub-sites, that are likely to be later eliminated by more competitive species (e.g. Watkinson and Davy 1985). Such elimination by invasive weed *Parthenium hysterophorus* is indicated from this study too. The dominant species composition at different sub-sites of study here showed that the vegetation in this region is basically grass-dominated, herbaceous and weedy in nature. The dominance of weeds, however, showed spatial and temporal variations. The predominant common weeds who appear eliminating the grasses (e.g. *Cynodon dactylon*) or those who competed strongly for the top dominant position included *Chenopodium murale, Achyranthes aspera* and *Parthenium hysterophorus*. While *Parthenium hysterophorus* is a well recognized exotic invasive species that has successfully established in almost every part of India, *Chenopodium murale* has recently been recognized as the alien aggressive invader in this region (Gupta and Narayan 2012).

Table 2. Dominant species of five recognized herb communities (on the basis of DCA clusters) in Bulandshahr- Khurja region. Density (D, no. of individuals/m^2) and % Frequency (F) of only the leading dominants in each community are shown.

***Chenopodium-Achyranthes* Community**			***Cynodon-Parthenium* Community**		
Species name	**D**	**F**	**Species name**	**D**	**F**
Chenopodium murale	56	33	*Cynodon dactylon*	116	76
Achyranthes aspera	34	30	*Parthenium hysterophorus*	43	40
Cynodon dactylon	19	26	*Cyperus rotundus*	28	61
Parthenium hysterophorus	19	60	*Eclypta erecta*	28	30
Malvastrum tricuspedatum	18	12	*Rumex dentatus*	18	32
Sida acuta	15	21	*Polygonum plebejum*	17	12
others (28 species)	59		others (19 species)	119	
Grass-Weed Community			**Mixed-Weed Community**		
Species name	**D**	**F**	**Species name**	**D**	**F**
Saccharum munja	18	60	*Cannabis sativa*	29	38
Achyranthes aspera	14	31	*Croton bonplandianum*	25	42
Abutilon indicum	12	43	*Malvastrum tricuspedatum*	25	23
Triumfetta rhomboidea	10	36	*Cassia obtusifolia*	22	32
Panicum maximum	10	32	*Parthenium hysterophorus*	21	43
Dichanthium annulatum	8	26	*Cynodon dactylon*	20	24
others (17 species)	45		others (22 species)	109	
Crop-Weed Community					
Species name	**D**	**F**			
Zea mays	14	30			
Trianthema portulacastrum	9	24			
Parthenium hysterophorus	2	30			
Amaranthus viridis	2	10			
Cynodon dactylon	1	21			
others (9 species)	3				

The dominance diversity curves for different communities showed a comparable steep slope in the initial segment (suggesting geometric pattern of resource share by a few species only) (Fig. 2). The equitable

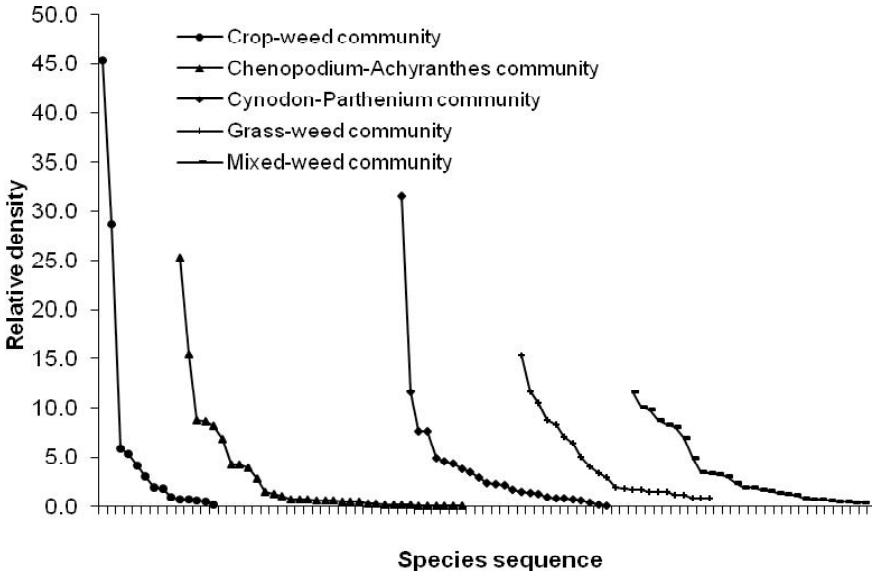

Fig. 2. Dominance-diversity structure of the five herb communities in Bulandshahr-Khurja region.

resource share among much larger number of species is exhibited in all communities. Mixed-weed community, however tended to showed log-normal pattern of resource share among the competing weeds in the pottery town of Khurja. The steep nature of relation corresponded to geometric series, theoretically corroborating the niche preemption hypothesis. Some workers e.g. Odum (1985) have suggested relationship of geometrical series of resource share (reflected by increased dominance) with occurrence of environmental stress. The environmental stress in the present study could be visualized in term of pressure intensity due to land use. However, the near lognormal pattern of resource share pattern at pottery sites in Khurja indicated disturbance-induced equitable resource share amongst weed species here at sub-sites characterized by pottery dump points. Statistically, along DCA axis 1 and DCA axis 2 no obvious significant environmental gradients in terms of the habitat variables like soil temperature and soil organic carbon existed. This showed that these two edaphic variables (soil temperature and soil organic carbon) are not decisive factors for the distribution of communities in this area. However these five groups discerned, were easily distinguishable along these two variables (Fig. 3). Several workers have suggested that the processes by which heterogeneity, as witnessed here, increases diversity are scale dependent end encompasses variation in other important processes, such as productivity, disturbance, and temperature (Gupta and Narayan 2011, McClain and Barry 2010).

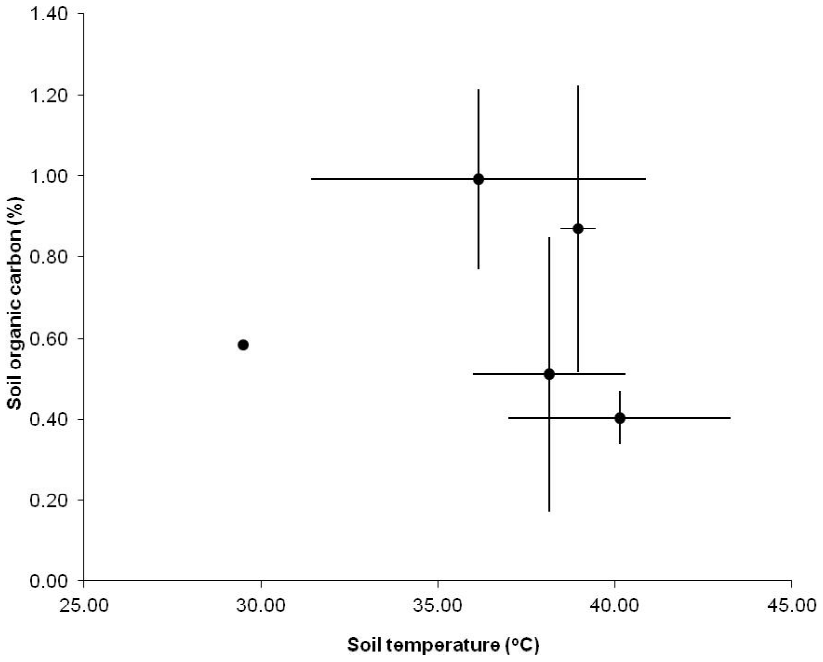

Fig. 3. Five herb communities, spatially separated along the combination of soil organic carbon and mid-day soil temperature. Bold dark circles represent the co-ordinates of mean soil temperature and mean soil organic carbon of each community and horizontal and vertical lines represent their ranges of variation (± S.D.), respectively, amongst the constituent stands (1-4).

The four communities viz. *Chenopodium-Achyranthes*, *Cynodon-Parthenium*, mixed-weed and crop-weed showed varying degree of overlap in terms of both floristic similarity as well as soil characteristics. The fifth community (grass-weed community) formed a distinct identity, representing vegetation along the nahar bank. These ordinated noda indicated presence of mosaic of vegetation patches in the study area. Such a vegetation mosaic in the urban ecosystem corresponded to diversity of habitat conditions that were created due to multiplicity of landuse and varying degree of disturbance pressure. In fact, the annuals are considered ecological opportunists having a short life span and high fecundity that enabled them to colonize rapidly the open spaces created by disturbances. Several studies have reported annuals predominating disturbed soils (Foster and Stubbendieck 1980, Tilman 1983).

The diversity indices ranked the communities differently in the order of their diversity levels. In terms of species count the *Chenopodium-Achyranthes* community assumed the highest value (34), and crop-weed

community the lowest (14) (Table 3). However, in terms of Information Statistic index (Shannon-Wiener) mixed-weed community was maximally diverse (H´ = 2.91). Dominance measure (Simpson index) was highest for crop-weed community (0.30) and lowest for mixed-weed community (0.07). The mixed-weed and grass-weed communities exhibited much higher evenness index.

Table 3. Diversity estimates of five herb communities in dry tropical Bulandshahr-Khurja region (using relative density data of the species).

Diversity Index	*Chenopodium -Achyranthes* community	*Cynodon-Parthenium* community	Grass-weed community	Mixed-weed community	Crop-weed Community
Species count	34	25	23	28	14
Shannon Index	2.53	2.52	2.76	2.91	1.62
Simpson (dominance concentration)	0.12	0.14	0.08	0.07	0.30
Evenness (Pielou 1966)	0.72	0.78	0.88	0.87	0.61

The edaphic conditions at the study sites showed a general poor nutrient status and relatively harsh environment comparable to that reported by Gupta (2008). The mean soil organic carbon across various stands ranged between 0.11 ± 0.03 (brick kiln stand, Bulandshahr) and 1.15 ± 0.28 (Suman India Pottery, Khurja). Mid-day soil temperature ranged between 29.5°C ± 0.94 (nahar bank) and 43.7°C ± 1.62 (abandoned land, IMCL). Mixed-weed community soils showed better soil organic carbon 0.99% compared to *Cynodon-Parthenium* (0.40%) and *Chenopodium-Achyranthes* (0.51%) communities. The soils under *Chenopodium-Achyranthes* and *Cynodon-Parthenium* communities reflected harsher environmental conditions (relatively low fertility levels, mean soil organic carbon 0.40% to 0.51%). Relatively better competitive ability of the exotic weed Par*thenium hysterophorus* is apparent under harsh edaphic conditions (mean soil temperature more than 40ºC) reflected by its sub-dominant status in *Cynodon-Parthenium* community.

In nature species diversity is maintained through regeneration of component species. The seed bank study here indicated range of seed density, indicating varying regeneration potential of the sites. In the first week nearly no seedling was recorded in the soils of kalinadi bank, brick kiln and slaughter area (Bulandshahr) (Table. 4). Second week showed emergence of seedlings in all the sub-site soils in large numbers except slaughter area and kalinadi sub-site. Of these, the largest density occurred in dairy complex (1833/m^2) and agriculture land (1063/m^2). In the third

Table 4. Density (individuals/m^2) of seedling emergents (Number/m^2) in the three weeks of study at different sites located in Bulandshahr (BSR) and Khurja (KRJ).

	Seedling Emergents (No./m^2)		
Study sites	**1st Week**	**2nd Week**	**3rd Week**
Grazing land (BSR)	78	583	1638
Agriculture land (BSR)	220	1063	988
IMCL (abandoned) (BSR)	253	808	530
Kalinadi (BSR)	0	1	33
Nahar (BSR)	113	238	1013
Slaughter area (BSR)	0	0	125
Dairy complex (BSR)	1300	1833	875
Brick kiln area (BSR)	0	155	83
Hindustan pottery (KRJ)	50	183	513
Agriculture land (KRJ)	70	350	700
Slaughter area (KRJ)	100	183	83
Suman India pottery (KRJ)	50	143	95

week, however, while some sub-site soils showed increase in density in comparison to that in second week (e.g. grazing land, kalinadi, nahar bank, agriculture land at Khurja), the other sub-site soils exhibited decline in density of seedling emergents. In case of annuals, species that regenerate with seeds, the recolonization of patches following disturbances depends on species dispersal abilities (Huiskes et al. 1995). If seeds are not present in soil seed bank, this recolonization requires the existence of source sites capable of providing propagules. The seed bank density estimated at different sub-sites reflected relatively poor seed storage under the soils of kalinadi banks, animal slaughter area and brick kiln industrial area. The post monsoon rise of kalinadi water-level, carrying sediments down stream and along the slope on the banks, and sweeping off of the surface soil seeds, could be the major cause of poor seed density here. The other two sub-sites represented two different disturbance regimes originating from landuse-generated edaphic modification. The animal slaughter area appears to be affected by animal organic wastes accumulated in this restricted area, modifying the physical and chemical characteristics of soil here (relatively high soil organic carbon 1.12%). On the other hand, the brick kiln sub-site with accumulated brick dust (Gupta and Narayan 2010), showed poor organic carbon (0.11%). Despite the poor soil seed bank storage here at

these sub-sites, the vegetation similarity with the neighboring patches of vegetation, corroborated that recolonization is possibly due to existence of neighboring source sites that provided the propagules. The higher seedling density at some sub-sites e.g. dairy complex, nahar bank, agriculture land (Bulandshahr) and grazing land (Table 4) indicated a healthy reproductive potential available here. But relatively poor seedling emergents in the soils of other sub-sites that included Khurja pottery sites and abandoned land of IMCL, suggest that higher recruitment of individuals could be ensured at these sub-sites if anthropogenic pressure is controlled. It is also likely that these sub-sites would witness further aggressive colonization by weed recruits.

Considering the mean density of seeds across the soils in different communities (Table 5), *Chenopodium-Achyranthes* community showed highest density in both the first week (380/m^2) and second week (763/m^2). In third week the highest seedling density was observed in grass-weed community. Thus, Seedling emergent density, although variable with the passage of time on account of mortality, competition etc., showed better and denser colonization potential of soils under grass-weed and *Cynodon-Parthenium* communities. The mixed-weed and crop-weed communities at pottery site in Khurja appear to be greatly affected by anthropogenic pressure.

Table 5. Density (Mean ± S.E.) of seedling emergents (Number/m^2) in the three weeks of study in different herb communities.

	Seedling Emergents (No./m^2)		
	1st Week	**2nd Week**	**3rd Week**
Chenopodium-Achyranthes Community	380 ± 311	763 ± 427	518 ± 240
Cynodon-Parthenium Community	110 ± 75	464 ± 240	733 ± 474
Mixed-weed Community	50 ± 0	163 ± 20	304 ± 209
Crop-weed Community	85 ± 15	266 ± 84	391 ± 309
Grass-weed Community	113	238	1013

In the present study, it is concluded that the vegetation mosaic witnessed in this dry tropical region is a likely product of various anthropogenic pressure operating here. The herb diversity appears much susceptible to competition by weedy intrusions. The structural variability and habitat variety of the semi-arid herbaceous vegetation in the study area is evident from the variations in characteristics pertaining to vegetation, soil, diversity and soil seed bank. The dynamic nature of communities is

apparent from the seasonal dynamics in community description, dominance diversity structure and the preponderance of annuals. In light of this study, the different landuse/disturbed habitats encountered here, needs to be intensively investigated at varying scales to understand the ecological change, particularly around kalinadi, brick kiln industrial areas, animal slaughter area, pottery dump sites and abandoned lands.

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Plant diversity change along disturbance gradient in Mizoram, Northeast India

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Abstract

The present study has been carried out in Mizoram University campus situated in Tanhril area of Aizawl district, Mizoram, India, to investigate on plant community characteristics, phytosociological attributes and the medicinal uses of plants and their status of availability in the area. A total of 120 species representing 102 genera and 53 families, 134 species belonging to 106 genera and 50 families and 105 species belonging to 87 genera and 46 families were reported from undisturbed, moderately disturbed and highly disturbed stand, respectively. *Schima wallichii* was dominant tree species and *Chromolaena odorata* was dominant shrub species in all the stands. However, *Costus speciosus* was dominant herb species in the undisturbed stand and *Mimosa pudica* in the moderately disturbed and highly disturbed stands. Plant species with local names from the area along with their parts used and mode of their administration in different ailments has been tabulated in the last. This information will be useful in recording the ethono-botanical use in the future and economic prosperity that can enhance employment opportunity to the local people.

Keywords: Mizoram, plant community, phytosociological attributes, medicinal uses, economic prosperity

Introduction

India is a mega-diverse country representing ca. 2.4% of the geographical area and ca. 7-8% of plant and animals of the world. Bulk of diverse flora and fauna resides in tropical forests and are facing high degree of threat due to anthropogenic disturbances as a result of increasing human

population and developmental activities. Therefore, efforts for the conservation of biodiversity in different ecological zones are needed. Tropical forests are often referred to as one of the most species diverse terrestrial ecosystems, covering only 7% of the earth surface, and they account for about 70% of the world's species. Since past few decades, majority of tropical forests are facing different degrees of disturbance due to increasing anthropogenic pressure with time and thus, require management interventions to maintain the overall biodiversity, productivity and sustainability.

The massive destruction of tropical forests worldwide has led to limit our knowledge on taxonomy and the structural and functional dynamics of many tropical forests (Parthasarathy and Sethi 1997). The exploitation of natural resources by the local populations has resulted in depletion of the biodiversity of forest communities (Ramakrishnan 2003). Forest degradation is usually accompanied by species extinction, loss of biodiversity and decrease in primary productivity. Consequently, there is a growing interest in quantifying habitat characteristics like forest structure, floristic composition and species richness in Indian forests (Nirmal Kumar et al. 2001, Yadav and Yadav 2005). Diversity of plant has high functional role in providing nutrients for an ecosystem, and provides suitable habitat, food and shelter for other biota. Knowledge on floristic composition is valuable for many ecological studies such as succession and nature of plant communities which are supportive in reclamation of abandoned sites. The loss of diversity is perhaps the most crucial concern for human survival as it influences ecosystem services and livelihoods.

Global change factors like land use pattern and increasing atmospheric CO_2 concentration have been reported to drastically affect species composition and their relative abundance in natural ecosystems worldwide (Chapin et al. 2000, Chapin et al. 2001). Land use pattern has been ranked as one of the most important drivers for terrestrial biodiversity change in the 21st century (Sala et al. 2000, 2001) with its more prominent role in tropical forests. Further forecasts for massive demands of natural resources in future as a result of increasing world human populations will magnificently increase the pressure on natural ecosystems. Land degradation arising out of mining and quarrying activities is altering ecosystem structure due to excavation and overturning of top soil for dumping of mined overburden in adjoining areas.

Forest disturbance has been reported as invasion by exotic species like weeds and affecting community structure and dynamics of native

species (Sagar and Singh 2004, 2005), and causing species extinction and biodiversity loss (Koh et al. 2004, Pimm and Raven 2000). In the past few decades, anthropogenic pressure in central India has led to depleting species diversity in dry deciduous forest and modifying them into dry deciduous scrub, dry savanna and dry grasslands. These ecosystems are characterized open canopy which supports the growth of invasive weeds and other herbaceous plants which usually interfere with regeneration and impede recovery of trees and shrubs (Madoffe et al. 2006). Invasive weeds cause threat to biodiversity by displacing native species and disrupting community structure (Stein et al. 2000).

Further, disturbance plays a central role in shaping the species composition in forests (Pickett and White 1985). It directly influences the community structure and population dynamics by altering resource availability (Denslow et al. 1998) through influencing the relative competitive status of individuals (Sousa 1984), which causes mortality of mature tree species and hampers establishment of new recruits (Canham and Marks 1985). The vegetation structure of tropical dry forests is not uniform but varied in different habitats. In tropical forest, it has also been argued that species richness and diversity are invariably affected by frequent and fluctuating disturbances of low-intensity namely, grazing and browsing, and collection of firewood and fodder, suggesting the importance of combined effect of multiple factors (Sagar et al. 2003, Zhu et al. 2007). The vegetation composition is closely linked with soil characteristics which drastically affect after anthropogenic activities that lead to alter vegetation composition as result of changes in the soil nutrients. The biotic legacies that remain after disturbance vary in quality and quantity leading to a range of regeneration patterns like fine scale gap dynamics, patch dynamics or regeneration efficiency (Van der Maarel 1996).

The loss of species from the community affects energy flow and material cycling, and the extent of effect varies from the species to species that maintains stability of the biotic community. Some species has been identified as keystone which play significantly large impact on the functioning of community and thus loss of such species from a forest can create havoc for the normal functioning of the ecosystem (Fahey 2001). Keystone species differ from dominant species, as their effects are much larger than would be predicted from their abundance (Power et al. 1996). The loss of keystone species would result in widespread changes in the community structure and function and may often lead to species loss or elimination (Tripathi and Law 2006). The identification of keystone species and study of their population dynamics in a forest ecosystem are important

for biodiversity manipulation and management as well as for the sustainability of the forest. The population dynamics of keystone species is very useful in determining the pattern of succession of vegetation (Tripathi and Law 2006).

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

Material and Methods

Study site

The study was conducted during 2009 to 2011 in the forest patches within and outside the Mizoram University campus situated in Tanhril area (23°45'25" N- 23°43'37" N latitude and 92°38'39''E- 92°40'23"E longitude) of Aizawl district, Mizoram. The University campus is located in the western part of Aizawl district which is about 15 km away from the Aizawl city, the state capital.

For detailed investigation, a total of three study sites were selected along age gradient after disturbance in terms of sandstone quarry, representing undisturbed (UD), moderately disturbed (MD) and highly disturbed (HD) stands. The natural forest stand where no sandstone mining activity was done in the past referred to as undisturbed stand. The moderately disturbed forest stand is a secondary forest developed naturally after the abandonment of sandstone quarry (mining operation about 7 years back in 2002). The highly disturbed forest stand is an open mining area where sandstone mining is continued. The forest vegetation falls under three tropical semi-evergreen forests (Champion and Seth 1968). Vegetation characteristics of the study sites are shown in Table 1.

Vegetation Analysis

For field study quadrat method was adopted. The size of quadrat was 10m x 10m for trees, 5m x 5m for shrubs/ saplings and 1m x 1m for herbs/ seedlings. The plant species were identified with the help of herbarium of the concerned University Department; herbarium of the BSI, Eastern circle, Shillong, and counter checked with the help of regional floras (Kanjilal et al. 1934-40, Haridasan and Rao 1985). The field data on vegetation was quantitatively analyzed for phyto-sociological attributes namely, frequency, density and abundance as proposed by Curtis and

Mclntosh (1950). The Importance value index (IVI) was determined as per Phillips (1959). Species diversity and dominance indices were determined following the methods as outlined in Misra (1968) and Mueller-Dombois and Ellenberg (1974).

Results and Discussion

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

The findings on phytosociological attributes reveal that *Schima wallichii* was dominant tree species in all three stands. However, co-dominant species *Castanopsis tribuloides* was replaced by *Sterculia villosa* in the highly disturbed stand. It was also observed that dominant and co-dominant species normally contributed much towards IVI with increased degree of distribution. Moreover, *Chromolaena odorata* was dominant shrub species in all the stands. Whereas, co-dominant species in undisturbed stand was: *Rubus rugosus* and *Mussaenda glabra* , moderately disturbed stand: *Urena lobata* and *Solanum xanthocarpum* and highly disturbed stand: *Melastoma melabatricum* and *Solanum xanthocarpum*. However, in herbs species, *Costus speciosus* was dominant species in the undisturbed stand which was replaced by *Mimosa pudica* in the moderately disturbed and highly disturbed stands.

The Sorenson's Index of similarity for tree species was maximum (0.58) between undisturbed and moderately disturbed stands. On contrary, value was minimum (0.46) between moderately disturbed and highly disturbed stands (Table 2). The log-normal dominance-diversity curve (based on IVI) was found in the undisturbed and moderately disturbed stands, however, it was short hooked in case of highly disturbed stand

Table: 1. Canopy cover, light interception and disturbance index in the undisturbed, moderately disturbed and highly disturbed forest stands.

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

Table: 2, Sorenson's index of similarity

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

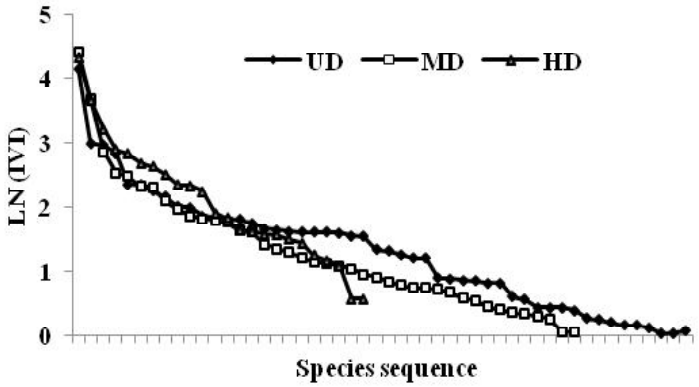

Figure: 1. Dominance- diversity curves of tree species along disturbance gradient

Asteracease was the dominant family in the undisturbed and moderately disturbed stand. However, in the highly disturbed stand, Euphorbiaceae was the dominant family, followed by co-dominant family Papilionaceae, Euphorbiaceae in the undisturbed stand, Caesalpiniaceae, Euphorbiaceae, Fabaceae in moderately disturbed stand and Asteraceae, Papilionaceae, Caesalpiniaceae in highly disturbed stand. The plant used to cure different types of disease is presented in Table-3.

Table: 3, Ethnomedicinal plants species found in study area.

Botanical name	Local name (Mizo)	Family	Part use	Therapeutic use	Apecimen collection no.
Abelmoschus moschatus Linn.	Uichhuhlo	Malvaceae	Roots, seeds and bark	Stimulant, antispasmodic, glycyrrhizin useful in coughs, emmenagogue.	H- 1
Achyranthes aspera Linn.	Buchhawl	Amaranthaceae	Whole plant	Pungent, purgative, astringent, hydrophobia.	H- 2
Ageratum conyzoides Linn.	Vailenhlo	Asteraceae	Root and leave	Tuberculosis. Leave and inflorescences are used for hair wash by women.	H- 3
Albizia chinensis (Osb.) Merr.	Vang	Mimosaceae	Bark	Piscicidal	T- 1
Albizia procera (Roxb.)	Kangtek	Mimosaceae	Bark and leaves	Stomach, intestinal disease, anti cancer activity.	T- 2
Albizia lebbek Benth.	Thing-chawk-e	Mimosaceae	Leave, bark and seeds	Antiseptic, antidysenteric and antitubercular properties.	T- 3
Aporusa octandra (Buch.-Ham. Ex D.Don)	Chhawntual	Euphorbiaceae	Bark	Stomach ulcer, diarrhoea and dysentery.	T- 4
Artocarpus heterophyyllus Lamk	Lamkhuang	Moraceae	Root and fruit	Ddiarrhoea. Unripe fruit is astringent and the ripe is laxative.	T- 5
Amaranthus spinosus Linn.	Len-hling	Amaranthaceae	Root and leave	Menorrharia, eczema and colic pain.	H- 4
Bombax ceiba Linn	Phunchawng	Bombacaceae	Root, bark, leave and gum	Demulcent, haemostatic, astringent, roots are stimulant,tonic.	T- 6
Bridelia stipularis(Linn.) Bl.	Phaktel	Euphorbiaceae	Roots, leaves	Seeds possess hemagglutinating properties.	S- 1

			and seed		
Biden pilosa Linn.	Vawk-pui-thai	Compositae	Flower, seed and roots	Diarrhoea.	H- 5
Barleria cristata Linn.	Ui-te-ke	Acanthaceae	Roots and leave	Swelling and snake bite.	H- 6
Bauhinia purpurea Linn.	Vau-fa-vang	Caesalpiniaceae	Bark and roots	Bark extract in leucorrhoea, leprosy.	T- 7
Callicarpa arborea Roxb.	Hnahkiah	Verbenaceae	Bark	Cutaneous disease	T- 8
Cassia fitula Linn	Ngaingaw	Caesalpiniaceae	Root, bark	Chronic fever, purgative, ringworms	T- 9
Cassia hirsuta Linn	Caesalpiniaceae	Leaves	Ringworms and pustules		S- 2
Cassia occidentalis Linn.	Rengan	Caesalpiniaceae	Roots and seed	Laxative, arphrodisiac	S- 3
Centella asiatica Linn	Lambak	Apiaceae	Whole plant	Diabetes, stomach-ache, dysentery, high blood pressure	H- 7
Castanopsis tribuloides (Sm.) DC.	Thingsia	Fagaceae	Bark and leaves	Contain tannin.	T- 10
Chromolaena odorata Linn.	Tlangsam	Asteraceae	Leaves	Fish poison	S- 4
Costus speciosus (Koenig) Smith.	Sumbul	Zingiberaceae	Rhizome and seeds	Dysuria, fever, bronchitis, rheumatism	H- 8
Cynodon dactylon Pers.	Phaitaulhlo	Gramineae	Rhizome	Genito-urinary troubles	H- 9
Desmodium gyroides DC.	Hmeithaisarawhtui	Papilionaceae	Leaves	Lumbago	S- 5
Debregeasia velutina Gaud.	Lehngo	Urticaceae	Leave	Applied on burns	T- 11

Derris robusta Benth.	Thingkha	Papilionaceae	Roots	Fish poison	T- 12
Emblica officinalis Gaertn	Sunhlu	Euphorbiaceae	Fruit	Vitamin C, astringent, diuretic and laxative	T- 13
Engelhardtia spicata Lindl.	Hnum	Juglandaceae	Bark	Fish poison	T- 14
Erythrina stricta Roxb.	Fartuah	Papilionaceae	Bark	Stomach trouble	T- 15
Eucalyptus globulus Labill.	Nawalhthing	Myrtaceae	Leaves	Expectorant, stimulant, insect repellant	T- 16
Ficus hirta Linn.f	Sazutheipui	Moraceae	Leaves	Ringworms, dysentery	T- 17
Flemingia stricta Roxb.	Uifawmaring	Papilionaceae	Root	Swelling and pain	S- 6
Gynura nepalensis Benth.	Buar	Compositae	Leave	Stopping bleeding, headache	H- 10
Hedychium spicatum Buch-Ham	Aithur	Zingiberaceae	Rhizomes	Stomachic, carminative, stimulant	H- 11
Impatiens chinensis Linn.	Hawilo	Balsaminaceae	Whole plant	Burns and taken internally with milk in gonorrhoea.	H- 12
Imperata cylindrica Wall.	Di	Gramineae	Root	Restrorative, haemostatic, antifebrile properties	H- 13
Inula cappa DC.	Hmeithaisatui	Compositae	Root	Adulterant of Kuth.	S- 7
Largerstroemia speciosa Pers	Thlado	Lythraceae	Seed, bark, leave and roots	Narcotic, purgative, astringent	T- 18
Lantana camara Linn	Tilduhpar	Verbenaceae	Leaves	Antispasmodic, diaphoretic, abdominal viscera	S- 8
Macaranga denticulata Muell.-Arg	Zawngtenawhlung	Euphorbiaceae	Gum	Antiseptic	T- 19

Mangifera indica Linn.	Theihai	Anacardiaceae	Fruit,bark and gum	Riboflavin, haemorrhoids, tonic	T- 20
Melastoma nepalensis Lodd.	Builukhamnu	Melastomaceae	Fruit	Dysentery, constipation	S- 9
Meliosma pinnata (Roxb)Walp.	Buangthei	Sabiaceae	Leave	Vitamin A and C	S- 10
Michelia champaca Linn.	Ngaiuhnahhlai	Magnoliaceae	Flower and bark	Insect repellant, tonic, stomachic	T- 21
Mimosa pudica Linn.	Hlonuar	Mimosaceae	Root	Urinary complaints, pile	H- 14
Murraya koenigii (Linn.) Spreng.	Arpatil	Rutaceae	Leaves	Diarrhoea, dysentery, digestive	S- 11
Mussaenda glabra Vahl.	Vakep	Rubiaceae	Root and leaves	Snake bite, leucoderma	S- 12
Phyllanthus glaucus Wall.ex Muell.-Arg	Saisiakte	Euphorbiaceae	Whole plant	Astringent, deobstruent, febrifuge.	S- 13
Physalis minima Linn.	Chalpangpuak	Solanaceae	Shoot	Urinary disorder, jaundice	H- 15
Plantago major Linn.	Kelbaan	Plantaginaceae	Leave and root	Fever, genito-urinary tract complaints	H- 16
Oroxylum indicum Vent.	Archangkawm	Bignoniaceae	Leave and root bark	Epilepsy, tonic and astringent.	T- 22
Psidium guajava Linn.	Kawlthei	Myrtaceae	Young leave and bark	Dysentery, anthelmintic,tonic	T- 23
Rhus succedanea Linn.	Chhimhruk	Anacardiaceae	Leave and fruit	Kidney and urinary complaints due to stones	T- 24
Rubus rugosus Sm.	Sailinuchhu	Rosaceae	Leave and fruit	Astringent, abortifacient	S- 14
Schima wallichii (DC.) Korthals.	Khiang	Theaceae	Bark	Expelling worm from intestine, gonorrhoea	T- 25

Scoparia dulcis Linn.	Perhpawngchaw	Scorphulariaceae	Whole plant	Emetic, antidiabetic, anaemia	H- 17
Solanum nigrum Linn.	Anhling	Solanaceae	Whole plant	Dysentery, pile, heart disease	H- 18
Solanum torvum Swartz	Tawkpui	Solanaceae	Fruit	Sedative, diuretic	S- 15
Spilanthes acmella Murr.	Ansapui	Compositae	Flower and root	Relieve toothache, mosquito larvicide, purgative	H- 19
Stephania rotunda Hoof. F. and Thoms	Chaihchun	Menispermaceae	Tuber	Intestinal complaints, asthma.	C- 1
Sterculia villosa Roxb.	Khaupui	Sterculiaceae	Gum	Antiseptic, veterinary medicine	T- 26
Toona ciliata M.Roem	Tuipui	Meliaceae	Leave and bark	Vomiting, chronic infantile dysentery	T- 27
Urena lobata Linn.	Sehnap	Malvaceae	Leave and root	Fever, cough, headache, diuretic	H- 20
Wendlandia tinctoria DC.	Batling	Rubiaceae	Bark	Cholera patients	T- 28

T- Tree, **S**- Shrub, **H**- Herb, **C**- Climber

*Source- Singh *et al.*, 2012, Nebio (3). Pp15-19

Discussion

Species diversity is an important attribute of a natural community that influences functioning of an ecosystem (Hengeveld 1996). Richards (1996) has argued that high species richness may be due to the presence of many synusiae in the forest. The species richness was reported high in the undisturbed and moderately disturbed stand. This could be attributed due to favourable edapho-climatic conditions (high and prolonged rainfall, moderate temperature, high relative humidity, status of soil) that support overall plant diversity. The rich diversity may also be due to an increase in spatial heterogeneity because of the various effects of disturbances in lands as well as latitudinal and lavational gradient which are compatible with the maintenance of high diversity. The trend in the results on the species richness, tree density and basal area are similar to the findings of past workers who studied different tropical forest ecosystems over the World (Murphy and Lugo 1986, Singh and Singh 1991, Ravan 1994, Verghese and Menon 1998, Sunderpandian and Swamy 2000, Chowdhury et al. 2000, Fox et al. 1997, Khera et al. 2001, Kadavul and Parthasarathy 1999). The sand stone mining has resulted in drastic decrease in species richness, tree density and basal area. Mishra et al. (2004) have also reported a similar trends along disturbance gradient in subtropical humid forest of Meghalaya. The tree population structure observed in present study is similar to those reported from the forest at Costa Rica (Nadakarni et al. 1995), Brazalian Amazon (Cambell et al. 1992), Eastern Ghats (Kadavul and Parthasarathy 1999) and sub tropical humid forest of Meghalaya (Mishra et al. 2005). The shift in position of species could be linked with disturbance. Moreover, the species tolerant to stress showing better growth and survival under disturbed condition, such species express greater IVI in the disturbed stand. On contrary, the species sensitive to the disturbance either eliminated with increase in degree of disturbance or showing poor growth. The shift in position of the species and families along the disturbance gradient could be linked with the levels of anthropogenic disturbance and similar trends was also reported by number of workers in the past (Thorington et al. 1982, Visalakshi 1995, Parthsarathy and Sethi 1997, Parthsarathy and Karthikeyan 1997, Kadavul and Parthasarathy 1999, Mishra et al. 2003, 2004, 2005 and Mishra and Laloo 2006).

Conclusion

The anthropogenic pressures including stone mining have resulted in degradation of natural habitats and subsequently loss of biodiversity. During present investigation it was found that a large forest area have

been turned into degraded forest due to extensive stone mining, creating unfavourable habitat conditions for plants. The unfavourable habitat conditions prevailing in the mined areas have reduced the chances of regeneration of many species, thereby reducing the number of species in mined areas. The shift in position of species and families from undisturbed to highly disturbed stands could be linked with degree of disturbance. The tree species sensitive to disturbance as reflected by their reduced abundance or complete absence in the highly disturbed stand (like *Acacia fernesiana*, *Engelhardtia spicata*, *Oroxylum indicum*) appear to be more vulnerable to the disturbance.

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

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Changes in plant species composition, biomass structure and allocation pattern in a peri-urban region in tropical India

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Abstract

The present study investigated seasonal biomass structure (AGB and BGB) of six differing anthropogenic sites (brick kilns, grazing land, polluted Kali river bank, and agricultural land) in a dry tropical peri-urban region of Bulandshahr. Surface-soils of all sites in three seasons were analyzed for physico-chemical characteristics. Five commom weeds *Parthenium hysterophorus* L., *Cassia obtusifolia* L., *Achyranthes aspera* L., *Sida acuta* Burm. f. and *Chenopodium murale* L. were examined for their biomass partitioning to leaf, root, stem and reproductive parts. Of the 125 recorded species, predominantly annuals, belonging to 34 angiospermic families, maximum occurred in rainy season and minimum in summer. Beta diversity showed reverse trend. Grazing land and river bank were more diverse. Dominants altered with sites and seasons with increasing dominance of invasive alien *Parthenium hysterophorus*. The soils were heterogeneous with generally lower soil-moisture, organic C, total N at abandoned brick kiln site. AGB and BGB of the vegetation showed much temporal and spatial variability. Belowground biomass decreased significantly with increasing soil fertility. Larger subterranean allocation at dry and infertile brick kiln site reflected enhanced growth of nutrient-absorption organs by plant species here. Species diversity was higher at both low as well as higher productive systems in anthropic habitats. Biomass allocation to different plant components varied with species and soil-resource conditions. *Chenopodium murale* showed maximum shoot length with higher biomass of stem, reproductive parts, shoot and total plant. *Parthenium hysterophorus* and *Achyranthes aspera* had

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comparable allocation pattern. *Sida acuta* had larger belowground allocation (17%), whereas *Cassia obtusifolia* had greater reproductive allocation (11%). Thus, this study revealed that the drier months after rains, soil nutrient and disturbance regimes considerably influenced species diversity, biomass production and allocation in the peri-urban habitats in Indian dry tropics. Biomass allocation differed with species, soil resource and disturbance experienced by plants.

Keywords: Aboveground; Belowground; diversity; peri-urban vegetation

Introduction

The peri-urban areas may be considered highly dynamic and important both ecologically as well as economically. These areas represent a transition or interaction zone, where urban and rural activities are juxtaposed, and landscape features are subject to rapid modifications due to human activities (Douglas 2006). McGranahan et al. (2004) opined that peri–urban zones are often far more environmentally unstable than either urban or rural settings. Urbanisation in its vicinity creates new opportunities for many, but, it simultaneously results in accelerated environmental degradation in these peri-urban zones. Persisting ecosystem perturbation in peri-urban areas reportedly threatens the sustainability of cities through both direct and indirect impacts on health and essential life-support systems. For cities to remain sustainable in future, the natural resource base and the ecosystem services in the peri-urban areas surrounding cities need to be judiciously maintained.

A variety of landuse changes have often been discerned in dry tropical peri-urban regions at relatively lower spatial scale (Gupta and Narayan 2011). In these areas, diversity structure of the plant communities is greatly impacted by human activities (Gupta and Narayan 2006), which may inadvertently affect the productivity of these ecosystems. On account of continuous anthropogenic pressure, these areas have been transformed into relatively low productive systems with weak soil micro-floral development. This makes these ecosystems highly fragile from the point of view of their structure and functioning. The plant community organization in these peri-urban ecosystems is determined to a great extent by productivity and nutrient availability (Austin 1990, Foster et al. 2004). Studies on understanding community organization, particularly in peri-urban regions, in terms of both aboveground and belowground biomass structure and their relations with environment has been rather few despite recognition of their importance in ecological investigations. The differential allocation of biomass to aboveground and belowground plant parts has

implications for a plant survival under different environmental conditions which determine its relative competitive ability for aboveground and belowground resources, and ultimately, survival, growth, and reproduction of the plant population (Werner and Murphy 2001). Belowground organs appear immensely important for their role in structure and function of a plant community especially in dry tropical peri-urban habitats that are exposed to relatively greater human intervention. However, they have received little ecological attention, mainly because they are more difficult to work with (Titlyanova et al. 1999, Yang et al. 2009). The soil resources in such habitats are often limiting. In such conditions plants may respond by enhancing subterranean allocation to optimize the capture of soil nutrients and maximize plant growth rate (Bonifas et al. 2005, Mahoney and Swanton 2008). Biomass allocation also varies in response to the developmental stage of a plant (ontogenetic shift, Evans 1972). While the allocation of biomass to component plant organs has been relatively much explored, few studies have dealt with the way in which biomass is distributed among species at the community level (Luzuriaga et al. 2002). Ecological investigations pertaining to biomass allocation strategy of plant species growing in anthropic ecosystems particularly in dry tropics are also few, and such studies are still fewer with respect to biomass distribution to reproductive parts/efforts. These studies are of immense importance to understand the expansionist growth strategy of weeds and ruderals that are fast intruding into these peri-urban areas (Gupta and Narayan 2012).

The present study designed in a dry tropical peri-urban weedy vegetation aimed to: (i) assess the dominance of species across different season and site conditions, (ii) understand the spatial and temporal variation of plant biomass, (iii) study the biomass production and allocation pattern of selected weed species, and (iv) study vegetation, biomass and allocation characteristics in relation to physico-chemical characteristics of soils.

Study Area

The study area was located at Bulandshahr (28º 24´ N lat. and 77º 51´ E long.) in western part of Uttar Pradesh, surrounded in vicinity by several developed urban centres e.g. Delhi, Noida, Ghaziabad, Meerut and Aligarh (Fig. 1). Six study sites were established for intensive study in an area of 3 km^2 that covered diverse habitat conditions / land-uses. Three study sites were: (i) Grazing land (GL), (ii) Kali river bank (KRB), and (iii) Agricultural land (AL). The other three sites were established in brick kiln industrial area differing from each other w.r.t. the period of industrial operation and distance from the brick kiln unit. They were: (i) Abandoned

brick kiln (ABK), (ii) Working brick kiln (WBK), and (iii) Intervening brick kiln (IBK) sites.

The climate of the study area is semi-arid having three seasons: rainy, winter and summer. The monthly mean minimum temperature ranged from 7.9°C (January) to 28.3°C (June) and the mean maximum from 17.2°C

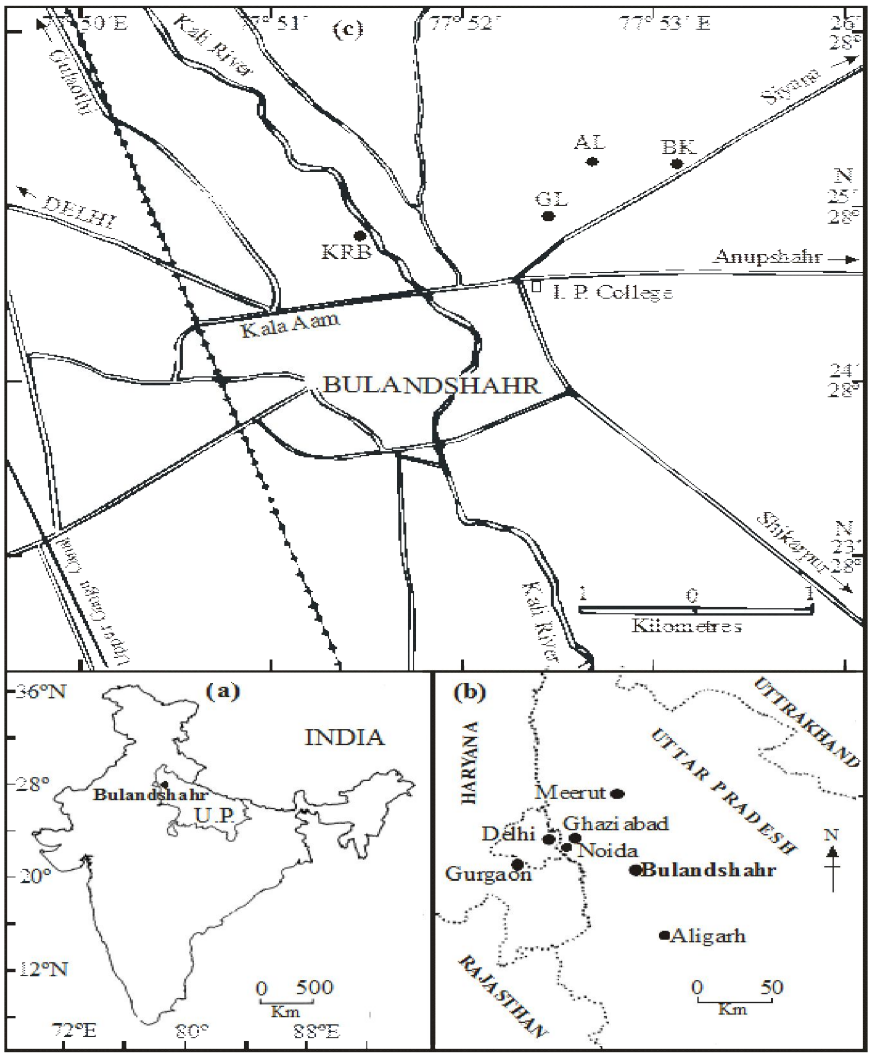

Fig.1. Map showing location of study area (a), the peri-urban region of Bulandshahr surrounded by some developed urban centres (b), and distribution of study sites in Bulandshahr (c). Study-site Codes: KRB, Kali river bank; GL, Grazing land; AL, Agricultural land; BK, Brick kiln industrial area (three sites established here included Abandoned, ABK; Intermediate, IBK; and Working brick kiln, WBK).

(January) to 39.4°C (June) (Fig. 2). Annual mean rainfall was 469 mm, of which more than 82% occurred in the three wet months of July, August and September. This was distributed over 55 rainy days in a year, which included 40 days of rains from July to September.

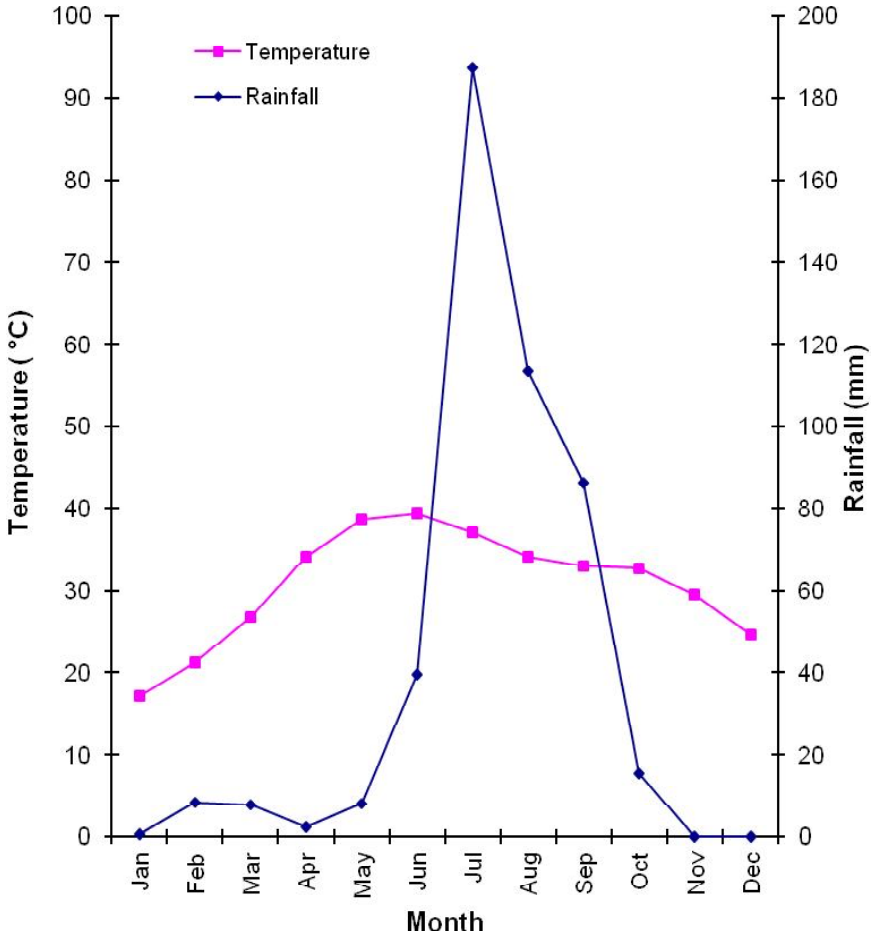

Fig.2. Ombrothermic diagram for Bulandshahr showing temperature and rainfall distribution over different months.

Materials and Methods

Floristic composition

Floristic composition of the study sites was recorded at monthly intervals for two years.

Plant biomass sampling

A total of 300 monoliths (each of 400 cm^2 surface area and 20 cm depth) were excavated with the help of soil corer and washed over a sieve system to estimate aboveground (AGB), belowground (BGB) and total biomass (TB) across six different sites in three seasons. Plant material was separated into different species as far as possible. All plant individuals were fractioned into aboveground and belowground plant parts, dried (for 48 hrs at 80°C) and weighed. Unidentified species were placed under miscellaneous category. Biomass (g m^{-2}) of aboveground and belowground organs was calculated for each of the species. The biomass data of all species was pooled to get total site biomass.

Species Diversity

Species diversity of the study sites was estimated in terms of species count and Shannon-index using total biomass of the species as dominance data.

Species count (the number of species that occurred in monoliths sampled across a study site).

Shannon-index (H') (Shannon and Weaver 1949) $= -\sum pi \ln pi$, where *N* = total sum of relative dominance of all species i.e. 100, *pi* = proportional dominance of i^{th} species (*ni/N*), *ni* = relative dominance of each species.

Beta diversity was calculated within the vegetation at a study site by dividing the total number of species at a site by the average number per sample (Whittaker 1972).

Biomass allocation pattern of selected species

A total of 415 individals (~30 of each species at each study site) belonging to five species *viz*. *Parthenium hysterophorus* L., *Cassia obtusifolia* L., *Achyranthes aspera* L., *Sida acuta* Burm. f. and *Chenopodium murale* L. were selected at Grazing land, Kali river bank and Brick kiln sites, across a wide range of shoot length. They were dug out, washed and measured for growth characteristics (root length, shoot length, and basal diameter). All individuals were fractioned into various plant components (root, leaf, stem and reproductive parts), dried (80°C for 48 hr) and weighed to determine component biomass, aboveground (shoot), belowground (root) and total biomass (TB). The component mass fractions (leaf mass fraction, LMF; stem mass fraction, SMF; reproductive parts mass fraction, RPMF; and root mass fraction, RMF) were estimated

as the biomass of each component relative to the total plant biomass (TB).

Soil analysis

Four representative surface soil samples (0–10 cm) were collected from each study site in each of the months of October, February, and June. The soil samples were air-dried and sieved (2 mm). The soil moisture content was determined on dry weight basis. Soil pH was determined by a digital pH meter (1:5 soil:water ratio). Soil organic carbon (Walkley and Black method) and total nitrogen (micro-Kjeldahl method) were estimated according to Piper (1944). Available phosphorus, exchangeable calcium and potassium were estimated according to Allen et al. (1986).

Statistical Analysis

Statistical and graphical analyses were carried out using SPSS 16.0 and Sigma Plot 10.0.

Results

In all, 125 plant species distributed over 34 families (31 dicot and 3 monocot) were recorded during the study period (Appendix). Considering all study sites together in a season, maximum flora was recorded in rainy season (84) followed by winter (68) and summer (58) season. The herbaceous species belonging to Poaceae (27), Asteraceae (11), Leguminosae (11), Malvaceae (8), Cyperaceae (7) and Amaranthaceae (7) comprised more than 55% of total flora recorded in the present study. Of this, the grasses belonging to Poaceae and Cyperaceae alone accounted for more than 25% of the total species.

In terms of total (aboveground + belowground) biomass dominant species generally changed with site and season (Table 1). *Saccharum munja* at ABK site was a distinct dominant accounting for >71% of site biomass in winter and summer and 30% in rainy season. In rainy season the sub-dominant associates of *Saccharum munja* included *Dactyloctenium aegypticum* and *Achyranthes aspera* together accounting for 25% of the total site biomass. At GL site non-grass species were the top dominants: *Cassia obtusifolia* in rainy, *Sida acuta* in winter and *Chenopodium murale* in summer season. Biomass contribution by non-grass species increased in winter and summer seasons e.g. in summer where *Chenopodium murale*, *Parthenium hysterophorus* and *Cannabis sativa* together shared >70% of total site biomass. Increasing dominance of *Parthenium hysterophorus* is apparent at KRB, where it was top dominant in summer (>34% of site biomass). In winter season here, *Rumex dentatus* and *Alternanthera sessilis*

together shared 57% biomass, and in rainy season, several close contesting species *Sida acuta, Parthenium hysterophorus, Cassia obtusifolia, Abutilon indicum* and *Sida cordifolia* together accounted for 52% of total site biomass. At AL site under wheat (contributed >60% of site biomass) cultivation in winter, weeds *Phalaris minor* and *Cynodon dactylon* too showed the total biomass contribution of about 17%. However, under no crop status of AL as seen in rainy season, the graminoids like *Cynodon dactylon, Cyperus rotundus, Paspalidium flavidum* showed a share of over 35% biomass. In summer under *Zea mays* and *Vigna radiata* crops that together accounted for 70% of total biomass, the *Trianthema portulacastrum* alone showed about 15% of total biomass.

Table 1. Vegetation, biomass and soil characteristics of four different study sites in a dry tropical peri-urban area.

	Kali river bank	**Grazing land**	**Abandoned brick kiln**	**Agricultural land**
1. Dominant species (in terms of % of total site biomass)				
(i) Rainy season	*Sida acuta* (14.0)	*Cassia obtusifolia* (21.2)	*Saccharum munja* (73.8)	*Cynodon dactylon* (20.9)
	Parthenium hysterophorus (11.4)	*Cynodon dactylon* (11.5)	*Dactyloctenium munja* (32.6)	*Trianthema portulacastrum* (9.4)
	Cassia obtusifolia (9.7)	*Sida acuta* (10.5)	*Achyranthes aspera* (28.8)	*Cyperus rotundus* (7.6)
(ii) Winter season	*Rumex dentatus* (32.8)	*Sida acuta* (10.5)	*Saccharum munja* (72.9)	*Triticum aestivum* (60.7)
	Alternanthera sessilis (24.2)	*Oxalis corniculata* (9.0)	*Boerhavia diffusa* (10.6)	*Phalaris minor* (11.8)
	Cynodon dactylon (10.4)	*Malva sylvestris* (8.9)	*Sida rhombifolia* (2.4)	*Cynodon dactylon* (5.3)
(iii) Summer season	*Parthenium hysterophorus* (34.2)	*Chenopodium murale* (27.2)	*Saccharum munja* (71.9)	*Zea mays* (45.1)

	Cynodon dactylon (9.7)	*Parthenium hysterophorus* (23.2)	*Boerhavia diffusa* (4.6)	*Vigna radiata* (24.4)
	Croton bonplandia-num (9.5)	*Cannabis sativa* (19.8)	*Urena lobata* (4.5)	*Trianthema portulacastrum* (14.9)
2. Plant biomass (g m^{-2})				
Aboveground biomass				
Rainy season	674±29	738±83	539±64	238±32
Winter season	350.±40	278±30	307±21	228±25
Summer season	544.±46	631.±64	516±73	328±10
Belowground biomass				
Rainy season	215±14	288±34	240±37	106.±6
Winter season	122±22	96±9	253±29	163±19
Summer season	173±29	148±14	179±28	83±10
3. Species diversity				
No. of species recorded				
Rainy season	63	56	35	33
Winter season	46	41	31	22
Summer season	28	22	26	23
Shannon Index				
Rainy season	2.79	2.68	2.38	2.68
Winter season	2.11	3.07	0.98	1.54
Summer season	2.28	1.91	1.20	1.67
Beta diversity				
Rainy season	6.12	4.78	3.68	1.98
Winter season	11.21	6.66	5.16	2.36
Summer season	9.86	6.43	5.53	2.80
4. Range of Soil characteristics				
Summer moisture (%)	1.35 - 5.63	1.01 - 3.46	1.01 - 2.04	0.99 - 1.02
pH	7.0 - 7.9	6.9 - 7.3	7.3 - 7.7	7.8 - 7.9
Org. C (%)	0.84 - 1.16	1.14 - 1.33	0.11 - 0.31	0.39 - 0.66

Total N (%)	0.03 - 0.04	0.07-0.08	0.02-0.03	0.02-0.05
C:N ratio	28 – 31	17 - 18	08 – 10	18 - 21
Available P (mg/g)	0.019-0.040	0.018-0.043	0.012-0.016	0.023-0.041
K (mg/g)	0.25 - 0.53	0.41 - 0.48	0.24 - 0.36	0.21 - 0.69
Ca (mg/g)	0.16 - 0.85	0.26 - 0.90	0.28 - 0.70	0.16 - 0.99

The range of total site biomass over three seasons was maximum at GL (652 g m^{-2}) followed by KRB (417 g m^{-2}) and ABK (219 g m^{-2}) and minimum at AL site (67 g m^{-2}) (Table 1). In different seasons total build up of plant biomass (aboveground, belowground and total) at GL and KRB sites showed a similar trend: rainy>summer>winter. At ABK site AGB and TB followed a similar trend, BGB here, however, showed maximum value in winter and lowest in summer. AL site showed varying trend in terms of BGB, AGB and TB in different seasons.

In all seasons, number of species recorded was maximum at KRB and minimum at AL. Shannon index was maximum at KRB (2.79), and lowest at ABK (2.38). The highest level of diversity attained across all sites and seasons was shown by GL in winter (Shannon index 3.07). In summer, however, KRB was most diverse followed by GL and ABK. ABK site, compared to others consistently showed highest dominance concentration in all seasons. Beta diversity ranged between 1.98 and 11.21 (Table 1). It was lowest at AL site. Beta diversity generally increased in winter and summer compared to that in rainy season for all study sites. Beta diversity at KRB site was maximum in all seasons compared to that at other study sites.

The soils of the study sites were highly heterogeneous (Table 1). They were neutral to slightly basic (pH 6.9 - 7.9). The moisture content of the summer soils varied from 0.99 % to 5.63%. Across all sites and seasons soil organic C ranged from 0.11 % to 1.33 %, total N from 0.02 % to 0.08 %, available P from 0.012 mg/g to 0.043 mg/g, exch. K from 0.21 mg/g to 0.69 mg/g and exch. Ca from 0.16 mg/g to 0.99 mg/g.

On the mean basis, amongst the investigated plant species, *Chenopodium murale* showed maximum biomass of stem, reproductive parts, shoot and total plant (Table 2). This species showed lowest RL:SL ratio (0.27), BGB:AGB ratio (0.11), LMF (0.26) and RMF (0.10). In this species RPMF was markedly higher (0.27) compared to that in others. *Sida acuta* showed the highest biomass allocation to belowground parts

Table 2. Growth (shoot length, root length, basal diameter) and biomass (leaf, stem, reproductive parts, roots) characteristics of plant samples belonging to five different species (mean ± S.E.).

	Achyranthes aspera	***Cassia obtusifolia***	***Chenopodium murale***	***Parthenium hysterophorus***	***Sida acuta***
Shoot length (SL) (cm)	40.40±2.12	41.83±2.16	57.15±4.49	38.07±2.63	35.91±1.85
Root length (RL) (cm)	17.11±0.76	13.46±0.40	11.55±0.50	10.87±0.31	16.72±0.66
Basal diameter (cm)	0.50±0.03	0.58±0.03	0.58±0.03	0.60±0.02	0.48±0.03
Leaf biomass (g)	2.51±0.31	3.03±0.33	1.82±0.27	1.68±0.13	1.79±0.21
Stem biomass (g)	4.03±0.65	4.65±0.60	5.25±0.97	2.45±0.29	3.47±0.59
Reproductive parts biomass (g)	0.83±0.16	1.25±0.19	2.83±0.48	0.49±0.08	0.55±0.08
Belowground (BGB) / Root Mass (g)	1.02±0.14	0.89±0.11	0.99±0.18	0.70±0.08	0.92±0.12
Aboveground (AGB) / Shoot Mass (g)	7.13±1.03	8.83±1.03	9.52±1.61	4.50±0.43	5.64±0.82
Total biomass (g)	8.15±1.15	9.72±1.13	10.51±1.79	5.19±0.50	6.57±0.94
AGB (%)	86.49±0.64	89.77±0.49	90.07±0.36	86.35±0.53	82.93±0.55
BGB (%)	13.51±0.64	10.23±0.49	9.93±0.36	13.65±0.53	17.07±0.55
RL:SL ratio	0.51±0.03	0.41±0.03	0.27±0.02	0.61±0.09	0.56±0.03
BGB:AGB ratio	0.16±0.01	0.12±0.01	0.11±0.00	0.16±0.01	0.21±0.01
Leaf mass fraction (LMF)	0.41±0.01	0.37±0.01	0.26±0.02	0.41±0.02	0.36±0.01
Stem mass fraction (SMF)	0.41±0.01	0.43±0.01	0.45±0.01	0.40±0.02	0.43±0.01

Root mass fraction (RMF)	0.14±0.01	0.10±0.00	0.10±0.00	0.14±0.01	0.17±0.01
Reproductive parts mass fraction (RPMF)	0.07±0.01	0.11±0.01	0.27±0.02	0.06±0.01	0.06±0.01
n_t*	90	85	60	90	90
n_r*	64	78	43	68	63

* n_t = total number of plant samples

n_r = number of plant samples having reproductive parts.

(RMF: 0.17). RL:SL ratio of the investigated plant species generally varied from 0.41 (*Cassia obtusifolia*) to 0.61 (*Parthenium hysterophorus*). For *Chenopodium murale*, this ratio was 0.27 only. While the mean root length of species varied between 11 and 17 cm, shoot length varied from 36 to 57 cm. BGB:AGB ratio of the plant species ranged from 0.11 to 0.21. *Parthenium hysterophorus* and *Achyranthes aspera* showed much comparable biomass allocation pattern: RMF (0.14), LMF (0.41), SMF (0.40-0.41) and RPMF (0.06-0.07). On the other hand, *Cassia obtusifolia* and *Sida acuta* allocated 43% to stem and 36-37% to leaf but differed in root and reproductive allocation. *Sida acuta* allocated comparatively larger proportion of total biomass to belowground parts (RMF:0.17), whereas *Cassia obtusifolia* allocated comparatively more to reproductive parts (RPMF:0.11).

Discussion

As evinced from the present ecological study on structure of species diversity across four major contrasting habitat conditions (Kali river bank, brick kiln, grazing land and agricultural land) in the dry tropical peri-urban area of Bulandshahr, there was preponderance of weedy herbs, spatially mosaic in pattern, that was more pronounced in dry months than in wet months (Gupta and Narayan 2006). Species dominance altered with sites and seasons (Table 1) with increasing dominance of exotic species like *Parthenium hysterophorus*. A total of 125 plant species, predominantly annuals belonging to 34 angiospermic families were recorded here (Appendix). This is reflective of relatively higher species diversity here, when compared with diversity of comparable habitats in semi-arid region, Sanganer, Jaipur (Sharma et al. 2001). Total number of species at each of the study sites (α diversity) was highest in rainy season and lowest in summer, whereas the reverse trend was observed for beta diversity (Table 1). This could be attributed to environment homogenization impact in soils by plentiful soil moisture in rainy season. Lososova et al. (2004) too showed higher beta diversity in summer for weed communities. Higher beta diversity, suggesting higher habitat heterogeneity, was found at higher soil resource regimes (Fig. 3a). This possibly reflected larger range of micro-sites differing in micro-environment, available at relatively enhanced nutrient condition of soil, thus allowing larger number of species with varying ecological amplitude to survive under such conditions (Gupta and Narayan 2006). The soils of the study sites were heterogeneous with lower moisture, organic C and total N at brick kiln compared to Kali river bank and grazing land sites (Table 1).

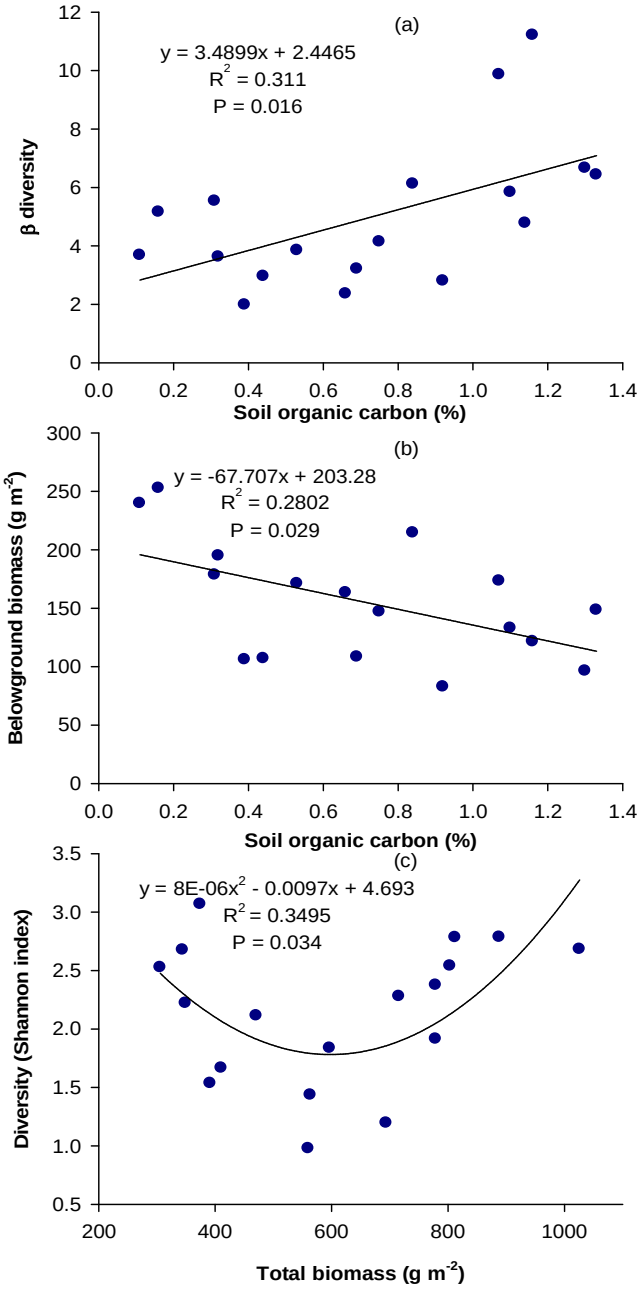

Fig. 3. Relationship between soil organic carbon and beta diversity (a), soil organic carbon and belowground biomass (b), and total biomass and diversity (Shannon index) (c) of the study sites in a dry tropical region.

Plant biomass, although often considered an ideal measure of abundance (Chiarucci et al. 1999) may vary in reference to aboveground (AGB) or belowground (BGB) biomass, despite a strong interrelationship between these two (Gupta and Narayan 2010, 2011). Biomass production showed wide spatial and temporal variations (Table 1). Aboveground and belowground biomass of the plant community at a site were significantly affected by site and season.

Temporal dynamics in weed communities on the scale of seasonal changes (Lososova et al. 2003) was evident in this study. The biomass build up strategy of plant assemblages at different sites under study in different seasons showed that the biomass production is conditioned by environmental harshness e.g. temperature, moisture availability etc. The plant response to harshness of environment in dry tropical disturbed habitats, as apparent from this study, is better reflected by BGB distribution corresponding to resource availability.

It was observed that plant communities in habitats with lower soil nutrient and moisture e.g. abandoned brick kiln site (Table 1), allocated larger proportion of their biomass to subterranean parts. A negative correlation between soil organic C and BGB (Fig. 3b) is likely an indicative of greater investment of resources in roots in dry and infertile environment to maximize growth and fitness conditions, and thus compensate for scarcely available soil nutrients (Gupta and Narayan 2010, 2011, Geng et al. 2007, Sultan 2000). This probably explained much comparable total plant biomass (AGB + BGB) at disturbed sites viz. ABK, GL and KRB in moisture-limited conditions in summer. Changes in partitioning of plant biomass often allow plants to maximize their growth rates and optimize resource capture in variable environments (e.g. Bloom et al. 1985, Gleeson 1993, Hilbert 1990, Reynolds and Thornley 1982). The biomass allocation strategy of plant communities under favorable conditions e.g. rainy season tended to be much similar at different sites compared to that in dry months. The AGB range recorded in the present study sites (228-738 g m^{-2}) was comparable to herb biomass range 33-504 g m^{-2} for semi-arid grazingland of Madurai (Meenakshisundaravalli and Paliwal 1997), and 87-848 g m^{-2} for semi-arid habitats in Jaipur (Sharma et al. 2001).

Species diversity and total plant biomass of sites depicted 'U' shaped relationship, explicable by quadratic polynomial relation ($R^2 = 0.3495$, $p = 0.0397$) (Fig. 3c). In a relatively small spatial scale of study as observed here, that included a range of disturbed habitats as well as similar observation noted across various sites within the brick kiln industrial area (Gupta and

Narayan 2010), the 'U' shaped relationship between species diversity and site-biomass indicated that the species diversity in disturbed habitats could be high under both low as well as high production systems. Connell (1978) and Pickett and White (1985) opined that the disturbances allowed the maintenance of species richness by creating a mosaic of patches. Infact, disturbance has been widely recognized as one of the major factors driving variations in species diversity (Huston 1979, 1994, Noss 1996).

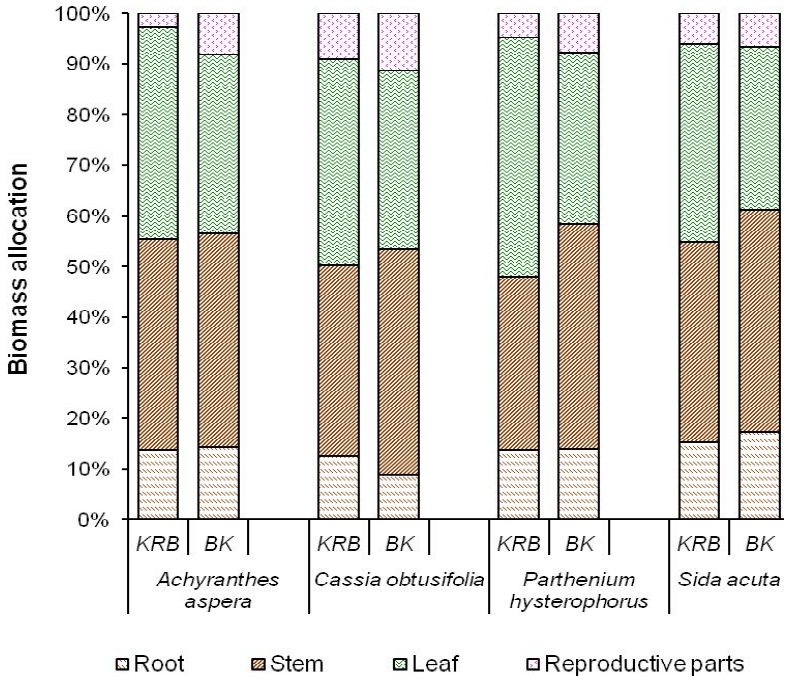

Fig. 4. Varying allocation to different plant components by four species at two sites differing in stress: brick kiln industrial area and bank of Kali river.

The disturbance affecting soil nutrients is intelligible in brick kiln habitats e.g. ABK. In such habitats that experienced long-term stress in the past, with the arrival of favorable environmental conditions e.g. rainy season or period of time with higher soil moisture, the species diversity is likely to increase. It appears that after cessation of disturbance, the annuals considered as ecological opportunists in disturbed habitats (Foster and Stubb-endieck 1980, Tilman 1983), recorded in predominance here, competed to intrude and establish in newly created ecological locations from where the disturbance is withdrawn, as evident at abandoned brick kiln. There was a trade off between species' ability to compete and their ability to tolerate disturbance (Connell 1978, Huston 1994). Thus, competition in seral stages (the studied vegetation patches) is likely to cause high plant diversity

under ecologically favorable conditions. On the other hand, increased diversity under higher production system (WBK here, Table 1) with relatively fertile soil is likely due to larger heterogeneity of differing microsites in dry tropical habitats, supporting greater variety of species as suggested by Gupta and Narayan (2006). The higher diversity at higher sites' total biomass also indicated that a stable multispecies coexistence is allowed to a more efficient use of available resources, the result of complimentarity effect (Kahmen et al. 2005, Tilman et al. 2001).

Five weedy plant species analyzed for their biomass allocation pattern included *Chenopodium murale*, *Achyranthes aspera*, *Sida acuta*, *Cassia obtusifolia* and exotic weed *Parthenium hysterophorus*. Their growth and biomass allocation characteristics showed variability with species (Table 2). While these species are annuals, generally found in field conditions all the year round, *Cassia obtusifolia* is basically a rainy annual weed. These species generally completed only one generation in a year. The exotic invasive weed *Parthenium hysterophorus*, however, completed 2-3 generations in a year, indicating that the plant's life history could also influence plant growth and biomass allocation patterns (Abrahamson 1979). Perennials and annuals may exhibit differing growth strategies (Delph 1990), and strategies may also alter over the life of the individual. In particular, perennials tend to allocate more resources to root production than annuals (Tilman 1988) and fewer resources to reproduction (Gadgil and Solbrig 1972). In this study, of the investigated five weed species, *Sida acuta* allocated maximum belowground biomass (17%) (Table 2) comparable to the adult deciduous plants contributing 16% subterranean allocation (Korner 1994), indicating the tendency of this species to a perennial life form in this region. This species allocated much lower biomass to reproductive parts (6%) but allocated higher biomass to stem (43%). Table 3 compares the ranges of biomass allocation to different plant organs in the presently investigated five weed species with those reported by various workers across different life forms and environments. The investigated annual weeds indicated lower subterranean allocation (9%-17%) compared to perennial herbs and much higher allocation to support structure like stem (stem mass fraction 0.40-0.45). The leaf mass fraction of these species compared well with LMF range of 0.43-0.64 for perennial herbaceous species in Western Europe (Poorter and Remkes 1990) and a mean LMF of 0.46 for herbaceous plants (Poorter and Nagel 2000). LMF in this study was found highest in *Parthenium hysterophorus* indicating its priority investment in photosynthesizing organs, which possibly facilitated its fast establishment and growth to maturity. The pattern of biomass

allocation has been recognized to influence the performance of plants that included growth (Osone and Tateno 2005), reproduction (Schmid and Weiner 1993), and competitive ability (Grime 1979, Tilman 1982).

Table 3. Comparison of averaged biomass allocation values of different categories of plant species. Allocation is characterised either as S/R, or as a fraction of total biomass allocated to leaves (LMF), stems (SMF) and roots (RMF).

Species	LMF	SMF	RMF	RPMF	S/R	Reference
Adult conifers	0.04	0.76	0.20	-	4.10	Korner (1994)
Adult deciduous	0.01	0.81	0.17	-	5.20	Korner (1994)
Tropical trees	0.11 (0.02-0.34)	0.70 (0.52-0.86)	0.20 (0.08-0.36)	-	-	Ovington & Olson (1970)
Tree seedlings (n = 750)	0.40	0.28	0.32	-	2.10	Poorter & Nagel (2000)
Biennial wormwood (*Artemisia biennis*)	0.25	0.20	0.15	0.40	-	Mahoney & Kegode (2004)
Herbaceous (n = 500 plants)	0.46	0.24	0.30	-	2.30	Poorter & Nagel (2000)
Herbaceous species (24)	0.54 (0.43-0.64)	0.17 (0.07-0.27)	0.29 (0.22-0.38)	-	-	Poorter & Remkes (1990)
Herbaceous weeds	0.37 (0.26-0.41)	0.42 (0.40-0.45)	0.13 (0.10-0.17)	0.10 (0.06-0.27)	7.96	Present study

Biomass allocation could also be defined in terms of leaf, stem and root weight ratio, the fraction of total biomass allocated to leaves, stems and roots respectively. The allocation of biomass to different plant organs varied with species (Table 2), and environment experienced by the plants (Poorter and Nagel 2000). Plants also allocated their biomass to different organs or different functions in response to differing resource availabilities (as observed under nutrient-limited or rich soil conditions in study sites) in an economical manner (Bloom et al. 1985). Allocation to reproductive parts was also affected by environmental stress. This was evident from Fig. 4 where different weed species at nutrient-scarce brick

kiln site showed greater biomass allocation to reproductive and stem components, but lower to leaf compared to the Kali river bank site.

The species vary in their invasive ability typified by having no special germination prerequisites, fast seedling growth, a high degree of phenotypic plasticity, rapid attainment of reproductive maturity, quick flowering, high seed yield and high competitive ability (Baker 1965). Botanical invaders, especially in disturbed habitats due to human intervention, as observed in the presently studied peri-urban sites, also often showed high population growth rates and short generation times (Bazzaz 1986) e.g. *Parthenium hysterophorus* in this study. Although no plant species possessed all of these suggested characteristics, it was still useful to consider the impact they could have on plant growth and biomass allocation, especially under variable environmental conditions. An invasive plant with high fecundity e.g. *Chenopodium murale* in this study allocated a greater proportion of its total biomass to reproductive structures (Gupta and Narayan 2012) under a range of environmental conditions, whereas species with high phenotypic plasticity e.g. exotic invasive weed *Parthenium hysterophorus*, in this study, showed much greater flexibility in growth and allocation strategies over a range of habitats.

In conclusion, the drier months after rains, soil nutrient and disturbance regimes considerably influenced the species composition, biomass production and allocation, and species diversity in the peri-urban habitats in Indian dry tropics. Biomass allocation strategy of plant communities was also significantly impacted by site and season. Allocation of biomass to different plant components differed with species, soil resources, and disturbance regimes experienced by the plants.

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Appendix: Floristic composition of different study sites in three seasons. Site codes: GL Grazing land, KRB Kali river bank, AL Agricultural land, ABK Abandoned brick kiln, IBK Intermediate brick kiln, WBK working brick kiln area, . + and - indicate presence and absence of a species respectively.

Family and Species	Rainy Season						Winter Season						Summer Season					
	GL	KRB	AL	ABK	IBK	WBK	GL	KRB	AL	ABK	IBK	WBK	GL	KRB	AL	ABK	IBK	WBK
Acanthaceae																		
Peristrophe bicalyculata (Retz.) Nees	+	-	-	+	+	+	+	-	-	-	+	-	-	-	-	-	-	-
Aizoaceae																		
Trianthema portulacastrum L.	+	+	+	+	+	+	-	-	-	+	-	-	-	-	+	-	-	-
Amaranthaceae																		
Achyranthes aspera L.	+	+	+	+	+	+	+	+	-	+	+	+	+	+	-	+	+	+
Alternanthera polygonoides (Linn.) R. Br.	-	+	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-
Alternanthera pungens Humb. Bonpl. and Kunth	+	+	-	+	+	+	-	-	-	+	+	-	+	-	-	+	+	-
Alternanthera sessilis (L.) DC.	-	-	-	-	-	+	+	+	-	+	+	+	+	+	-	+	+	+
Amaranthus spinosus L.	-	-	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-
Amaranthus viridis L.	+	+	-	-	-	+	+	+	-	-	-	+	+	+	+	-	-	+

Digera muricata (L.) Martius	+	-	+	-	+	+	-	-	-	-	-	-	-	-	+	-	-	-
Gomphrena celosioides Martius	-	+	-	-	-	+	-	-	-	-	-	-	-	+	-	-	-	+
Asclepiadaceae																		
Calotropis gigantea (L.) Dryander	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-
Calotropis procera (Aiton) Dryander	+	+	-	+	-	-	+	+	-	+	-	+	+	+	-	+	+	+
Asteraceae																		
Ageratum conyzoides L.	-	-	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-
Blumea lacera (Burm. F.) DC.	-	-	-	-	-	-	+	+	-	+	+	+	+	-	-	+	+	-
Cnicus arvensis (L.) Roth	-	-	-	-	-	-	+	-	+	-	-	-	-	-	-	-	-	-
Eclipta erecta L.	+	+	-	-	-	-	+	-	-	-	-	-	-	-	+	-	-	-
Gnaphalium luteo-album L.	-	-	-	-	-	-	+	+	-	+	-	-	-	-	-	-	-	-
Launaea asplenifolia (Willd.) Hook. F.	-	-	-	+	-	-	-	-	-	-	-	+	-	-	-	+	-	-
Parthenium hysterophorus L.	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Sonchus asper (L.) Hill	-	-	-	-	-	-	+	+	-	+	+	+	-	-	-	-	-	-
Tridax procumbens L.	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Xanthium strumarium L.	+	+	+	-	+	+	-	-	-	-	-	-	+	-	-	-	-	-

Brassicaceae																			
Brassica campestris L.	-	-	-	-	-	-	+	-	+	-	-	-	-	-	-	-	-	-	
Senebiera didyma (L.) Persoon	-	-	-	-	-	-	+	+	+	+	+	+	+	-	-	-	-	-	
Sisymbrium irio L.	-	-	-	-	-	-	+	+	-	-	+	-	-	-	-	-	-	-	
Cannabinaceae																			
Cannabis sativa L.	+	+	+	-	-	-	+	+	+	-	+	+	+	+	-	-	-	-	
Capparaceae																			
Cleome gynandra L.	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Caryophyllaceae																			
Silene conoidea L.	-	-	-	-	-	-	-	-	+	+	+	-	-	-	-	+	-	-	
Spergula arvensis L.	-	-	-	-	-	-	+	-	-	+	+	+	-	-	-	-	-	-	
Stellaria media (L.) Villars	-	-	-	-	-	-	+	+	+	+	+	+	-	-	-	-	-	-	
Chenopodiaceae																			
Chenopodium album L.	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	
Chenopodium ambrosioides L.	-	-	-	-	-	-	-	+	-	-	-	-	-	+	-	-	-	-	
Chenopodium murale L.	+	+	+	+	+	+	+	+	-	+	+	+	+	+	-	+	+	+	
Commelinaceae																			

Commelina attenuata Koen. Ex Vahl.	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Commelina benghalensis L.	+	+	+	+	+	+	-	-	-	-	-	-	-	-	+	-	-	-	
Cyanotis axillaris (L.) D. Don	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Convolvulaceae																			
Convolvulus arvensis L.	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Ipomoea pes-tigridis L.	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
*Cucurbitaceae																			
Luffa cylindrica (L.) M. Roemer	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Cyperaceae																			
Cyperus alopecuroides Rottb.	-	+	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	
Cyperus bulbosus Vahl	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Cyperus iria L.	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Cyperus kyllingia Endl.	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Cyperus rotundus L.	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
Fimbristylis dichotoma (L.) Vahl	-	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Scirpus sp.	+	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	

Euphorbiaceae																			
Croton bonplandianum Baillon	+	+	+	-	-	+	+	+	-	+	+	+	+	+	-	-	-	+	
Euphorbia hirta L.	+	+	+	+	+	+	-	-	-	+	+	-	-	-	+	+	-	+	
Euphorbia thymifolia L.	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Phyllanthus fraternus Webster	-	-	+	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	
Ricinus communis L.	-	-	-	+	-	-	-	+	-	+	-	-	-	-	-	+	-	-	
Fumariaceae																			
Fumaria indica (Haussknecht) Pugsley	-	-	-	-	-	-	+	-	+	-	-	-	-	-	-	-	-	-	
Lamiaceae																			
Anisomeles indica (L.) Kuntze	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Ocimum canum Sims.	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Leguminosae (i) Fabaceae																			
Dalbergia sissoo Roxb.	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Lathyrus odoratus L.	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	
Medicago sativa L.	-	-	-	-	-	-	+	+	+	+	+	+	-	-	-	-	-	-	
Melilotus indica (L.) Allioni	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	
Tephrosia villosa (Linn.) Pers.	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	+	-	-	

Trifolium alexandrinum L.	-	-	-	-	-	-	+	-	+	+	-	-	-	-	-	-	-	-
Vicia hirsuta (L.) S. F. Gray	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-	-	-
Vigna radiata (L) R.Wilczek	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-
Leguminosae (ii) Caesalpinaceae																		
Cassia obtusifolia L.	+	+	+	+	+	+	-	-	-	-	-	-	+	-	+	-	-	-
Cassia occidentalis L.	+	+	+	+	+	+	-	-	-	-	-	-	+	-	+	-	-	-
Leguminosae (iii) Mimoseae																		
Prosopis chilensis (Molina) Stuntz.	+	+	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-
Malvaceae																		
Abutilon indicum (L.) Sweet	+	+	-	-	-	-	-	+	-	-	-	-	-	+	-	-	-	-
Malva sylvestris L.	-	-	-	-	-	-	+	+	-	-	+	+	-	-	-	-	-	-
Malvastrum tricuspidatum (R. Br.) A. Gray	+	+	-	-	-	+	+	-	-	-	+	+	+	+	+	-	+	+
Sida acuta Burm. F.	+	+	+	+	+	+	+	+	-	+	+	+	+	+	-	+	+	+
Sida cordifolia L.	+	+	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-
Sida ovata Forsk.	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sida rhombifolia L.	+	+	+	+	+	+	-	+	-	+	+	+	+	+	-	+	+	+
Urena lobata L.	+	+	+	+	+	+	-	-	-	-	-	-	+	+	-	+	+	-

Menispermaceae																			
Cissampelos pareira L.	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Moraceae																			
Morus indica auct. Non L.	+	-	+	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-
Nyctaginaceae																			
Boerhavia diffusa L.	+	+	+	+	+	-	-	-	-	-	-	-	-	+	-	+	+	+	
Oxalidaceae																			
Oxalis corniculata L.	-	-	-	-	-	-	+	+	+	-	-	-	-	-	-	-	-	-	
Oxalis latifolia H.B. and K.	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	
Papaveraceae																			
Argemone mexicana L.	+	-	-	-	-	-	+	+	-	-	+	-	-	+	-	-	-	-	
Poaceae																			
Acrachne racemosa (Roemer and Schultes) Ohwi	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Alloteropsis cimicina (L.) Stapf	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Avena sativa x sterilis Bor A. Camus	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	
Bothriochloa pertusa (L.)	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	

Cenchrus ciliaris L.	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cenchrus setigerus Vahl.	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chloris dolichostachya Lagasca	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-
Cynodon dactylon (L.) Persoon	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Dactyloctenium aegypticum (L.) P. Beauv.	+	-	+	+	+	+	+	-	-	-	+	-	-	-	+	+	+	+	+
Dichanthium annulatum (Forsk.) Stapf	+	+	+	+	-	-	-	-	-	+	-	-	-	+	-	+	-	-	-
Digitaria adscendens (Kunth) Henrard	+	+	-	+	+	-	-	+	-	-	-	-	+	+	-	-	-	-	-
Echinochloa colona (L.) Link	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Eleusine coracana (L.) Gaertner	+	+	-	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-
Eragrostis ciliaris (Linn.) R.Br.	+	+	+	+	+	+	-	-	-	+	+	+	-	-	+	-	-	-	-
Leptochloa panicea (Retz.) Ohwi	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-
Oplismenus burmannii (Retz.) P. Beauv.	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Panicum miliaceum L.	-	+	+	+	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-

Panicum trypheron Schultes	-	+	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	
Paspalidium flavidum (Retz.) A. Camus	+	+	+	+	+	+	-	-	-	-	+	-	-	-	+	+	-	-	
Perotis indica (Linn.) Kuntze	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Phalaris minor Retz.	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	
Poa annua L.	-	-	-	-	-	-	-	+	+	-	-	+	-	-	+	-	-	-	
Saccharum munja Roxb.	+	+	-	+	-	+	+	+	-	+	-	+	+	+	-	+	-	+	
Setaria glauca (L.) P. Beauv.	+	+	+	-	+	-	-	-	-	-	-	-	-	-	+	-	-	-	
Sporobolus diander (Retz.) P. Beauv.	+	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Triticum aestivum L.	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	
Zea mays L.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	
Polygonaceae																			
Polygonum barbatum L.	-	-	-	-	-	-	-	+	-	-	+	+	-	-	-	+	-	-	
Polygonum glabrum Willd.	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	
Polygonum plebejum R.Br.	-	-	-	-	-	-	+	+	-	+	+	+	-	-	-	+	+	+	
Rumex dentatus L.	-	-	-	-	-	-	+	+	+	-	+	+	-	-	-	-	-	-	
Primulaceae																			
Anagallis arvensis L.	-	-	-	-	-	-	+	+	+	+	+	+	-	-	-	-	-	-	

Rannunculaceae																			
Ranunculus sceleratus L.	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	
Scrophulariaceae																			
Celsia coromandeliana Vahl	-	-	-	-	-	-	-	+	-	+	-	-	-	-	-	+	-	-	
Mazus japonicus (Thunb.) Kuntze	-	-	-	-	-	-	+	+	-	+	+	+	-	-	-	-	-	-	
Veronica anagallis-aquatica L.	-	-	-	-	-	-	+	-	+	-	+	-	-	-	-	-	-	-	
Solanaceae																			
Datura stramonium L.	-	+	-	-	+	-	-	+	-	-	-	-	-	+	-	-	-	-	
Physalis minima L.	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Solanum nigrum L.	+	-	-	+	-	-	+	+	-	-	-	-	-	+	-	-	-	-	
Withania somnifera (L.) Dunal	-	+	-	-	-	+	-	+	-	-	-	+	-	+	-	-	-	+	
Sterculiaceae																			
Melochia corchorifolia L.	+	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Tiliaceae																			
Corchorus aestuans L.	+	+	+	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	
Corchorus tridens Linn.	+	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	
Triumfetta rhomboidea	+	+	+	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	

Jacquin																		
Verbenaceae																		
Lantana camara L.	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zygophyllaceae																		
Tribulus terrestris L.	+	-	+	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-
Total No. of Species	**56**	**63**	**33**	**35**	**26**	**32**	**41**	**46**	**22**	**31**	**33**	**30**	**22**	**28**	**23**	**26**	**16**	**19**

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Diversity of pollen morphological characters in *Acer* Linnaeus (Sapindaceae) from Darjiling and Sikkim Himalayas

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Abstract

Based on light microscopic observations, the pollen morphology of 13 species and subspecies of *Acer* Linnaeus (Sapindaceae) from Darjiling and Sikkim Himalaya has been described. Pollen types, sizes, ornamentation are summarized. Dominance of 3-colporate pollen and similarities with respect to morphology and size was observed. Correlation analysis and cluster diagram has been constructed on the basis of the studied attributes.

Keywords: Diversity, pollen morphology, *Acer*, Darjeeling, Sikkim Himalaya.

Introduction

The importance of pollen in sexually reproducing spermatophytes is immense as it represents the microspore in which the male gametophyte develops. As the pollen has certain species specific and stable characteristics, earlier workers like Erdtman (1944, 1952), Rudenko (1959), and Wodehouse (1929) have stressed the utilization of pollen morphological characters in taxonomic studies. Workers including Blackmore (1984), Chanda et al. (1988), and Manna et al. (1988) have used palynology for numerous taxa of variable ranks.

The Maple genus *Acer* Linnaeus (Sapindaceae) is recognized by its 114 species distributed in north temperate and tropical mountains of the world (Mabberley 2008). Previous studies on pollen morphology of *Acer* have been based on light microscopic observations (Philbrick and Bogel 1981). Wodehouse (1935), Erdtman (1952), Erdtman et al. (1961) and Praglowski (1962), provided basic pollen morphological information for a few species of the genus. Helmich (1963) made a thorough microscopic study and provided a key to eighteen, and illustrations of nine, North American species, as an aid toward the identification of *Acer* pollens in Cenozoic sediments.

Species of *Acer* do not produce large quantities of pollen. As the sporopollenins in the genus are more perishable as compared to most other trees, the microfossil studies for the genus have not been particularly helpful in paleobotany. Studies on the pollen grains of living species of *Acer* has been made by a number of workers like Biesboer (1975), Pozhidaev (1993) and Gogichaishvili (1964).

In most pollen morphological investigations, pollen forms deviating from the ones typical to the species are usually regarded as abnormal (teratical) and left unregistered although such forms are present in a number of angiospermic families. Pozhidaev (1993) with the help of light and scanning electron microscope has reported the existence of forms that deviate from the typical pollen grains of 31 of the 68 species of *Acer* that he studied.

Das (1986) and Das and Chanda (1987) recorded the occurrence and flowering periods of eight species of *Acer* in temperate hills (1500 – 2400 m) of Darjiling. Later on Lama (2004) recorded the occurrence of 13 species of the genus from Darjiling and Sikkim parts of the Eastern Himalaya out of which one species *A. osmastonii* is endemic to Darjiling (Grierson and Long 1991) and Dehradun (Nayar and Dutta 1982) regions of the country. In the present investigation, we studied the pollen morphology of these 13 species of *Acer* collected.

Material and methods

The Darjiling and Sikkim parts of the Eastern Himalaya extends between 26° 31' and 28° 10' N Latitude, and 87° 59' and 88° 53' E Longitude. Out of the total 1, 22, 802 sq km area of the Eastern Himalaya, the Darjiling hills cover an area of about 9020 sq km (Negi 1990). Survey for the species of *Acer* Linnaeus (Sapindaceae) in Darjiling and Sikkim Himalayas was initiated by Lama (2004) in 1998, and through this process 13 species of

Table 1. Voucher specimens and the flowering periods of different species of *Acer* Linnaeus (Sapindaceae)

Species	Voucher specimen	Local name *N- Nepali,L- Lepcha*	Altitudinal distribution (mt)	Flowering period
Acer acuminatum *ex* D. Don	*Lama and Das 0211,* 29.05.2000	*N-Lekh kapasi*	2500 - 4000	May – June Wallich
Acer campbellii Hooker *f.* and Thomson *ex* Hiern	*Lama and Das 0101, 09.05.1999; Moktan and Das 0702, 09.09.2010*	*N- Kapasi; L- Doom kung*	1600-3700	April – May
Acer caudatum Wallich	*Lama and Das 0037, 13.05.1998; Moktan and Das 0820, 21.05.2012*	*N-Lekh kapasi*	2500-4000	April – May
Acer hookeri Miquel	*Lama and Das 0065, 11.05.1998; Moktan and Das 1084, 12.10.2012*	*N-Laharey kapasi, L- Phaley kung*	2200-3200	March – April
Acer laevigatum Wallich	*Lama and Das 0112. 21.04.1999; Moktan and Das 0565, 08.09.2010*	*N-Putli*	1600-2000	April – May
Acer oblongum Wallich *ex* DC.	*Lama and Das 0185, 21.09.1999; Moktan and Das 0462, 16.04.2010*	*N-Phirphiri*	1400-2200	April – May
Acer osmastonii Gamble	*Lama and Das 0179, 13.05.1999*	*N-Kapasi*	1800-2000	May
Acer palmatum Thunberg *ex* Murray	*Lama and Das 0013, 28.02.1998*	*N-Kapasi*	1800-2400	February – March
Acer pectinatum Wallich *ex* G. Nicholson	*Lama and Das 0041, 13.05.1998; Moktan and Das 0984, 23.05.2012*	*N- Lekhkapasi L-Yatli kung*	2600-3600	April – May
Acer sikkimense Miquel	*Lama and Das 0009, 02.02.1998; Moktan and Das 2161, 16.10.2012*	*N-Bahuna*	1200-2600	March – April

Acer stachyophyllum Hiern	*Lama and Das 0208, 28.05.2000; Lep -Yatlikung*	2700-3800	May
Acer sterculiaceum Wallich **ssp**. ***sterculiaceum***	*Lama and Das 0038, 12.05.1998; N-Lekh kapasi Moktan and Das 0864, 21.05.2012*	2300-2900	April – May
Acer sterculiaceum* ssp. *thomsonii (Miquel) Murray	*Lama and Das 0092, 09.11.1998; N- Melokapasi Moktan and Das 0239, 14.05.2010*	1200-2200	October – November

Acer including two varieties and an ornamental species *Acer palmatum* which is now semi-naturalized Darjiling (Das 1986) and Sikkim Himalayas. The distributional range of these species extends from 950 m to 4100 m amsl in the study area. However, most of the species remains distributed in the temperate and cold temperate zones of this region.

For the pollen morphological study mature flower-buds were collected from the field and the voucher specimens (Table 1) are deposited in NBU Herbarium and pollen slides are stored in the Museum of St. Joseph's College, Darjeeling.

The external morphology of the pollen grains of the available species of *Acer* was studied. Anthers from flowers/mature bud were collected, dried and preserved in dessicator with silica gel. The acetolysis method of Erdtman (1960) with modifications of Chanda (1966) and Nair (1970) were followed. The acetolysed pollen grains were examined under the light microscope and quantitative measurements was done. For the preparation of slides, method as described by Kisser (1935) was followed. Correlation analysis and cluster diagram of the attributes was prepared.

Results

A brief pollen morphological description of the species of *Acer* studied from the Darjiling and Sikkim Himalayas have been enumerated below:

Acer acuminatum Wallich *ex* D. Don. Prodr. Fl. Nepal.249.1825; Banerjee and Das in Ind. For.97: 248.1971; En. Fl. Pl. Nep. 2: 97. 1979. *A. caudatum* G. Nicholson 1881 [Tropicos database record 50324551]

Pollen Morphology: Pollens 3 – colporate, spheroidal; PA x ED ± 16.0 x 15.0 µm, colpi±12.0 x 2.0µm;exine 2.0 µm thick; ora lalongate; sexine 1.5 µm thick, reticulate.[**Plate 1: A**]

Acer campbellii Hooker *f.* and Thomson *ex* Hiern in Fl. Brit. Ind. 1: 696. 1875. Fl. E. Him. 1: 191.1966; 2: 72.1971; En. Fl. Pl. Nep. 2: 97. 1979; Fl. Pl. Kurseong 23. 1981; Fasc. Fl. Ind. 9: 5. 1982; Das andChanda in Trans. Bose Res. Inst. 51(4): 104. 1987: Fl. Bhutan 2(1): 67. 1991.

Pollen Morphology: Pollens 3 – colporate, prolate; PA x ED ± 25.3 x 16.2 µm, colpi ±21.5 x 2.0µm; exine 2.0 µm thick; ora circular; sexine 1.0 µm thick, striato-reticulate. [**Plate 1: C – D**]

Acer caudatum Wallich, Pl. Asia. Rar. 2: 4 and 28,t. 132. 1831; Fl. Brit. Ind. 1: 695. 1875, p.p.; Fl. E. Him.1: 191. 1966: 2: 73. 1971; En. F. Pl.

Nep. 2: 98. 1979: Fasc. Fl. Ind. 9: 8. 1982; Fl. Bhutan 2(1): 67. 1991. *A. papilio* King in J. Asia. Soc. Beng. 65(2): 115. 1896; Banerjee and Das in Ind. For. 97: 249. 1979.

Pollen Morphology: Pollens 3 – colporate, prolate-spheroidal; PA x ED ± 21.0 x 16.5 µm; syncolpate; colpi ±20 x 2.4µm; lalongate, median placed, exine 2.0 µm thick; nexine 0.5 µm thick striato-reticulate. (**Plate 1: B**)

Acer hookeri Miquel in Arch. Neeri. Sci. Nat. 2: 471. 1852; Fl. Brit Ind. 1: 694. 1875; Fl. E. Him.1: 191. 1966: 2: 73. 1971; En. Fl. Pl. Nep. 2: 98. 1979; Fasc. Fl. Ind. 9: 9. 1982: Das and Chanda in Trans. Bose Res. Inst. 51(4): 104. 1987. Fl. Bhutan 2(1): 64. 1991.

Pollen Morphology: Pollens 3 – colporate, prolate; PA x ED ± 37.4 x 27.0 µm; colpi ± 33.0 x 2.0µm; ora circular; exine 2.0 µm thick, sexine 0.4 µm thick, striato-reticulate. [**Plate 1: E**]

Acer laevigatum Wallich, Pl. Asia.Rar. 2:3,t. 104. 1831; Fl. Brit. Ind. 1: 699. 1875; Fl. E. Him. 1: 192. 1966; En. Fl. Pl. Nep. 2: 98. 1979; Fasc. Fl. Ind. 9: 10. 1982: Das and Chanda in Trans. Bose Res. Inst. 51(4): 104. 1987. Fl. Bhutan 2(1): 64. 1991.

Pollen Morphology: Pollens 3 – colporate; prolate-spheroidal; PA x ED ± 37.0 x 30.0 µm; colpi ± 35.0 x 3.0µm; ora lalongate; exine 2.5 µm thick, sexine 2.0 µm thick, striato-reticulate. [**Plate 1: F – G**]

Acer oblongum Wallich *ex* DC.,Prodr. 1: 593. 1824; Fl. Brit. Ind. 1: 693. 1875; Fl. E. Him.1: 192. 1966: 2: 73. 1971; En. Fl. Pl. Nep. 2: 98. 1979; Fasc. Fl. Ind. 9: 12. 1982; Das and Chanda in Trans. Bose Res. Inst. 51(4): 104. 1987: Fl. Bhutan 2(1): 63. 1991. *A. lanceolatum* Molliard, Bull. Soc. Bot. Fr. 50: 134, t.5. 1903.

Pollen Morphology: Pollens 3 – colporate, prolate; PA x ED ± 40.0 x 26.0 µm; colpi ± 36.0 x 2.0µm; exine 2.0 µm thick, sexine 1.5 µm, striato-reticulate. [**Plate 1: H**]

Acer osmastonii Gamble in Bull. Misc. Inform. Roy. Bot. Gard. Kew: 446. 1908; Fasc. Fl. Ind. 9: 14. 1982; Das andChanda in Trans. Bose Res. Inst. 51(4): 104. 1987. Fl. Bhutan 2(1): 66. 1991.

Pollen Morphology: Pollens 3 – colporate, spheroidal; PA x ED ± 27.5 x 25.5 µm; colpi ± 24.0 x 2.0µm; ora lalongate; exine 2.0 µm thick, sexine 1.5 µm thick, striato-reticulate. [**Plate 1: I – J**]

Acer palmatum Thunberg *ex* Murray in Kaemp, Illustratus. Nova Acta

Regiae Soc. Scientiarum 4: 36, 40. 1783; Systema Vegetabilium 1784; 14th ed Stafleu and Cowan, 3: 670. 1981; Das and Chanda in Trans. Bose Res. Inst. 51(4): 104. 1987.

Pollen Morphology: Pollens colpate or 3 – colpate, prolate; PA x ED ± 18.0 x 15.0 µm; colpi ± 15.0 x 2.0µm; exine 1.5 µm thick; nexine not differentiated; striato-reticulate. [**Plate 1: K**]

Acer pectinatum Wallich *ex* G. Nicholson in Gard. Chron. 1881(1): 365. F. 69. 1881:Fl. E. Him. 1: 192. 1966: 2: 73. 1971. *non* Wallich, En. Fl. Pl. Nep. 2: 98. 1979; Fasc. Fl. Ind. 9: 15. 1982; Fl. Bhutan 2(1): 67. 1991. *A. caudatum* sensu Fl. Brit. Ind. 1: 695. 1875. p. p. non Wallich

Pollen Morphology: Pollens ½, colpate or 3 – colporate, subprolate; PA x ED ± 25.0 x 14.0 µm; colpi ± 21.0 x 2.5µm; ora constricted; exine 2.0 µm thick, sexine 1.5 µm thick, striato-reticulate. [**Plate 1: L – M**]

Acer sikkimense Miquel in Arch. Neeri. Sci. Nat. 2: 471. 1852; Fl. Brit Ind. 1: 694. 1875; Fl. E. Him.1: 192. 1966: 2: 73. 1971; En. Fl. Pl. Nep. 2: 98. 1979; Fasc. Fl. Ind. 9: 16. 1982: Das and Chanda in Trans. Bose Res. Inst. 51(4): 104. 1987; Fl. Bhutan 2(1): 64. 1991.

Pollen Morphology: Pollens 3 – colporate, subprolate; PA x ED ± 40.0 x 30.0 µm; colpi ± 6.0 x 2.0µm; ora circular; exine 2.0 µm thick, sexine 1.0 µm thick, striato-reticulate. [**Plate 1: N – O**]

Acer stachyophyllum Hiern in Fl. Br. Ind. 1: 696. 1875; Fl. E. Him.1:193. 1966: 2: 73. 1971; En. Fl. Pl. Nep. 2: 98. 1979; Fl. Bhutan 2(1): 66. 1991.

Pollen Morphology: Pollens 3 – colporate, prolate-spheroidal; PA x ED ± 16.0 x 13.5 µm; colpi ± 13.0 x 1.5µm; exine 1.5 µm thick, sexine and nexine not differentiated, striato-reticulate. [**Plate 1: P – R**]

Acer sterculiaceum Wallich, Pl. Asia. Rar. 2: 3,t. 105 1831; Fl. E. Him. 1: 192. 1966: 2: 74. 1971; En. Fl. Pl. Nep. 2: 98. 1979: Fasc. Fl. Ind. 9: 17. 1982; Fl. Bhutan 2(1): 68. 1991. *A. villosum* Wallich, Pl. Asiat. Rar. 2: 4. 1830; Fl. Brit. Ind. 1: 695. 1875.

subsp. *sterculiaceum*

Pollen Morphology: Pollens 3 – colporate, prolate-spheroidal; PA x ED ± 18.0 x 14.0 µm; colpi ± 14.0 x 1.8µm; exine 2.0 µm thick; nexine 0.5 µm thick; striato-reticulate. [**Plate 1: S**]

Acer sterculiaceum* subsp. *thomsonii (Miquel) Murray, Arch. Néerl. Sci. Exact. Nat. 2: 470 1867. A. thomsonii Miquel in *Acer* notes nos. 1-6. Kalmia

1: 1-42. 1969; *A. thomsonii* Miquel in Arch Neeri. Sci. Nat. 2: 470. 1867; Fl. E. Him.1: 193. 1966: 2: 73. 1971; En. Fl. Pl. Nep. 2: 98. 1979; Fasc. Fl. Ind. 9: 18. 1982: Das and Chanda in Trans. Bose Res. Inst. 51(4): 104. 1987; Fl. Bhutan 2(1): 66. 1991. *A. villosum* var *thomsonii* (Miquel) Hiern in Fl. Brit Ind. 1: 695. 1875.

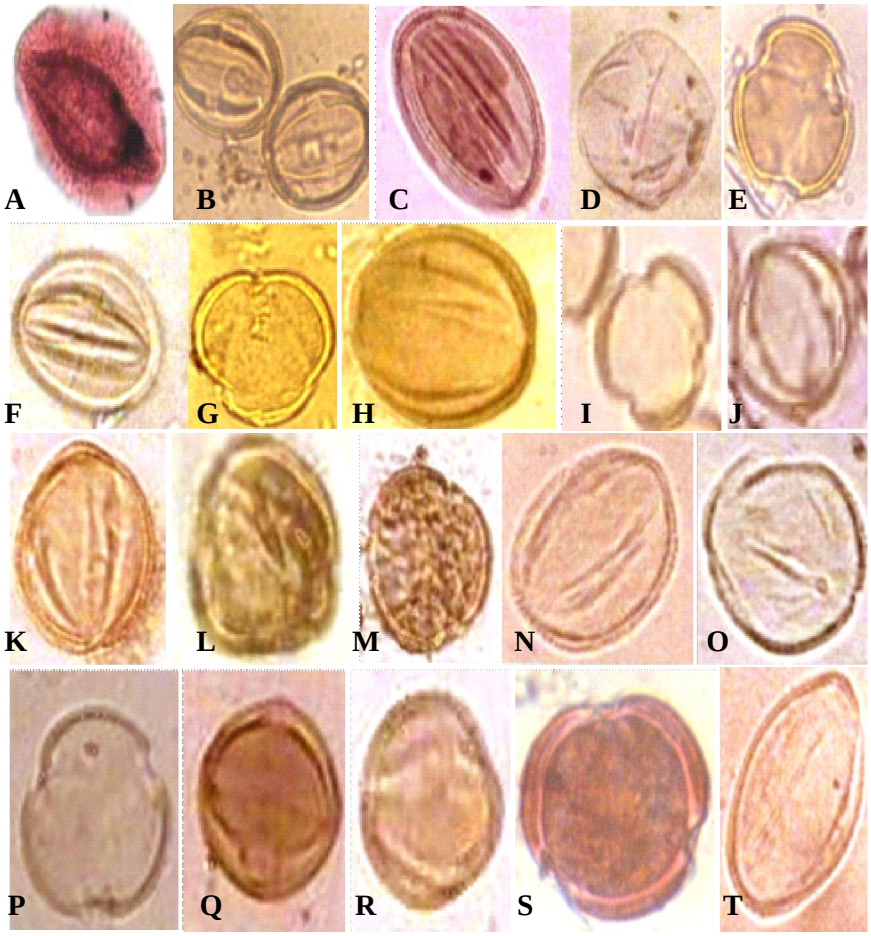

Plate 1: Lighmicroscopic photographs of different species of *Acer* Linnaeus (Sapindaceae). **A-** *A. acuminatum* **B-***A. caudatum* **C-D-***A. campbellii* **E-***A. hookeri* **F-G-***A. laevigatum* **H-***A. oblongum* **I-J-***A. osmastonii* **K-***A. palmatum* **L-M-***A.pectinatum* **N-O-***A. sikkimense* **P-R-***A. stachyophyllum* **S-***A. sterculiaceum* ssp. *sterculiaceum* **T-***A. sterculiaceum* ssp. *thomsonii*

Pollen Morphology: Pollens 3 – colporate or ½ colpate; PA x ED ± 38.0 x 26.0 µm; colpi ± 33.0 x 2.0µm; ora constricted; exine 2.0 µm thick, nexine 0.5 µm. [**Plate 1: T**]

DISCUSSION

The different species of Acer this region exhibit pollen grains those are mainly 3-colporate with only one (*A. palmatum*) 3-colpate, radially symmetrical, isopolar and prolate to nearly spheroidal (Table 2). Out of the 13 species under study, 12 species showed 3 – colporate grains while the introduced species *A. palmatum* shoed 3- colpate pollens. However, species like *A. pectinatum* and *A. sterculiaceum* ssp. *thomsonii* also produced 3 – colpate grains in low frequency. The pollens were spheroidal in *A. sterculiaceum* ssp. *thomsonii* and *A. sterculiaceum* ssp. *sterculiaceum* and sub-prolate in *A. sikkimense* and *A. pectinatum* while 8 other species exhibited prolate pollen grains. The smallest pollen grain was found in *A. acuminatum* and *A. stachyophyllum* and the largest grain was found in *A. oblongum* and *A. sikkimense.* All other species showed intermediate size to this two species. The ora ranged from circular to lalongate type except in *A. pectinatum* where it remains constricted. The thickness of the wall is thickest in *A. laevigatum* and narrowest in *A. caudatum* with outer ornamentation reticulate in *A. acuminatum* and straito-reticulate in all other species. The 3-colpate aperture type in *A. palmatum* dissociates it from other recorded species and is an outsider for the flora for this region.

Table 2: Excerpt of the pollen morphological characters of *Acer* Linnaeus of Darjiling and Sikkim Himalaya

Species	Aperture type	Shape	PA x ED	Colpi (µm)		Ora type	Thickness (µm)			Ornamentation
			(µm)	Length	Breadth		Exine	Nexine	Sexine	
Acer acuminatum	3-colporate	spheroidal	± 16.0 x 15.0	± 12.0	± 2.0	lalongate	2.0	-	1.5	Reticulate
Acer campbellii	3-colporate	prolate	± 25.3 x 16.2	± 21.5	± 2.0	circular	2.0	-	1.0	Striato-reticulate
Acer caudatum	3-colporate	prolate	± 21.0 x 16.5	± 20.0	± 2.4	-	2.0	0.5	-	Striato-reticulate
Acer hookeri	3-colporate	prolate	± 37.4 x 27.0	± 33.0	± 2.0	circular	2.0	-	0.8	Striato-reticulate
Acer laevigatum	3-colporate	prolate-spheroidal	± 37.0 x 30.0	± 35.0	± 3.0	lalongate	2.5	-	2.0	Striato-reticulate
Acer oblongum	3-colporate	prolate	± 40.0 x 26.0	± 36.0	± 2.0	-	2.0	-	1.5	Striato-reticulate
Acer osmastonii	3-colporate	spheroidal	± 27.5 x 25.5	± 24.0	± 2.0	-	2.0	-	1.5	Striato-reticulate
Acer palmatum	3-colpate	prolate	± 18.0 x 15.0	± 15.0	± 2.0	lalongate	2.0	-	1.5	Striato-reticulate
Acer pectinatum	3-colporate	subprolate	± 25.0 x 14.0	± 21.0	± 2.5	constricted	2.0	-	1.5	Striato-reticulate
Acer sikkimense	3-colporate	subprolate	± 40.0 x 30.0	± 6.0	± 2.0	circular	2.0	-	1.0	Striato-reticulate
Acer stachyophyllum	3-colporate	prolate-spheroidal	± 16.0 x 13.5	± 13.0	± 1.5	-	1.5	-	-	Striato-reticulate
Acer sterculiaceum* ssp. *Sterculiaceum	3-colporate	prolate-spheroidal	± 18.0 x 14.0	± 14.0	± 1.8	-	2.0	0.5	-	Striato-reticulate
Acer sterculiaceum* ssp. *Thomsonii	3-colporate	prolate-spheroidal	± 38.0 x 26.0	± 33.0	± 2.0	-	2.0	0.5	-	Striato-reticulate

Table 3. Correlation analysis of the attribute of the pollen grains studied (units in µm)

	Polar aperture	Equatorial diameter	Colpi length	Colpi breadth	Exine thickness	Nexine thickness	Sexine thickness
Polar aperture	X						
Equatorial diameter	**0.919**	X					
Colpi length	**0.616**	0.526	X				
Colpi breadth	0.313	0.317	0.419	X			
Exine thickness	0.446	0.504	0.456	**0.841**	X		
Nexine thickness	-0.116	-0.157	0.030	-0.040	0.000	X	
Sexine thickness	0.230	0.290	0.207	0.512	**0.566**	**-0.747**	X

In bold, significant values (except diagonal) at the level of significance alpha=0.050 (two-tailed test)

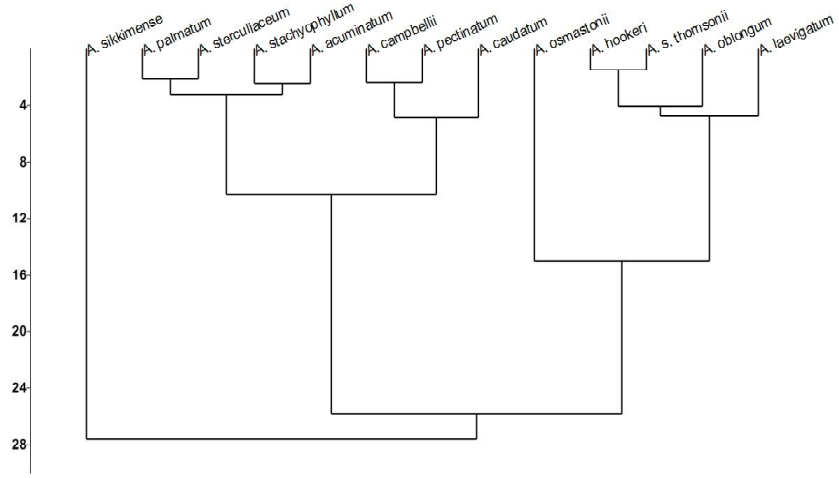

Fig. 1. Cluster diagram of the pollen attributes of the studied species of *Acer*

The result of pollen morphology confirms the dominance of 3-colporate pollen grains. Synecolpate, straito-reticulate surface ornamentation of majority of the pollens under study indicates their close relationship. On the other hand, wide differences in their sizes, ora structure, reticulate ornamentation in *A. acuminatum*, spheroidal grains in *A. acuminatum* and *A. sterculiaceum* ssp. *thomsonii* are not only helpful in identification, but can also be used in phylogenetic analysis. The correlation

analysis of the attributes of the 13 species studied showed pollen aperture and equatorial diameter as highly correlated followed by colpi breadth and exine thickness (Table 3).

The cluster diagram (Fig. 1) divided the 13 species into four groups and out grouped the species *A. sikkimense* and *A. laevigatum.* Species such as *A. palmatum* and *A. sterculiaceum* ssp. *sterculiaceum*, *A. acuminatum* and *A. stachyophyllum, A. campbellii* and *A. pectinatum,* and species like *A. hookeri* and *A. sterculiaceum* ssp. *thomsonii* showed close relationship. *A. oblongum* seems closer to *A. sterculiaceum* ssp. *thomsonii* but distant from rest of the three groups.

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Diversity in reproductive phenology of Indian dry tropical forest trees

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Abstract

The trees in dry tropical environment show variations in the seasonal patterns of flowering, fruiting and seed settings that has been strongly related to the abiotic parameters and plant functional traits. This study has focused on the changes in the diversity of phenolgical patterns of trees and their relationships with the abiotic factors, and has shown the probable global climatic change effects on the future reproductive success of dry tropical trees. The results of this study will serve as the baseline information to evaluate possible future phenological deviations in dry tropical forests in the global climatic change scenario.

Keywords: Diversity, reproductive phenology, dry tropical forest, climate change.

Introduction

In-depth understanding of the dynamics of tropical dry forests with special emphasis on reproductive phenology is of paramount importance in future biodiversity conservation efforts (McLaren and McDonald 2005). Flowering initiation in tree species indicates switch between vegetative and reproductive phases and is crucial for optimal seed set and future sustainability (Bernier 1988). The reproductive events are not self-regulating and flowering may be partly or wholly dependent on vegetative phenology (van Schaik et al. 1993, Kushwaha et al. 2011). Many deciduous

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tree species show flowering and fruiting during the leafless period, exhibiting wide separation between leafing and flowering. In many evergreens and in some deciduous species leaf flush and flowering occur close in time on the same new shoot. An analysis of the proximate controls of flowering in tropical deciduous forest species indicates that the timing of vegetative phenology strongly determines the flowering periods, and thus flowering at least depends indirectly on environmental periodicity (Rivera et al. 2002). However, examination of possible functional significance of an interrelationship between vegetative (in-leaf and deciduous state) and reproductive (flowering and fruiting) events in tropical trees is highly limited (Singh and Kushwaha 2005). Relative to vegetative phenology, variation in flowering induced by a variety of factors (significant rain in winter/summer, decreasing or increasing photoperiod, or drought induced leaf fall), results in a number of flowering patterns in tropical trees (Borchert et al. 2004).

In seasonal tropical forests, tree phenology appears to be driven by seasonal distribution of precipitation (Singh and Kushwaha 2005) and rainfall seasonality has been indicated as major governing factor for the flowering and fruiting periodicities (Borchert et al. 2004, Singh and Kushwaha 2006, Boulter et al. 2006). Given that water availability is prerequisite to expand growing cells during leaf flush, flowering and fruit development, existence of long and/or severe drought (resulting in seasonal variation in the soil moisture availability) in seasonally dry tropical forests is expected to be a major selective factor in the timing of flowering and subsequent fruiting in tree species (Singh and Kushwaha 2005, Zimmerman et al. 2007). Apart from this in many species switch from vegetative growth to flower production requires a signal in which drought or shortage of moisture is involved (Borchert et al. 2004, Singh and Kushwaha 2006). However, the degree of drought faced by trees varies widely, depending on temperature and availability of soil water, and also tree characteristics such as rooting depth (van Schaik et al. 1993) results in variety of species-specific phenological patterns in dry tropical trees (Borchert, 2000, Singh and Kushwaha, 2005). In Indian dry tropical forests, tree species show wide variation in leaf strategy index, annual deciduousness, stem wood density and LMA (Kushwaha et al. 2010) (Table 1). Stem wood density in association with leaf mass per area (LMA) and resource use rate significantly affect the flowering time in tropical tree species (Kushwaha et al. 2011). Differences in tree leaves and wood density, arising from phylogeny and adaptations, are helpful for species co-existence (King et al. 2006, Kitajima and Poorter, 2008).

Table 1. Variation in wood density, leaf mass per area (LMA) and leaf strategy index (ratio of leaf fall duration to leaf flush duration) in tree species in Vindhyan dry forest in India. Values are mean±SE. Source: Kushwaha et al. (2011).

Species name	Wood density ($g\ cm^{-3}$)	LMA ($g\ cm^{-2}$)	Leaf strategy index
Leaf-exchanging			
Albizia odoratissima (L. f.) Benth.	0.625±0.015	108.7±1.0	0.46±0.015
Bauhinia racemosa Lamk.	0.667±0.013	119.0±1.1	0.44±0.013
Shorea robusta C.F. Gaertn.	0.718±0.011	112.7±1.2	0.44±0.015
Soymida febrifuga (Roxb.) A. Juss.	0.859±0.021	140.2±0.2	0.46±0.004
<2-month deciduous			
Buchanania lanzan Spreng.	0.458±0.006	97.6±0.8	0.64±0.011
Cassia fistula L.	0.735±0.018	92.7±0.5	0.60±0.005
Diospyros melanoxylon Roxb.	0.685±0.013	124.0±0.9	0.68±0.018
Elaeodendron glaucum Pers.	0.666±0.018	109.8±0.6	0.64±0.004
2-4-month deciduous			
Flacourtia indica (Burm. f.) Merr.	0.616±0.009	101.4±1.1	0.88±0.028
Gardenia turgid Roxb.	0.645±0.027	99.4±0.7	0.86±0.006
Lagerstroemia parviflora Roxb.	0.617±0.010	112.3±0.8	0.81±0.007
Miliusa tomentosa (Roxb.) Sinclair	0.626±0.009	97.7±0.8	0.84±0.014
>4-month-deciduous			
Bombax ceiba L.	0.335±0.007	81.0±0.9	1.00±0.006
Boswellia serrata Roxb. cx Colebr.	0.505±0.008	85.4±0.6	0.98±0.003
Lannea coromandelica (Houtt.) Merrill	0.509±0.016	86.0±0.7	0.98±0.003
Sterculia urens Roxb.	0.411±0.007	74.9±1.2	0.96±0.010

Climatic changes (changes in temperature and precipitation) are known proximate cues of vegetative phenology and vegetative phenology is a strong determinant of flowering time in seasonally dry forests (Borchert et al. 2004, Singh and Kushwaha 2006). Variation in flowering time relative to vegetative phenology, induced by a variety of factors (significant rain in winter/summer, decreasing or increasing photoperiod, or drought induced leaf fall), results in a number of flowering patterns in tropical trees (Borchert et al. 2004). Due to increasing anthropogenic pressure tropical forest zone is likely to face rise in temperature and a change in rainfall pattern that

may cause increased dry season length, increased inter-annual variability in rainfall and a decrease in soil moisture status (Hulme and Viner 1998). Since the seasonal timing of phenological events in tropical forests is closely tuned to climatic patterns, a small deviation in climate (especially the onset, strength, and duration of dry and wet seasons) could lead to substantial changes in phenological events, especially the deciduousness of tree species, flowering and fruit set timing (in species showing drought triggered flowering) and the arrival of pollinators, dispersers etc. Tropical forests are being rapidly transformed, thus, precise documentation of reproductive events (including flowering, fruiting and seed production) of tree species from these forests may be useful to speculate on the conservation implications. Quantification of reproductive events is needed in tropical forests.

Various flowering cues in Indian tropical trees

Synchronization of flowering and subsequent fruiting with a particular seasonal timing by many tree species appears to be under the control of prevailing climatic conditions of that season in tropical deciduous forest trees (Singh and Kushwaha 2006). The detection of several season-linked flowering types in Indian dry tropics revealed that variety of environmental cues are involved in triggering the flowering and subsequent fruiting (Kushwaha et al. 2011). Predominant role of leaf fall in flowering initiation, as a result of stem rehydration, is indicated in leaf exchanging species (flowering initiated during mid- to late-dry season on foliated shoots soon after the initiation of drought induced leaf fall) and in >4-mo-deciduous species (flowering during mid dry season on leafless shoots). Interestingly, in both leaf-exchanging and >4-month-deciduous species (the two ends of deciduousness gradient) leaf fall induced flowering on leaf-exchanging or leafless shoots during dry season suggest that these species separate their vegetative and reproductive events in such a way that they can make maximum use of favorable season for their vegetative growth and initiated flowering during less favorable season. Species having maximum deciduousness (>4-mo-deciduous species) use favourable rainy season for leafing and photosynthate accumulation, and initiate reproduction just prior to the fall in soil water reserve during progressively drier period of the annual cycle (Figure 1). Water storage in their trunk may enable maintenance of a high stem water potential and flowering during the dry season (Schongart et al. 2002). In many species, flower buds formed during the growing season remain dormant until bud expansion is triggered during the dry season by rehydration of leafless twigs caused by leaf shedding (Borchert 2000); such bud endo-dormancy may represent a strategy to

separate resource use for vegetative and reproductive phenophases.

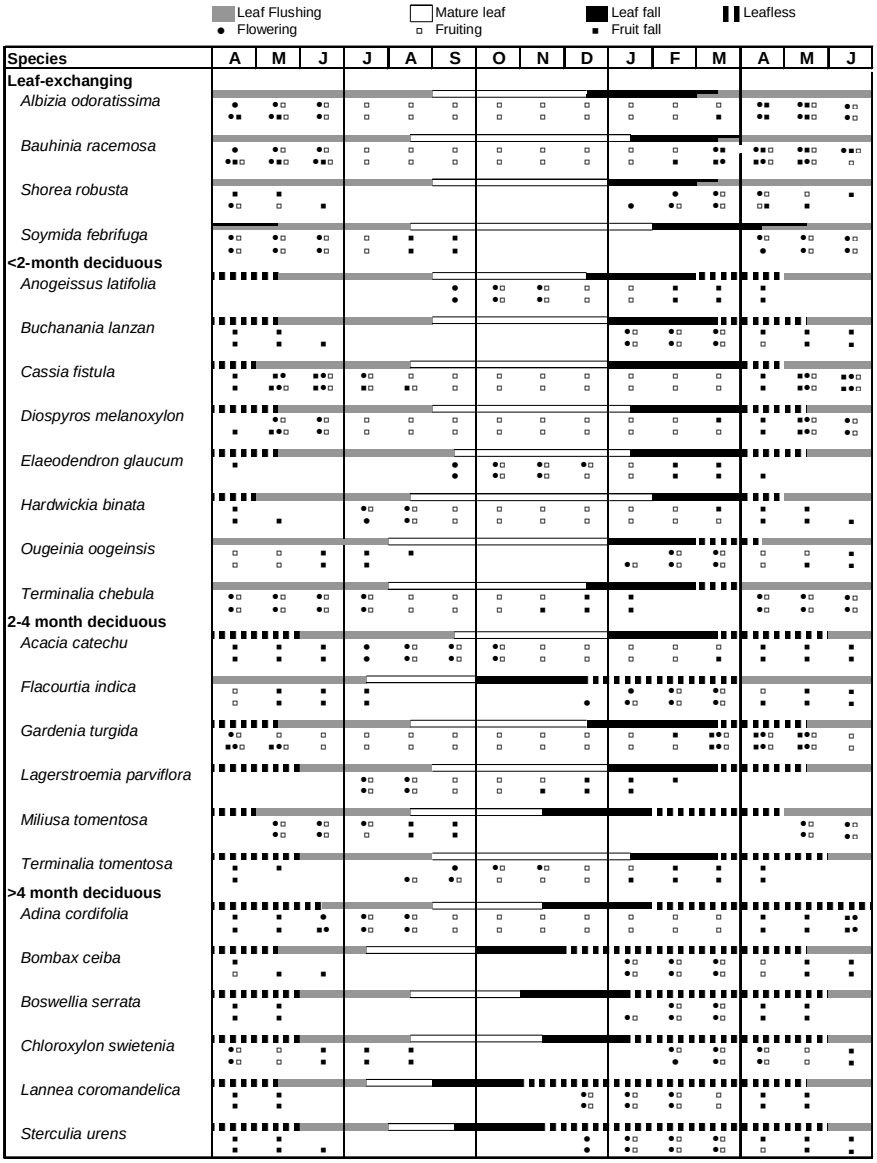

Fig 1.Leaf phenology and flowering and fruiting of key tree species as observed during two consecutive annual cycles in Vindhyan tropical deciduous forest in India. Source: Kushwaha et al. (2011).

In species with intermediate duration of deciduousness (<2-month deciduous and 2-4-month-deciduous) flowering initiation is triggered by several environmental cues i.e. increasing photoperiod and or temperature

(summer flowering), first significant rain (rainy flowering) and decreasing day length (autumn flowering). Many species have been reported to regularly flower synchronously after the spring equinox during March-June (Van Devender et al. 2000, Felger et al. 2001). In such species increasing day length and/or temperature may induce flowering during hot dry summer. In species flowering during the rainy season first heavy rain may act as a flowering cue. Synchronous development of lateral or terminal flowers on foliated shoots during early dry season after the autumn equinox (September-November) indicates flower induction by declining day length (Rivera and Borchert 2001).

In tropical trees flowering timing is resulting from the combination of abiotic (e.g. rainfall, day length, irradiance and temperature), biotic and evolutionary factors (Boulter et al. 2006). In relation to predict the effect of impending climate change on various ecosystem processes there is requirement of fraction of species expected to respond to various factors (Stevenson et al. 2008). In Indian dry tropical tree species onset of reproductive (flowering and subsequent fruiting) events depends on seasonal variation in rainfall, photoperiod and/or temperature and timing of leaf fall (Kushwaha et al. 2011). Trigger of phenological events directly or indirectly by several meteorological parameters showing seasonal predominance suggest for a species-specific time-lag between climate event and phenological response (Bendix et al. 2006). Large fraction of species (ca. 70% species; winter, dry season and summer flowering) flower during the dry period (December to June) when vegetative growth is at its minimum, reflects the availability of water required for the growing organs. The water requirement can be met by sporadic winter rains, water absorption from sub-soil water reserves (leaf exchanging species) or stored stem water (>4-months deciduous having low wood density) (Singh and Kushwaha 2006). However, the water availability and intensity of drought during dry period varies widely among tropical deciduous forests depending on rainfall patterns and soil conditions, resulting in the differing proportion of species flowering during the dry period; e.g. Guanacaste 53%, Yucatan 54%, Jalisco 19%, and Sonora 73% of total species (Borchert et al. 2004). Occurrence of flowering during dry period of the annual cycle (December-June) on foliated or leafless shoots in majority of Indian trees seems to be an unique adaptation to survive under strongly seasonal climate having short wet period (growth promoting) and a long dry (growth suppressive) period.

Flowering time varied with differing tree traits

In tropical tree species analysis of significance of functional

interrelationship between vegetative (in-leaf and leafless periods) and reproductive (flowering and fruiting) phenophases are highly limited (van Schaik et al. 1993, Singh and Kushwaha 2006). Species with high LMA tend to have long average leaf life span (inverse to deciduousness) and slow photosynthetic rates (Field and Mooney 1986, Niinemets 1999) resulting in decrease in mass based assimilation with increasing leaf life span (i.e. reduction in deciduousness) and LMA (Prior et al. 2003, Reich et al. 1992). Leaf-exchanging species having high WD, high LMA, slower resource use rate (reflected by leaf strategy index) and distribution on relatively moist sites starts the reproduction at a time when vegetative growth is at its minimum (Kushwaha et al. 2011). However, >4-months-deciduous species having low WD, low LMA, greater resource use rate and distribution on drier sites showed distinct separation of vegetative and reproductive events. Variability in tree functions and diversity (e.g. diameter growth rate, timing of reproduction, hydraulic capacities) have been highlighted to be closely tied to variations in WD and LMA (Enquist et al. 1999, Swenson and Enquist 2007). Significant relationship of LMA and wood density with leaf strategy index (reflecting the resource use rate) and with the extent of deciduousness in Indian tropical trees suggest that with increasing deciduousness species tend to exploit resources at rapid rate during their short vegetative growth period (Kushwaha et al. 2011). In these tree species, significant positive relationships of time lag (between first-leaf flush to first-visible flower) with the annual deciduousness (reciprocal to growing period) and leaf strategy index (indicating resource use rate) also suggest that with increase in the deciduousness (i.e. decrease in the vegetative growth period) resource utilization rate during vegetative growth increases and there is greater separation of vegetative and reproductive events. Occurrence of leaf flushing (vegetative phase) and flowering (reproductive phase), the two major phenological events, requires the availability of substantial amounts of resources within the trees. Various physiologically active sites or sinks (e.g. leaf buds and leaves, flower buds and flowers, and fruit) may compete for water, nutrients and metabolites within a plant (Lieberman 1982). Such internal competition may lead to the partitioning in time of plant functions like leafing and flowering. The temporal separation of leafing and flowering in tropical deciduous tree species serves as an important adaptation to a strongly seasonal, dry climate, where optimization of vegetative growth during the short growing season may be crucial for tree survival. Deciduousness is an adaptation to avoid water stress, and water stress affects flowering time in tropical forest trees (Bullock 1995). Increase in the annual deciduousness in deciduous species results in reduction in the vegetative growth period, and drought stress is not only reflected in terms

of without-leaf period, but is also evident from the seasonal separation between the two phases.

Initiation of flowering during early dry season (prior to the steep fall in soil water reserves) on leafless shoots in the >4-month-deciduous water-storing tree species (usually showing shallow root system and distribution in very dry sites) having low wood density, low LMA, leaf fall in early dry season and rapid resource use (indicated by leaf strategy index) may be an adaptation for rapid accumulation of sufficient photosynthate during short rainy season of the annual cycle. Other deciduous species (<2-month-deciduous and 2-4-month-deciduous), with relatively high wood density, high LMA, leaf fall in mid or late dry season and relatively long growing season with relatively slower resource use rate initiate flowering during summer, rainy, autumn or winter season. In these species both phases begin relatively close in time, possibly, due to slower resource use rate (reflected by longer leaf flush period) and greater tolerance to water stress (suggested by short leafless period) than the >4-mo-deciduous tree species (having short leaf flush period and longer leafless period). Leaf-exchanging species having higher wood density, higher LMA, longer growing season and lower resource use rate, predominantly show flowering and fruiting during winter or early summer which overlap with leaf transitional stage.

In tropical dry forests fruit maturation and suitable conditions for dispersal are closely synchronized because of the pronounced differences of biotic and abiotic conditions between dry and rainy seasons (Griz and Machado 2001). Different flowering types are related to varying durations of fruiting phenophase (ca. 11 mo, summer flowering species; 7-9 mo, rainy species; 6-7 mo, autumn species and 3-4 mo, winter and dry season species) (Table 2). Thus, all flowering types complete the fruiting phenophase during late dry season before the onset of the succeeding rainy season, ensuring that some, if not all, seeds are available for germination when the soil is sufficiently moist. This ensures that seed may take advantage of the rainy season for germination and seedling establishment. Fruit bearing species varies through time resulting in seasonal variation in the fruit availability in most plant communities (Ting et al. 2008). Presence of several seasonal flowering types in Indian dry tropical forest trees and varying annual deciduousness (an adaptation to the seasonal drought) associated with variation in wood density, LMA, leaf strategy index suggest that impending climatic change may affect differently their flowering and thus fruiting times.

Table 2. Flowering duration, fruiting duration, time lag (between first leaf flush to first visible flower) and deciduousness in tree species in Vindhyan dry forest in India. Source: Kushwaha et al. (2011).

Species name	Duration (months)		Time lag (days)	Deciduousness (days)
	Flowering	Fruiting		
Leaf-exchanging species				
Albizia odoratissima	3.5	13.0	35	7
Bauhinia racemosa	3.5	14.0	10	3
Shorea robusta	3.5	3.5	15	9
Soymida febrifuga	3.0	6.0	12	6
<2-month deciduous				
Anogeissus latifolia	3.0	7.0	105	52
Buchanania lanzan	3.0	6.0	225	47
Cassia fistula	3.0	14.0	30	46
Diospyros melanoxylon	2.0	11.5	20	46
Elaeodendron glaucum	3.5	6.5	120	56
Hardwichia binata	2.0	11.0	60	30
Ougeinia oogensis	2.5	7.0	270	42
Terminalia chebula	4.0	10.0	30	53
2-4-month deciduous				
Acacia catechu	4.0	11.0	30	93
Flacourtia indica	3.5	6.5	250	116
Gardenia turgid	3.0	11.5	280	75
Lagerstroemia parviflora	2.0	7.5	45	83
Miliusa tomentosa	2.5	5.0	30	102
Terminalia tomentosa	2.5	8.0	65	86
>4-month-deciduous				
Adina cardifolia	3.0	12.0	20	129
Bombax ceiba	3.0	6.0	195	152
Boswellia serrata	2.5	4.5	210	144
Chloroxylon swietenia	3.0	4.5	240	136
Lannea coromandelica	3.0	6.0	195	231
Sterculia urens	4.0	8.5	180	224

The ability to withstand drought (in semi-evergreen leaf-exchanging species) and the varying ability to avoid drought stress by deciduousness (in deciduous species) in association to varying seasonal flowering timings appear to be the two principal mechanisms that allow these tree species to survive in this extremely dry and seasonal region. The wide diversity of seasonal flowering and fruiting patterns with linkage to leafing and leafless phenophases encounter among the tree species occurring in tropical dry deciduous forest in India revealed a variety of strategies which have evolved in the pursuit of survival and reproduction under monsoonic bioclimate (Kushwaha et al. 2011). Since environmental characteristics affect flowering and fruiting either directly (e.g. through conditions in the habitat) or indirectly (e.g. through leafless period), the probable global climatic change will have serious implications on future reproductive success of dry tropical trees. Hopefully, the phenological information generated in this study will serve as the baseline to evaluate possible future phenological deviations in dry tropical forests in the global climatic change scenario.

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Diversity of leaf deciduousness in important trees of dry tropical forest, India

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Abstract

Tropical trees exhibit variations in leaf initiation, maturation and leaf fall patterns. This study has demonstrated the diversity of these leaf events in various tropical trees and their possible ecological adaptive mechanism of these species to survive in extreme events. The results of the study has strong implication for global climate change scenario on changing pattern of leafing of tropical trees in Vindhyan dry tropical region which is experiencing high degree of environmental change due to increased industrial intensification.

Keywords: Diversity, phenology, leaf deciduousness, tropical deciduous trees, dry tropical forest.

Introduction

Plant phenological patterns are amongst the most sensitive parameters assumed to be altered as a result of global climate change (Corlett and Lafrankie 1998). Plant phenological patterns are the outcome of plant responses to particular environmental conditions where they are growing. The phenological patterns are varying widely at various spatial and temporal scales among the vegetation around the world. Phenological patterns in tropical deciduous forest trees are difficult to study because of huge diversity in phenological events and even the available information with variable often confusing terminology that makes it more difficult to generalize the

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results of species data into broader geographical area i.e. biome (Singh and Kushwaha 2005a). Most studies available on community level phenology may not be appropriate for climatic change issues because certain information are lost in recording and so represents less diversity in phenological events. Quantitative approach to phenological studies at species or functional type level would be of great importance, particularly in tropical deciduous forests. Species level quantitative phenological studies of tropical trees are available with respect to timing and duration of different phenological events at level of species or functional types along with their interrelations and possible causal links between environmental variables and phenology (Borchert et al. 2002, Kushwaha and Singh 2005).

Widely distributed tropical forests play significant role in global carbon and regional water cycles, sustain large human populations, acts as sites of biological and cultural conservation, and have large economic values. Tropical deciduous forests are broadly defined as tree dominated communities growing in climates characterized by alternating wet and dry periods with extended drought (ca. 4-8 months during each annual cycle) during which the ratio of potential evaporation to rainfall is greater than one (Olivares and Medina 1992). Because of the prolonged drought in these forests, the predominant tree species showing degree of deciduousness as early dry season leaf fall and growth resumption after the onset of rainy season. Tropical deciduous forests represent great diversity of tree forming a mosaic composed of several phenological functional types adapted to seasonal drought in different ways (Borchert et al. 2002). This results in maintenance of high leaf cover well beyond the rainy season and least synchronization between periodic growth period of trees and duration of dry season.

In tropics, the degree of drought to which trees are exposed varies widely, depending on temperature and availability of soil water, and also tree characteristics such as rooting depth (van Schaik et al. 1993) all depend on site characteristics like elevation, soil conditions, and extent of seasonality. The extent and intensity of seasonal drought may differ with the geographical location in dry tropics; for instance, Costa Rican dry tropics (having low latitude of ~10° N; low annual temperature variability to <2°C and 5 months dry period) sharply contrasts with Indian Vindhyan dry tropics (having higher latitude of ~24°N; higher annual temperature variation to >20°C and 8 months dry period) (Singh and Kushwaha 2005a). Structural and ecophysiological properties of dry tropical forests are closely determined by the duration and seasonality of the dry period, which selects adaptations associated with avoidance, resistance, or tolerance to water

stress.

Leaf flush and fall

Marked annual periodicity in both leaf-exchanging and deciduous species has been observed due to episodic leaf flush and senescence in tropical deciduous forests. However, considerable diversity exists in timing of both events among species because of tree water status, which represents the interaction between the environmental water status and structural and functional state of tree (Borchert 2000). Recent quantitative and eco-physiological studies (e.g. timing, synchrony and inter-annual variation in vegetative bud break) showed that vegetative bud break (leaf flush initiation) in deciduous and semievergreen species mainly between be and triggered by factors; a) shedding of old leaves during mid dry season, b) increasing day length and/or temperature during late dry season, and c) first significant rain (>20-30 mm) of rainy season (Rivera et al. 2002, Singh and Kushwaha 2005a, Elliott et al. 2006). Leaf-exchanging (evergreen as well as semi-evergreen) species generally show vegetative bud break induced by shedding of old leaves and are mostly located on moist microhabitats within the tropical deciduous forests. In such species timing of bud break varies considerably among conspecific individuals depending on soil water availability and inter-annual variation in the last major rain of rainy season (Rivera et al. 2002, Singh and Kushwaha 2005b). In deciduous species bud break of vegetative buds is either induced by increasing photoperiod and/or temperature or by first significant rain of the rainy season. Bud break induced by the increasing day length and/or temperature occur around spring equinox a period with increasing day length (spring flushing, Rivera et al. 2002) or during late dry season when both day length and temperature are increasing (summer flushing, Kushwaha and Singh 2005). Such bud break occurs well before the first significant rain of rainy season and is highly synchronous in a landscape and show minimum inter-annual variation. In Indian tropical deciduous forest bulk of species show synchronous leaf initiation during hot-dry summer, suggesting the joint action of increasing day length and temperature in bud breaks. In dry tropics, both spring and summer flushing generally precede first rains by 1-2 month, suggesting their timing has been selected for by the rainfall patterns. Rain induced bud break occur after the first significant rain of rainy season. Rapid rehydration due to rains result in synchronous bud breaks in all individuals at a given site. Such bud break varies significantly between sites and years depending on the date of first rains. Apart from varying timing of leaf flush initiation, tropical trees also varies in term of leaf flush duration

that decreases with increase in the annual leafless period (Kushwaha and Singh 2005).

Fraction of species showing leaf flushing (bud break) induced by various triggering factors differs considerably among tropical deciduous forests (Figure 1). This suggests that response of tree community to impending climatic change (i.e. precipitation, temperature) will vary greatly among these forests. Role of several triggering factors in bud break has also been indicated in Australian seasonal tropics (Bowman and Prior 2005). In West African savanna, leaf-exchanging (evergreen and semi-evergreen) species and deciduous woody species differ in the timing of vegetative bud break (De Bie et al. 1998) which was evident from the varying timing of leaf flush initiation. Out of total deciduous species, 20% least deciduous species initiate leaf flushing in mid dry season, 42% intermediate deciduous species initiates flushing in late dry season, and remaining 38% long deciduous species flush their leaves during early rainy season. This indicates

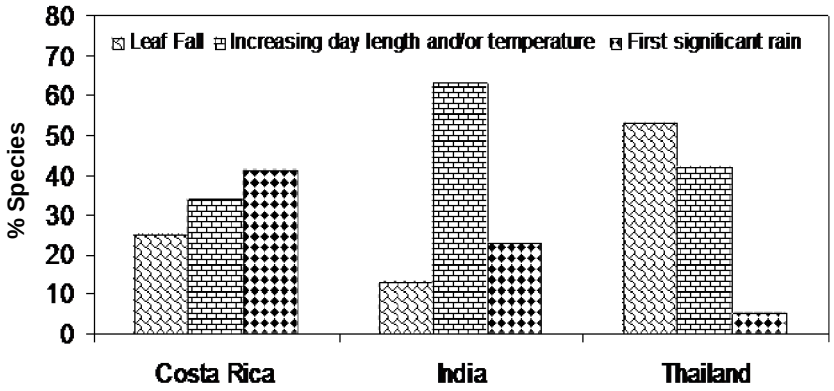

Fig.1 Fraction of tree species showing bud break of vegetative buds induced by leaf fall of old leaves, increasing day length and/or temperature, and first significant rain among tropical deciduous forests. Data source: Elliott et al. (2006).

the role various factors in triggering the vegetative bud breaks in deciduous species in this region.

Like leaf flush, leaf fall timing also varies among tropical trees. Species with longer deciduousness (>4-mo-deciduous and stem succulents, Figure 2) show leaf fall just after the cessation of rains in the early dry season of the annual cycle. However, leaf-exchanging and short deciduous species exhibit leaf falls in mid dry season. While in leaf-exchanging species old leaves are replaced with the new, deciduous species remain leafless till late dry or early rainy season. Given that leaf senescence is an evolutionarily

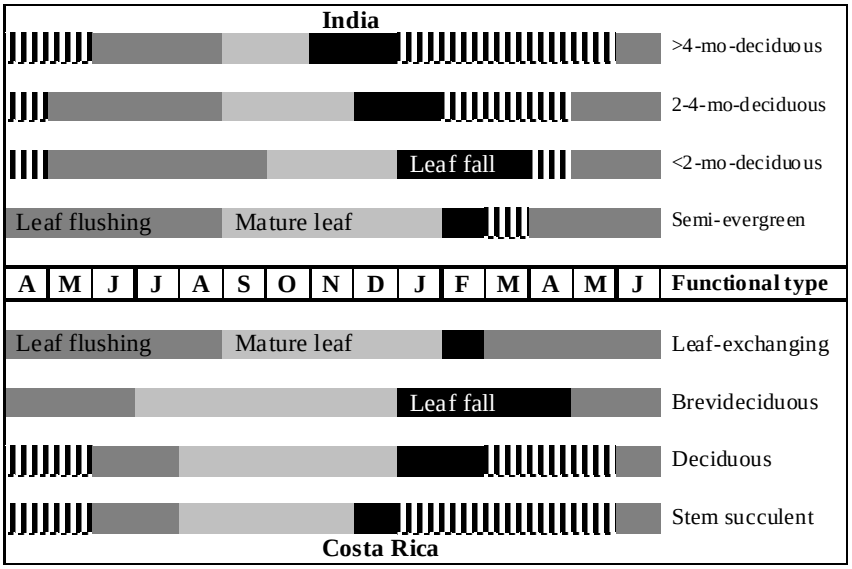

Fig. 2 Approximate duration of various vegetative phenological events in four major phenological functional types recognized in India and Costa Rica. Data source: Kushwaha and Singh (2005) for India; Rivera et al. (2002) for Costa Rica.

acquired process (Lim et al. 2007), variation in timing and pattern of leaf fall among phenological functional types may be result of their adaptations to microhabitats varying in soil moisture levels.

Duration of deciduousness

The tree deciduousness traits have been in existence for at least 100 million years and may have evolved at generally lower latitudes as an adaptation to seasonal drought under climatic conditions present during the early Cretaceous (or Jurassic) period (Axelrod 1966, Bowman and Prior 2005). Evolution of deciduousness trait in tropics is apparent from the contiguous vegetation zones distributed along climatic gradients in America, Africa, and southern Asia where such vegetation-climatic gradients from wet evergreen rain forest to tropical deciduous forest, deciduous woodland, thorn scrub, and tropical desert are seen (Axelrod 1959). In India, for instance, along progressively drier areas there is a rising degree and duration of deciduousness during the dry season and an accompanying decrease in tree height, leaf size, community complexity, and the number of families and genera represented (Table 1). These major plant formations appear to have evolved by gradual adaptation to decreased precipitation, increased seasonal drought, and greater range of temperature variability. This inference is consistent with the evidence provided by Cretaceous and Tertiary fossil

floras preserved in regions which are now semiarid to desert in southern California, northern Africa, India, south Australia, and central Chile (Axelrod 1966). In these areas the fossil floras suggest that with decreasing rainfall and longer drought period tropical and subtropical evergreen forests were replaced gradually in time by woodland and thorn forest and later by the present day tropical desert vegetation (Axelrod 1950). Stable isotopes study in permineralized wood of Permian polar forests has demonstrated the presence of deciduousness during the late Permian at polar latitudes (Gulbranson et al. 2012).

Table 1. Climo-vegetational characteristics of tropical forest in India (Data Source: Singh and Singh 1988).

Climate/ characteristics	Wet evergreen	Moist deciduous	Dry deciduous	Thorn forest
Mean annual temp. (°C)	23-27	20-29	20-29	24-29
Mean January temp. (°C)	15-21	12-26	16-25	13-26
Annual rainfall (cm)	240-320	120-300	75-140	25-90
Annual dry months	3-5	4-8	5-8	7-10
Vegetation deciduousness	Entirely or nearly absent	Predominan-tly deciduous; sub canopy evergreen	Entirely deciduous or nearly so	Entirely deciduous
Species richness	Extremely rich	Rich	Poor	Extremely poor
Canopy height (m)	40-50	25-40	8-20	<10
Basal area (m^2 ha^{-1})	40-55	35-50	15-20	<5
No. ligneous layer	4-6	3	2	1

In deciduous trees, leaf fall (indicating the end of growing season) and the subsequent leaf flush (growth resumption) are separated by a discrete but variable duration of leaflessness or deciduousness (indicating the rest period). In seasonally dry tropics plant species are believed to be characterized by tree functional traits like deciduousness (~leaflessness) and adaptation for drought tolerance. In dry tropics, the time lag between the completion of leaf fall and the initiation of leaf flushing (i.e. the duration of deciduousness) is an important attribute of deciduous tree species, showing adaptations related to the seasonal drought. The degree of water stress experienced by dry tropical forest trees differs widely due to their varying adaptations, resulting in marked differences in the duration of

deciduousness (from leaf exchanging to >8 months deciduous). Tropical deciduous forests are composed of mosaics of tree functional types showing considerable variations with respect to the time of bud break of vegetative bud and duration of deciduousness (Borchert et al. 2002, Singh and Kushwaha 2005a). The impending impact of global climate change (e.g. changes in temperature and precipitation) on the extent of deciduousness and vegetative growth period ranks high among critical questions in the ecology of dry tropics (Do et al. 2005). For instance, knowledge of the deciduousness period of various tree species in relation to the annual cycle is a prerequisite to estimate the annual carbon fluxes. Thus, vegetative (leaf) phenology in dry tropics may be viewed from the broader perspective of a gradient of duration of deciduousness across tree species. The co-existence of four tree functional types including one semi-evergreen and three deciduous ones showing progressive increase in deciduousness has been demonstrated in Indian Vindhyan dry tropical forests (Kushwaha and Singh 2005) (Fig. 2). The trend of increasing deciduousness is also clearly evident in the four major leaf functional types recognized in Costa Rica.

Singh and Kushwaha (2005a) have verified the ubiquitousness of deciduousness based tree functional types with a large species data-set and found that majority of tree species are <2-mo-deciduous (47%), 2-4-mo-deciduous (18%), >4-mo-deciduous (13%) and remaining are leaf-exchanging (21%). In deciduous forests of Costa Rica and Thailand 41% and 5% species show 3-5 months deciduousness and 34% and 42% species represent 1-3 months deciduousness, respectively (Elliott et al. 2006). Tropical tree species represent a gradient of deciduousness ranging from leaf-exchanging to >6 month deciduous species. Categorization of Indian tropical forests as moist evergreen, semi-evergreen, moist deciduous, dry deciduous and thorn forests based on annual canopy fullness and deciduousness (Champion and Seth 1968) can be regarded as marker of the amount and distribution of annual rainfall and seasonal variation in soil moisture availability. Proportion of deciduous species and the extent of deciduousness - both increasing with greater severity of annual drought – significantly affect structure and functioning in these forests.

In majority of species marked intra-specific asynchrony occurs in terms of deciduousness. Calculation of the duration of deciduousness in West African savanna trees from the data of De Bie et al. (1998, Appendix 1), indicating the periods in leaf and without leaf for different species at five sites, all located within the annual rainfall range 600-800 mm, show large variation in deciduousness duration of the same species growing at different sites (Table 2). Individuals of same species growing at different

sites differed radically from being leaf exchanging to 8 months deciduous (e.g. *Acacia seyal* and *Combretum nigricans*, Table 2), reflecting high sensitivity to small changes in growing habits. Under current tropical climatic conditions large inter-annual variations in the length of growing and deciduousness periods are noticed in the tropical trees (Yoshifuji et al. 2006). Even conspecific individuals of dominant species growing at the same site often differ with respect to growing and deciduousness periods in response to micro-site variations (Singh and Kushwaha 2005b). In dry environments, heterogeneity and periodicity of water availability have been demonstrated as being crucial factors in phenological rhythms of tree communities and populations (Seghieri and Galle 1999). Borchert (1994) showed that in dry forests intra-species variation in phenology is guided by differences in soil water availability. Thus, wide conspecific variation in the extent of deciduousness, resulting from varying leaf flush and leaf fall timings, seems to be an essential functional attribute that leads to broader ecological amplitude of tree species by adaptation to varying micro-conditions.

Table 2. Deciduousness variation in tropical tree species growing at five different sites in West Africa having long term average rainfall 600-800 mm; The representative data presented in this table has been deduced from the Appendix 1 of De Bie et al. 1998).

Species	**Range of deciduousness (mo) at different sites***						
	Y	**B**	**S**	**T**	**BB**	**Period**	**Variation**
Piliostigma reticulatum	0	0	0	1	0	Feb	1
Diospyros mespiliformis	0	2	0	0	0	Mar-Apr	2
Maytenus senegalensis	-	2	0	0	0	Apr-May	2
Adansonia digitata	6	7	4	4	6	Oct- Apr	3
Prosopis Africana	-	2	0	0	4	Nov-Apr	4
Combretum glutinosum	4	4	0	0	0	Nov-Mar	4
Sterculia setigera	7	8	4	4	8	Oct-May	4
Ziziphus mauritiana	0	0	0	5	1	Jan-May	5
Piliostigma thonningii	-	0	0	1	5	Dec-Apr	5
Daniellia oliveri	-	1	0	0	6	Oct-Mar	6
Combretum micranthum	6	7	2	1	4	Oct-May	6
Combretum nigricans	7	-	0	3	3	Sep-May	7
Parkia biglobosa	-	7	0	3	4	Sep-Apr	7
Acacia seyal	5	8	0	1	5	Oct-May	8
Pterocarpus lucens	7	8	2	-	7	Oct-Jun	8

*Y (Yabo), B (Bissiga), S (Sourou), T (Tisse) are located in Forest Reserves at Burkina Faso and BB (Boucle du Baoule) is located in Biosphere Reserve at Mali.

In tropical trees estimates related to leaf functions have been generally generated in fully expanded leaf condition, during the growth promoting period (period of maximal carbon assimilation) (Prior et al. 2004). Such approximations may not act as representative of the annual values. All deciduous species (leafless from <1 month to >7 months, inter-annual and conspecific variations) show an absolute decline in assimilation rate during the deciduousness period and rely on reserves to support their activities.

Deciduousness as an indicator of climate change

It is important to search and identify unambiguous indicators of the impact of global climate change at a regional or local level (Donnelly et al. 2004). Ecological indicators provide information about the phenomena that are regarded as typical for, and/or critical to, environmental quality and they are used to simplify a complex reality (Smeets and Weterings 1999). Currently, the phenological observations of tree developmental stages have proved to be most effective impact indicators of climate change (Donnelly et al. 2004). The criteria established by the OECD (1993) for indicator selection are listed in Table 3, which emphasize on relevance and utility for users, analytical soundness, and measurability of the ecological indicator. Identifying a set of indicators which fulfill all of these criteria is a challenging task. Due to the complex and uncertain nature of climate change effects it is difficult to establish appropriate indicators of climate change impact on the environment.

Table 3 . OECD (1993) criteria for indicator selection and suitability of tree deciduousness as an ecological indicator for climate change in dry tropics.

S.N.	OECD criteria for indicator selection	Suitability of deciduousness
1.	**Policy, relevance and utility for users**	A climate change indicator should:
	Provide representative picture of climatic conditions	Deciduousness in tropical trees is best indicator of drought experienced
	Be simple, show trends over time and be easily interpreted	Deciduousness can be depicted from naked eye, it is very sensitive to small variation in the climate
	Be representative to change and relate to human activity	Documentation of deciduousness in tree functional types over the period will represent the changes
	Be comparable internationally	Quantitative documentation will serve the purpose
	Be national in scope or applicable to regional climatic issue	Under different climatic conditions, its extent will indicate the prevailing climatic conditions

	Have a reference value against which comparisons	Values can be compared from the current extent of can be made so that users are able to assess the deciduousness in different tree functional types significance of the values associated with it
2.	**Analytical soundness** A climate change indicator should:	
	Be theoretically well founded in technical and scientific terms	Term deciduousness well situated for this criteria
	Be based on international standards	Quantitative documentation will be expected by Global scientific community
	Lend itself to being linked to economic models, forecasting and information system	Its role in C sequestration, as a drought and soil moisture condition indicator make it important
3.	**Measurability** The data required to support the indicator should:	
	Be readily available at a reasonable cost/benefit ratio	Documentation of deciduousness involves minimum cost but provides immense significance
	Be of high quality and well documented	The best indicator of tree rest period and can be deduced from growth period
	Be updated regularly in accordance with reliable	Once quantification made, it can be periodically updated procedures

In tropical trees the trait of deciduousness may act as a reliable indicator of climate change because it reflects an integrated effect of seasonal drought, tree characteristics and soil moisture conditions. Deciduousness is linked with rainfall, temperature and solar radiation and may be serve as an indicator of the response of vegetation to climate change (Bohlman 2010). Quantitative estimates of deciduousness may provide a means for predicting species ranges as well as other forest characteristics. Several models have depicted the possible response of tropical forests to future climatic changes (Steffen et al. 1996). Such models may have to be adjusted by assessing how well they predict deciduous behavior under different climates (Condit et al. 2000). Since deciduousness can be easily recorded from a satellite, it may become a key parameter for the analysis of the effect of climate change on tropical forests. Accurate quantitative documentation of deciduousness in tropical forests is essential for calibrating remote sensing images which attempt to assess canopy properties such as carbon cycling, productivity, or chlorophyll content (Condit et al. 2000). Recent advances in remote sensing have showed the potential to

generate valuable ecological information such as leaf level drought responses, phenological patterns, canopy nutrient and moisture content (Chambers et al. 2007).

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Regeneration status of *Melocanna baccifera* (Bambusaseae) after gregarious flowering in Assam, India

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Abstract

Melocanna baccifera locally called *Muli* is the most dominant species of bamboo in the forest tract of North East India which flowered gregariously during the years 2004-08, which subsequently set seed and died. The species is intricately interwoven with social, economical and ecological aspect of life of people and well suited to the landscape of the region. So knowledge on the population status of the species after gregarious flowering will form the basis for sustainable management of the species in its natural stand. In this paper, we took the advantage of gregarious flowering and regeneration event in Barak Valley part of North East India to study the regeneration status. We performed the managerial (private and *open access* management) and temporal (in the year 2011 and 2013) assessment of the regenerating stand to evaluate its regeneration status. Study revealed *open access* area experienced a loss of 75% of the total population from 2011 to 2013 in comparison to 30 % gain in private management system over the same period. We emphasize the need for adoption of alternative sustainable management strategy for the sustenance of *open access* area to ensure long term supply of goods and services to the local inhabitants.

Keywords Open access, Private management, Harvesting, Sustainable management

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Introduction

An unusual characteristic of some perennial bamboos is their habit of flowering at long intervals (3-120 yrs), dying back and then regeneration from seed (McClure 1966, Janzen 1976, Veblen 1982). The long intermast period for the mass flowering in bamboos has prevented documentation of germination and establishment of population except few works (Numata et al. 974, Venkatesh 1984, Qin 1985, Montti et al. 2011) while status of population establishment with respect to different management regime remains unexplored. In this paper we present the analysis of two levels of exploitation on *Melocanna baccifera* stands regenerating after gregarious flowering of 2007-08 in wild condition.

M. baccifera is the predominant bamboo species naturally growing in the forests of North East India (Banik 2000, 2010). This is a non-clump forming bamboo, culms diffused in the clump. It is an early colonizer and often forms the dominant vegetation on the tropical and subtropical hill slopes on which it grows (Banik 1997, Nandy et al. 2004). It is naturally distributed in a swathe cutting south to north from southwestern Myanmar through western central and northern Myanmar and the Chittagong hill tracts of eastern Bangladesh, to the North Eastern states of India, where it represents between 60 and 95 percent of the regions bamboo resources (INBAR 2004). Throughout North East India flowering was observed in 2004-08 (Jeeva et al. 2009) and in Cachar district of Barak Valley it flowered in 2007-08. The species has recognized its important role in rural socioeconomic and employment generation besides its industrial utility in North East India (INBAR 2004). Therefore successful regeneration of bamboos from seed is a key issue in livelihoods of their inhabitants (Nath et al. 2012). We took the advantage of gregarious flowering and regeneration event to investigate regeneration status of *M. baccifera* under different management options being adopted locally for its utilization and management.

Materials and methods

Study area

Cachar is the largest district (3,786 km^2) of Barak Valley of Assam with 2225 km^2 (58.76 %) of forest cover (FSI 2005). Forest vegetation of Cachar comes under Cachar Tropical Evergreen and Semi Evergreen forest (Champion and Seth 1968). Bamboo in the forest is primarily the seral type and its occurrence is attributed to heavy biotic interference. It forms the important natural resources for various family subsistence needs for the fringe forest villages. The district is a heterogeneous plain composed of

both the low lands and high hills and level plains. The climate of the district is tropical wet with hot and wet summers and cool winters. Rainfall ranges from 2226-3000mm per year, most of which is received during the southwest monsoon season (May-September). Southwest monsoon usually operates for a longer spell in the North-East region of the country compared to other parts of India. Average maximum and minimum temperatures were 34° C and 10° C respectively.

Present study was carried out in two selected *M. baccifera* forest stand of Cachar Tropical Semi Evergreen forest of Cachar district in Assam. During 2007-08, in the selected stands *M. baccifera* flowered gregariously, set seed and died. Subsequent seed germination started on the same year (i.e. 2007-08) with the onset of rain (May-June). The two selected study sites (Figure 1) viz. Rosekandy (24° 41.762 N, 92° 41.131 E) (referred as **Site A**) and Borokai (24° 38.038'N, 92° 39.901'E) (referred as **Site B**) are situated within a radius of 8 km. **Site A** is located in the forested stand of a tea garden. Forested portion of tea garden is managed by respective tea garden owners. Management system includes the regulation system on procuring and accessing of the forest product by fringe villagers and tea garden laborer. **Site B** is not under any private ownership and forest stand is managed by the common people who depend on it for their resource requirement.

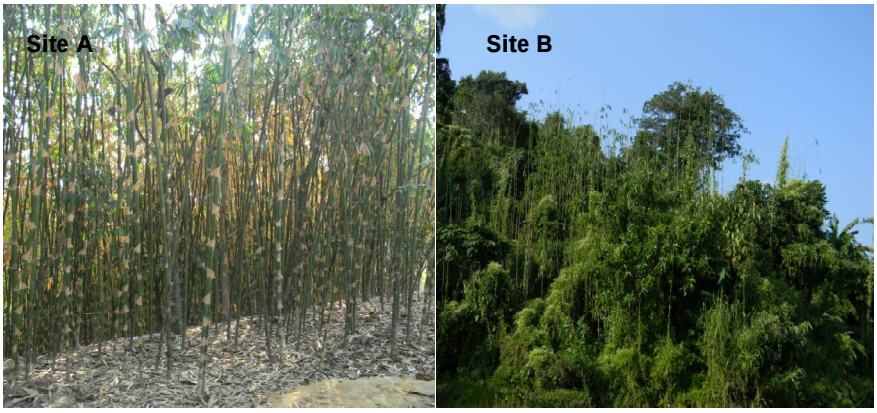


Figure 1. View of study sites

The purpose for selection of the two sites is to represent two management regimes prevailing in the study area. For example, (i) in **site A** tea garden authority permitted for very limited access to bamboo culms for harvest to the local tea garden labors who are residing inside the tea garden. Based on this regulation, limited harvest of bamboo culms by laborer

was recognized and therefore, we treated the particular study area as less disturbed. (ii) Site B is not under the regulation of any private owner; hence the access to bamboo culms for harvest to nearby villagers is not restricted. Unlimited harvest of culms from the bamboo stand was found to have occurred to suffice local villagers need and requirement for subsistence. For the reason stated here, we treated the area as severely disturbed.

Data collection

To evaluate the population status of *M. baccifera* after 4th and 6th year of gregarious flowering, two different site (Site A: less disturbed; Site B: severely disturbed) was selected and evaluated in January 2011 and February 2013. In 2011 five quadrats of 5m x 5m were laid in each of the selected sites and the GPS point was noted. Sampling strategy was stratified random sampling, the strata being dense population to sparse population. Assessment comprised a complete count of all the bamboo culms (from different culm ages) within the quadrat and measurement of culm diameter at 5 cm above the ground level. Culms were aged following Banik (2000) and Nandy et al. (2004). In 2013, the selected sites were revisited (identified from GPS points of 2011) and same assessments as of earlier visit was repeated. Only addition was counting and measurement of culm diameter at 5 cm above the ground level for cut stump within the quadrat. This was performed to know the size difference between standing culm and harvested culm.

Data analysis

Population status of the studied stand from 2011(α) and 2013(β) was evaluated from the calculated values of Net Change (α - β) and Percentage gain/loss [(Net Change X 100)/ α].

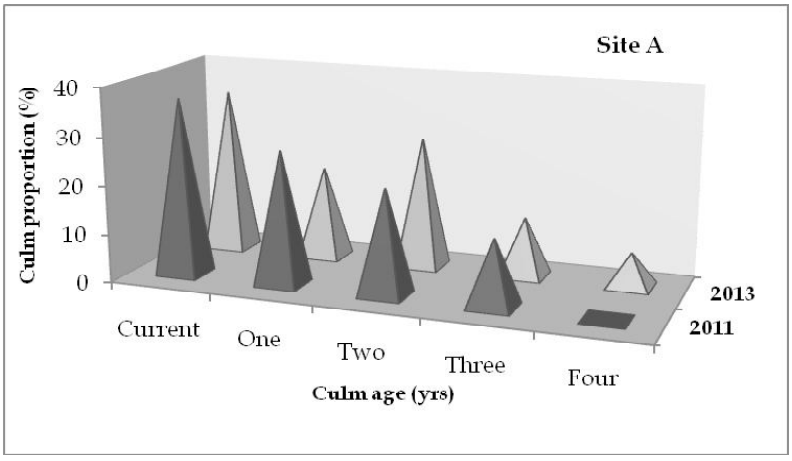
Results

M. baccifera flowered gregariously in Cachar district of Barak Valley, Assam in 2007-08. Post flowering successful regeneration from seed was observed in selected study areas. Table 1 depicts the population status of the species in two different areas after 4th and 6th year of flowering. After 4th year of flowering, stand density ranged from 34800 to 35600 culms ha^{-1}. In 2011, stand population structure was represented by current, one, two and three year old culms and 57 to 64 % of the total standing stock were represented by current and one year old culms (Figure 2). Evaluation of the same parameters on the revisit in 2013 revealed stand density of 9200 to 45600 culms ha^{-1}, stand population structure of five different age classes (current, one, two, three and fourth year) and contribution of current

Table 1: Culm density (no ha^{-1}) after 4th and 6th year of gregarious flowering in two different locations

	Culm ages					
	Current	One	Two	Three	Four	Total
			2011			
Site A	12800	9600	7600	4800	0	34800
Site B	12400	8000	8000	7200	0	35600
			2013			
Site A	15600	8800	12400	5600	3200	45600
Site B	2800	800	3600	1200	800	9200

and one year culms towards total standing stock was 39 to 54%. We analyzed net change and percentage gain/loss for different culm ages from two data series (2011 and 2013) as a measure to understand the effect of management regimes on culm population status (Figure 3). Positive net change was recognized for site A except for one year old culm. Site B exhibited negative net changes for all the age classes. Percentage gain in some age classes was observed for site A while site B experienced percentage loss in all culm ages. Harvesting was observed to be related with culm size rather than age class across the management systems (Figure 4). Average diameter range of standing culm was 4.1 to 10.8 cm, while it was 5.1 to 11.55 cm for cut stump. Culm size distribution was recognized to be related with management regimes, less disturbed sites with bigger culm and severely disturbed sites with smaller culm.



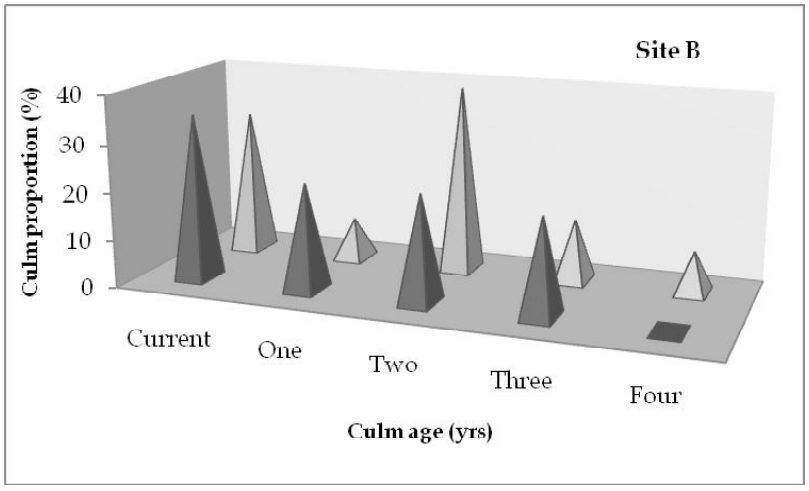


Figure 2: Culm population structure of *M. baccifera* after 4th and 6th year of gregarious flowering

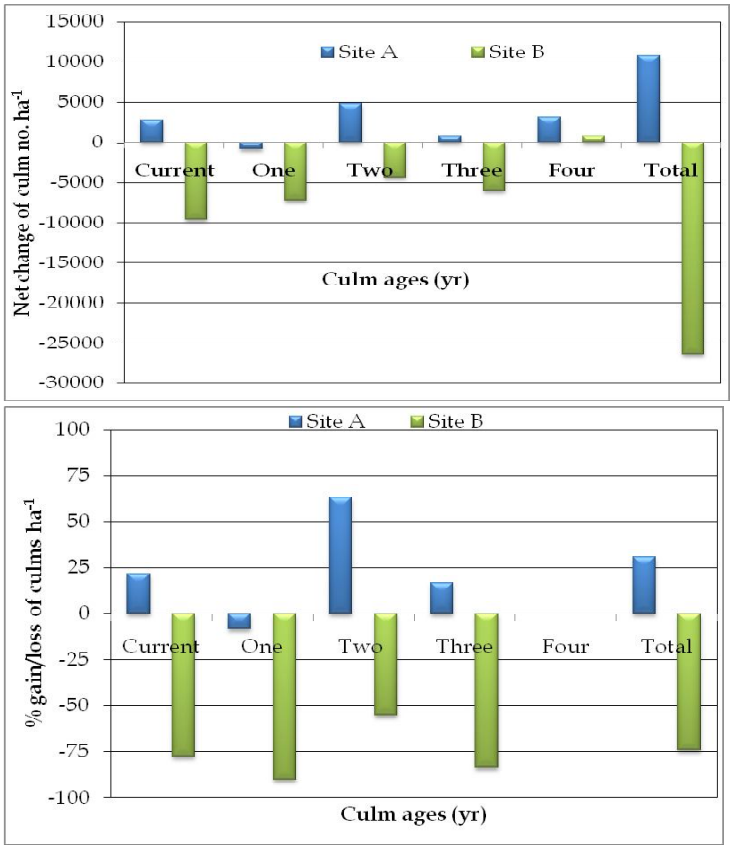


Figure 3: Net change and % gain/loss of *M. baccifera* culms during 2011 to 2013 with respect to two management regimes

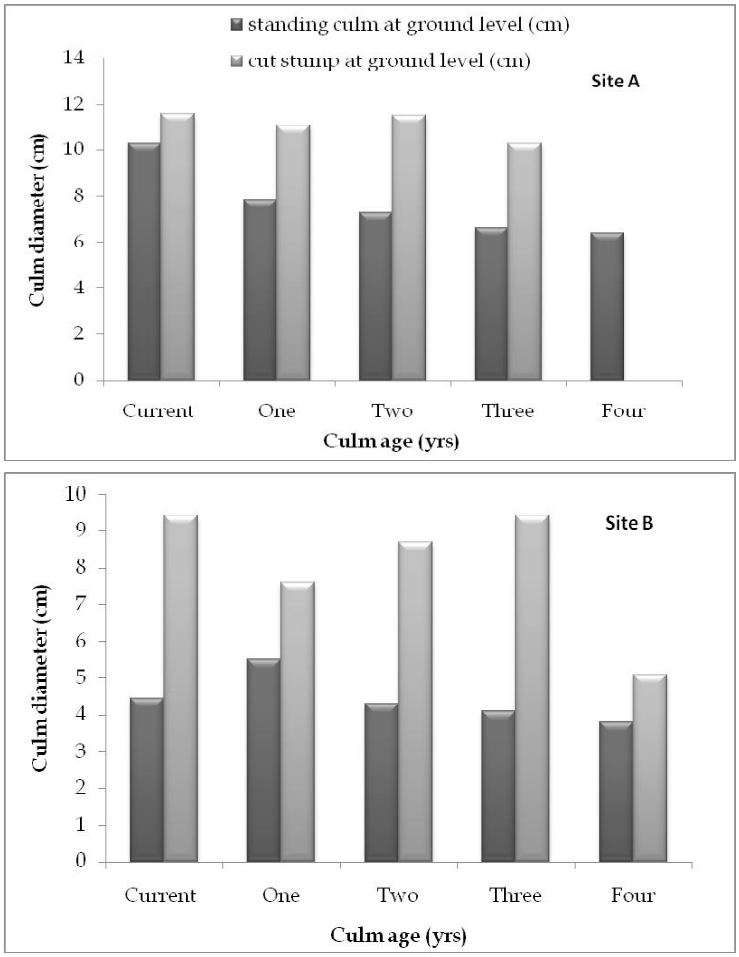


Figure 4: Mean differences in culm diameter between standing and harvested culm in *M. baccifera*

Discussion

M. baccifera is used in diverse purposes, ranging from commercial purpose to household family uses for subsistence. Commercial purpose includes selling to the paper industry while family uses include house construction, craft making, fencing, etc. Young shoots are also used for food items. *M. baccifera* is extracted in various intensities depending on its use and availability. Bamboo is one of the important minor forest products that assist in subsistence of people in North East India (Laha 2000, Bhatt et al. 2001, Sundriyal et al. 2002, Nath et al. 2011). Stand density in 2011 between the two sites did not varied markedly. This may be the initial phase of stand development for successful regeneration, protection

was provided in both private and common areas to ensure its future use. At the 4th year of stand age, stand structure was mainly represented by current and one year old culms. Smaller and thinner recruits up to fourth year of stand age reported in *M. baccifera* (Banik 1993). So immature culms, their small size can't yield the desired output of villagers and therefore not harvested at initial stage of stand development. Analysis of data series between 2011 and 2013 revealed a loss of 75% of the total stock in Site B from 2011 to 2013 (Figure 2). In the mean time Site A exhibited a gain of 30% in total stock over 2011. Fu and Banik (1995) reported given adequate protection, natural regeneration of bamboos occurs profusely after each gregarious flowering. Lack of protection and unregulated harvesting from villagers caused such drastic decline in stand density in Site B. Many forest areas in developing countries are exploited under an *open access* regime (Bishop 1999). Exploitation of wild bamboo stands is extensive in many parts of India (Rao and Rao 1995, Upreti and Sundriyal 2001, Nath et al. 2012). Culms are usually harvested for construction purposes in their third or fourth year and younger ones for preparation of crafts (Lybeer et al. 2006, Nath et al. 2007). Overexploitation also impair the culm population structure (evident from Figure 2, Site B), which is one of the important driver for stand sustainability. A stable population structure with preponderance towards young aged culm is key for maintaining the stand productivity (Yuming et al. 2001, Nath and Das 2011). Overexploitation may also decline the basal area of the bamboo stand and thus substantial loss of photosynthetic potential. The photosynthetic capacity of the available foliage was positively related to number and size of recruits in Chinese bamboo (Li et al. 1998). Many other negative consequences of overharvesting reported for wild bamboo stands. These include changes in stand structure and dynamics (Vazquez-Lopez et al. 2004, Franklin 2006, Nath and Das 2011); declines in nutrient availability and productivity (Banik 1997, Nath et al. 2006). Therefore consequences of over harvest raise the question of sustainability of the wild bamboo stand. Isagi et al. (1997) suggested sustainable management of regenerating bamboo stand requires maintenance of viable populations of ramets. This is because in pachymorph bamboos, interconnected and interdependent culms are aggregated into clumps which increase by peripheral expansion (McClure, 1966). Culms are recruited in annual cohorts by expansion of buds on a parent rhizome and subsequent rapid elongation of culms (Ueda 1960). Methods for sustainable harvest of plantation bamboo are available (Ueda 1960, Fu and Banik 1995) but for wild stand a sustainable harvesting technique requires to be worked out. What is most important at this stage is to develop an alternative management protocol including the local mass for *open access*

regime to sustain the bamboo stand from further degradation and to ensure its long term utilization.

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Plant species diversity and its utilization pattern in homegardens of Mizo community of North-East India

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Abstract

Homegardens (locally known as *Chuktuah huan)* are an important production system of food and other essential products, harboring unique and sometimes rare genetic diversity of crop plants, however, very little information on these aspects exist for Mizoram. Forty homegardens (size from 0.025 ha to 1.5ha) of Mizo community were surveyed to study the plant species composition and their uses in four villages of Aizawl district in Mizoram in Northeast India. The methods employed for the study included semi-structured interviews, direct observation and use of various phyto-sociological tools on vegetation inventory. A total of 198 species (82 trees, 31 shrubs, and 79 herbs, 6 palms) belonging to 69 families and 169 genus were recorded from the homegardens. Papilionaceae had the highest species number (11) followed by Cucurbitaceae (9) Caesalpiniaceae, Euphorbiaceae and Rutaceae (8 each). The most common of the plants was as vegetable (24%), followed by fruit (18%), firewood (12%), medicine (11%), ornamental (9.8%), fodder (9.2%). The species *Acacia pinnata*, *Artocarpus heterophyllus, Carica papaya, Clerodendrum colebrookianum, Musa paradisiaca, Parkia timoriana and Trevesia palmata* are the most common species found and forming the characteristic features of the homegardens. Commercial cultivation of some crops like *Anthurium spp, Areca catechu* and *Citrus reticulata* were found in some big gardens. This study suggests that homegardens are production system maintained purposively for harvesting diverse products and are important avenues for species conservation and food

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security at household level. Moreover, it reveals that species diversity of the homegardens was comparatively higher than reported values in tropics and most of the plant species grown were having multiple uses. Homegardens are rich in biodiversity, playing a role in the conservation and maintenance of the plants and needed to consider for development programs in future.

Keywords: *Chuktuah huan*, Inventory, Multipurpose tree, Species diversity.

Introduction

Homegardens (locally known as *Chuktuah huan)* are traditional agro-ecoystems characterized by complexity in their structure and multiple functions in tropical countries. They vary greatly in species, species richness, structural complexity and size (Gillespie et al. 1993, Birol et al. 2005). They are described as the production system that occupies land marginal to the field production system with marginal labour to major household economic activities and characterized by ecologically adapted and complementary species (Fernandez and Nair 1986, Okafor and Fernandez 1987, Snelder 1987). It is precisely a traditional agricultural production system spread all over the year, with low input and high output fulfilling different family food requirements at little or no extra cost. Species diversity is high in most of the homegardens which is a functional characteristic of homegardens (Brierley 1985) thereby the risk of crop failure and biological stability of crops is also ensured in the production system due to high diversity of crop plants. In terms of composition, high diversity of species with an immediate use in the homestead is the most prominent feature of homegardens (Hoogerbrugge and Fresco 1993). The features of homegardens are year round production of food and a wide range of other products such as firewood, fodder, spices, medicinal plants and ornamentals, decreased risks of production failure due to high diversity of species, increased resource productivity over time, expansion of the amount and quality of labor applied in the farm, provision of output flexibility and alternative production if unfavorable circumstances develop, potential to serve as repositories of genetic diversity, and acting as insurance against pests and disease outbreaks (Cromwell et al. 1999, Esquivel and Hammer 1992, Kehlenbeck and Maass 2004). In general, production in homegardens is year-round, unlike the seasonal harvest of farmers' fields. Although yields are normally low, this is more than compensated by the diversity and nutritious nature of the products (Fernández and Nair 1986, Torquebiau 1992, De Clerck and Negreros-Castillo 2000).

The structure and composition of homegardens can well be adjusted to various livelihood conditions such as size of landholdings, role of

homegardens within the overall farming-system and degree of commercialization (Wiersum 1982, Christanty et al.1986, Soemarwoto 1987). Distribution of the species spatially and temporally in the homegarden displays different vegetation layers forming forest like multistorey making them typical agroforestry systems. Food, fruit and timber species may dominate the homegardens and occupy the middle and upper strata, but medicinal plants, spices and vegetables occupy the lower stratum. A home garden will seldom host more than a few hundred plants (indeed, most often it will contain only a few individuals) even of the most important crops (Hodgkin 2001) and the population size is highly variable depending on the species. Ecology, local food culture, socio-economic condition, farmer's interest and market forces are some of the important factors that determine the species composition present in home gardens (Gajaseni and Gajaseni 1999, Hodel et al. 1999, Hoggerbrugge and Fresco 1993, Soemarwoto and Conway 1992, Jacob and Alles 1987). According to Articles 7, 8 and 10 (c) of the Convention of Biological Diversity, inventorisation of such high diversity areas can help in the identification and conservation of biodiversity (Huston 1994, Pascal 1988, Das and Das 2005). These gardens are planted and maintained by members of the household and their products are intended primarily for household consumption. Because of their great contribution to indigenous people's livelihoods, biodiversity conservation, ecological and economic functions, and modern agroscience, homegardens have been receiving increasing attention from scientists, especially ethnobotanists, but are still under-researched.

Homegardens are probably as old as shifting cultivation and evolved through generations of gradual intensification of cropping in response to increasing human pressure and the corresponding shortage of arable lands (Kumar and Nair 2004). In Mizoram context, while shifting cultivation has been researched well for their socio-ecological bearings in Mizoram, very little attention is given to the homegardens (Sahoo 2009). On the other hand, homegardening is the second most important land use system in Mizoram after shifting cultivation. There is lack of in-depth knowledge and information on species composition in Mizo homegardens. The purpose of the present study was to document species composition and their utilization in the homegarden maintained by Mizos.

Materials and Methods

Study site

A random stratified sample of 40 homegardens, situated in almost similar physico-climatic terrain in four villages viz Sairang, Selesih, Tanhril,

Maubawk (10 homegardens from each village) in Aizawl district ($92^0$38' to $92^0$42' E longitude and $23^0$42' to $23^0$46' N latitude, 950 m asl) of Mizoram were selected for a detailed study on homegarden composition and structural characteristics.

Data collection

In the homegardens of each household a detailed survey of the composition and management practices was made and the household elder members were interviewed about the uses of each species. Local names were recorded for all species. Plant species in the homegarden were identified by consulting the regional flora (Lalramnghinglova 2003) and other publications (Sahoo et al. 2012). The survey consisted of an inventory of trees and shrubs species and a count of all individuals per species. Only presence was recorded for herbs and (bi)-annuals. The species were classified according to their use into the categories fruits and nuts, food, fodder, vegetable, spices, timber and firewood, medicinal products, ornamentals, and other.

Results and discussion

The size of homegarden in the study villages ranged from 0.025 to 1.25 ha, with a mean size of 0.34 ha. This falls well within the range of the global inventories on tropical homegardens. Fernandes and Nair (1986) reported that the average size of the homegarden units is less than 0.5 ha. Other authors reported, to mention a few, from about 0.01 to greater than 0.2 ha in Ethiopia (Zemede 2001), 0.009 to 0.25 ha in Guatemala (Leiva et al. 2002) and 0.32 ha in Nicaragua. Also, it is reported 0.16-0.59 ha in Ghana (Bennett-Lartey et al. 2002), 0.09 ha in Cuba (Wezel and Bender 2003), 0.024-0.24 ha in Indonesia (Kehlenbeck and Maass 2004) and 0.30 ha in India (Das and Das 2005).

A total of 198 species (82 trees, 31 shrubs, and 79 herbs, 6 palms) belonging to 69 families and 169 genus were recorded from the homegardens. Papilionaceae had the highest species number (11) followed by Cucurbitaceae (9) Caesalpiniaceae, Euphorbiaceae and Rutaceae (8 each). Thirty families were represented by single species, while 14 families were represented by more than 5 species. Caesalpinaceae, Cucurbitaceae, Euphorbiaceae, Mimosaceae, Moraceae, Musaceae, Papilionaceae, Rutaceae, Solanaceae, Verbenaceae and Zingiberaceae were the most dominant families in the homegardens of Aizawl district of Mizoram**.** From total 90 plant families recorded, Papilionaceae had the highest species number (11), as it provides a variety of food crops like *Glycine max*,

Phaseolus vulgaris, *Cajanus cajan* etc followed by Cucurbitaceae (9), Caesalpiniaceae, Euphorbiaceae and Rutaceae (8 each) while Zingiberaceae, Moraceae, Mimosaceae, Solanaceae, shared 5 each as most of the vegetable crops preferred by the local farmers belong to these plant families. Most homegarden species were perennials (78%) while 16% were annuals and 6% biennials. According to habit, 79 species (40 %) were herbs, 31 (15 %) were shrubs, 82 (41 %) were trees, 6 (4%) were palm (Table 1).

Table1: Relative frequency (RF) of various plant species and their use in Mizo homegardens of North-East India (fr- fruit, lf- leaf, wd- wood, orn- ornamental, tlf- tender leaf, sd- seed, bk- bark, wp- whole plant, c- climber, fdd- fodder, veg- vegetable, fw- fuelwood, sh- shoot, st- stem, con- condiment, med- medicinal, fur- furniture, hdg- hedge, fla- flavour, rt- root, brl- branchlet, fd- food, pl- pole).

Botanical name	Local name	RF	Family	Parts used	Uses
Trees					
Aegle marmelos	Belthei	28.3	Rutaceae	fr, lf	fr, fdd
Albizia odoratissa	Thingri	40.7	Mimosaceae	wd	fw, con, Fur
Albizia procera	Kangtek	36.9	Mimosaceae	wd	fw
Anacardium occidentale	Sazupumpuithei	25.4	Anacardiaceae	nut	fd
Anogeissus acuminata	Zairum	39.3	Combretaceae	wd	fw
Aralia foliosa	Chimchawk	46.6	Araliaceae	tlf	veg
Artocarpus chama	Tatkawng	44.5	Moraceae	wd, fr	con, fr
Artocarpus heterophyllus	Lamkhuang	89.4	Moraceae	fr, lf, wd	veg, fdd, con
Averrhoa carambola	Theiherawt	60.8	Oxalidaceae	fr, lf, wd	fr, med, con
Azadirachta indica	Nimthing	70.5	Meliaceae	lf, fr	fdd, med
Baccaurea ramniflora	Pangkai	45.5	Euphorbiaceae	fr	fr
Bauhinia variegata	Vaube	56.9	Caesal-piniaceae	lf, fr, fl	veg, fdd
Bruinsmia polysperma	Theirelchhin	33.7	Styraceae	fr, wd	fr, fw, con
Callistemon lanceolatus	Botolbras	68.8	Mrytaceae	orn	orn
Carallia brachiata	Theiria	46.8	Rhizo-phoraceae	wd, fr, lf	fr, con, fdd
Cassia fistula	Phungril	43.3	Caesal-	fl, wd	veg, fw,

			piniaceae		med
Cassia tora	Kelbe	26.9	Caesal piniaceae	tlf, wd, pod, lf, fl	veg, fw, fdd
Castanopsis tribuloides	Thingsia	52.5	Fagaceae	wd, nut	fw, pst, fr
Celtis australis	Vaibawngchaw	21.3	Ulmaceae	lf, fr, wd	fdd, fr, fw
Cinnamomum tamala	Hnahrimtui	35.1	Lauraceae	lf, wd	con, fw
Citrus grandis	Sertawk	77.2	Rutaceae	fr	fr, med
Citrus macroptera var *anamensis*	Hatkora	46.8	Rutaceae	fr	med, flav
Clerodendrum colebrookianum	Phuinam	90.5	Verbenaceae	lf	veg
Clerodendron serratum	Leidumsuak	65.3	Verbenaceae	tlf, fl	veg
Delonix regia	April par	46.9	Caesal-piniaceae	wd, orn	fw, orn
Dillenia pentagyna	Dengte	62.5	Dilleniaceae	wd, fl bud, fr	fw, veg
Elaeocarpus floribundus	Thinglung	36.9	Tiliaceae	wd, fr	fw, con, fr
Emblica officinalis	Sunhlu	82.8	Euphorbiaceae	fr	fr
Erythrina indica	Fartuah	42.1	Papilionaceae	orn	orn
Eurya simplocina	Sihneh	46.9	Theaeceae	wd, lf	fw, veg
Ficus elastica	Thialret	32.8	Moraceae	wd, lf	Fw, fdd
Ficus hirta	Sazutheipui	36.8	Moraceae	lf, fr	veg, fr
Ficus hispida	Theithawt	46.1	Moraceae	wd, lf, fr	fw, veg
Ficus racemosa	Theichek	65.2	Moraceae	wd, fr, lf	fw, fr, fdd
Garcinia lanceaefolia	Chengkek	32.4	Guttiferae	fr, lf	fr, veg
Gmelina arborea	Thlanvawng	38.9	Verbenaceae	wd, fl, lf	con, veg, fdd
Grevillea robusta	Silver oak	41.3	Proteaceae	wd, wt	con, orn
Haldina cordifolia	Lungkhup	28.3	Rubiaceae	wd, lf	con, fur, fdd
Holarrhena antidysentrica	Thlengpa	35.9	Apocynaceae	wd, bk, lf, sd	con, med
Ilex umbellulata	Thinguihahni	26.8	Aquifoliaceae	wd	fw
Jacaranda mimosaefolia	Aprilparpawl	31.2	Bignoniaceae	wt	orn

Lagerstroemia speciosa	Thlado	58.4	Lythraceae	wd	con, fw
Leucaena leucocephala	JapanZawngtah	63.2	Mimosaceae	tlf lf, pod, wd	veg, fw, pl
Litchi chinensis	Vaitheifeimung	42.9	Sapindaceae	fr, wd	fr, fw
Litsea monopetala	Nauthak	55.3	Lauraceae	wd, lf	fw, fdd
Malus domestica	Apple	46.9	Rosaceae	fr	fr
Mangifera indica	Theihai	82.4	Anacardiaceae	fr	fr
Mangifera sylvatica	Haifavang	64.1	Anacardiaceae	fr	fr
Melia azaderach	Nimsuak	72.4	Meliacaeae	lf, fr, wd	med, fdd, fw
Mesua ferrea	Herhse	56.2	Guttiferae	wd	con, fur, fw
Michelia champaca	Ngiauhnahhlai	34.8	Magnoliaceae	wd	fur, con
Moringa oleifera	Thingantam	69.3	Moringaceae	tlf, fl, fr	veg, fdd
Morus alba	Thingtheihmu	35.8	Moraceae	tlf, wd	fdd, fw, con
Oroxylum indicum	Archangkawm	25.7	Bignoniaceae	tlf, gp	veg, fdd
Parkia timoriana	Zawngtah	92.5	Mimosaceae	pod, lf	veg, med
Persea americana	Butter thei	67.3	Lauraceae	fr	fr
Phyllanthus acidus	Kawlsunhlu	79.2	Euphorbiaceae	fr	fr
Pithecolobium montanum	Ardahsuak	24.8	Mimosaceae	lf	dye
Polyalthia pendula	Zathu	35.6	Annonaceae	wp	orn
Prunus domestica	Theite	29.4	Rosaceae	fr	fr
Prunus persica	Theitehmul	65.3	Rosaceae	fr	fr
Psidium guajava	Kawlthei	81.4	Myrtaceae	fr, lf	fr, med
Pyrus communis	Perthei	76.4	Rosaceae	fr, lf	fr, fdd
Rhus semialata	Khawmhma	69.5	Anacardiaceae	fr, wd	fr, fw
Samanea saman	Rain tree	44.8	Mimosaceae	wd, pod	fur, fdd
Saraca asoca	Baikang	38.9	Caesal-piniaceae	tlf, wt	veg, orn
Schima wallichii	Khiang	78.4	Theaceae	wd	con, fw
Semecarpus anacardium	Kawhtebel	34.8	Anacardiaceae	wd, rfr	fw,, fr
Spondias pinnata	Tawitaw	23.1	Anacardiaceae	wd, fr	fw, dr, fr

Sterculia alata	Vantai	34.1	Sterculiaceae	wd, sd	dr, fw, sd
Sterculia villosa	Khaupui	44.8	Sterculiaceae	wd, sd	dr, sd
Syzygium cumini	Hmuipui	57.6	Myrtaceae	fr, wd	fr, fw, panel
Tamarindus indica	Tengtere	53.2	Caesal-piniaceae	pod, lf, wd	fr, veg, fw
Tectona grandis	Tlawr	67.2	Verbenaceae	wd	con, fur, fw
Terminalia bellirica	Thingvandawt	45.6	Combretaceae	wd, sd	con, sd
Thuja compacta	Fartechi	24.7	Cupressaceae	wp	orn
Thuja orientalis	Fartechi	18.6	Cupressaceae	wp	orn
Toona ciliata	Teipui	33.1	Meliaceae	wd, lf	fur, fdd
Trema orientalis	Belphuar	23.4	Ulmaceae	lf	fdd
Trevesia palmata	Kawhtebel	100.0	Araliaceae	sh, fl, bud, fr, lf	veg, fdd
Ulmus lancifolia	Phan	34.1	Ulmaceae	wd, lf	post, fw, fdd
Vitex penducularis	Thingkhawilu	28.3	Verbenaceae	wd, lf, bk	post, fw, med
Zanthoxylum budrunga	Chingit	45.7	Rutaceae	wd, tlf	post, veg
Zizyphus jujuba	Borai	32.9	Rhamnaceae	fr, lf, wd	fr, fdd, fw
Shrubs					
Acacia pinnata	Khanghu	100.0	Mimosaceae		
Adhatoda vasica	Kawldai	56.6	Acanthaceae	lf, wp	med, hdg
Allamanda cathartica	Hruipangpar	24.9	Apocynaceae	fl	orn
Antidesma acidium	Thurtean	56.9	Euphorbiaceae	lf, fr	veg, fr
Bougainvillea spectabilis	Sarawn	37.9	Nyctaginaceae	fl	orn
Caesalpinia pulcherrima	Aprilte	44.8	Caesal piniaceae	fl	orn

Cajanus cajan	Behling	83.7	Papilionaceae	lf, pod, sd	veg
Camellia sinensis	Thingpui	35.7	Theaceae	lf	bvg
Carica papaya	Thingfanghma	92.5	Caricaceae	fr	fr
Cassia alata	Arzawldamdawi	25.9	Caesal-piniaceae	lf	med
Citrus aurantifolia	Serte	56.8	Rutaceae	fr	fr, med
Citrus limon	Ser	67.1	Rutaceae	fr	fr, med
Citrus reticulata	Serthlum	78.4	Rutaceae	fr	fr
Coffea khasiana	Thingsai ngal	36.8	Rubiaceae	fr	bvg
Coffea arabica	Coffee thing	41.1	Rubiaceae	fr	bvg
Crotolaria juncea	Tumthang	35.5	Papilionaceae	fl, hdg	veg, hdg
Duranta repens	Hlingdai	31.4	Verbenaceae	hdg	hdg
Eleagnus latifolia	Sarjukpui	52.7	Eleagnaceae	wd, fr	fw, fr
Euphorbia pulcherrima	Hnahsen	41.2	Euphorbiaceae	lf, fl	orn
Jatropha curcus	Thingthau	33.2	Euphorbiaceae	hdg	fen.
Kadsura heteroclita	Theiarbawm	26.6	Magnoliaceae	fr	fr
Murraya Koenigii	Arpatil	91.7	Rutaceae	lf	fla
Nerium indicum	Kananpar	34.0	Apocynaceae	fl	orn
Opuntia stricta	Rulpuilei	31.5	Cactaceae	fr, wp	fr, hdg
Psychotria calocarpa	Kawrpelh	45.8	Rubiaceae	lf, bk, st	lf, veg, med
Punica granatum	Theibuhfai	53.2	Punicaceae	fr	fr
Ricinus communis	Mutih	62.1	Euphorbiaceae	lf, sd	med
Sida acuta	Khingkhih	28.3	Malvaceae	brl, rt	broom, med
Solanum anguivi	Samtawkte	36.9	Solanaceae	fr	veg, med

Solanum melongena	Bawkbawn	84.3	Solanaceae	fr	veg
Solanum nigrum	Anhling	35.4	Solanaceae	lf	veg, med
Herbs					
Abelmoschus esculentus	Rahnal	84.4	Malvaceae	fr	veg
Acalypha indica	Thingtheihmupar	31.2	Euphorbiaceae	fl	orn
Agave americana	Saidai	20.1	Agavaceae	wp	orn
Allium cepa	Purunsen	93.3	Liliaceae	bulb, lf	veg, med
Allium hookerii	Mizopurun	79.4	Liliaceae	wp, rt	veg, med
Allium sativum	Purunvar	80.3	Liliaceae	bulb, lf	con. veg, med
Amomum dealbatum	Aidu	78.4	Zingiberaceae	rt, bud	veg
Amorphophallus paeonifolius	Telhawng	68.3	Araceae	corm, tlf	veg, med
Anannas comosus	LaKhuihthei	86.6	Bromeliaceae	fr	fr
Anoectochilus luteus	Hnahmawi	36.6	Orchidaceae	orn	orn
Arachis hypogaea	Badam	40.3	Papilionaceae	nut	fd
Brassica juncea	Antam	94.6	Cruciferae	lf, sd	veg, med
Bambusa tulda	Rawlak	53.8	Poaceae	yst culm	Veg, basket, mat
Brassica oleracea var *botrytis*	Parbawr	78.6	Cruciferae	fl	veg
Brassica oleracea var *capitata*	Zikhlum	82.4	Cruciferae	lf, head	veg
Canavalia ensiformis	Fangra	78.3	Papilionaceae	pod, sd, lf	Veg, pulse, fdd
Capsicum annum	Hmarcha	90.4	Solanaceae	Fruit	Condi-ment
Capsicum frutescens	Hmarchapui	78.2	Solanaceae	Fruit	Condi-ment
Catharanthus roseus	Kumtluang	51.7	Apocynaceae	wp	med, orn
Celosia argentea	Zoei	43.3	Amaranthaceae	lf, fl	veg
Centella asiatica	Lambak	87.1	Umbelliferae	lf, stalk	veg, med, fdd

Chrysanthemum indicum	Octoberpar	52.3	Compositae	fl	orn
Colocasia affinis	Baibing	82.5	Araceae	lf, stalk, fl	veg, fdd
Colocasia esculenta	Dawl	93.5	Araceae	corm, st, lf	Veg, fdd
Costus speciosa	Sumbul	33.5	Zingiberaceae	rt	med
Cucumis melo var saccharinus (C)	Hmazil	72.1	Cucurbitaceae	fr	fr
Cucumis sativus	Fanghma	82.1	Cucurbitaceae	fr	fr
Cucurbita maxima (C)	Maien	100.0	Cucurbitaceae	lf, fl, fr	Veg
Curcuma longa	Aieng	83.6	Zingiberaceae	rhz	cond, med
Daucus carota	Carrot	77.3	Umbelliferae	rt	veg
Dendrocalamus longispathus	Rawnal	51.4	Poaceae	yst,culm	Veg, building, basket
Dioscorea alata (C)	Rambachim	66.3	Dioscoreaceae	tuber	veg
Dioscorea glabra (C)	Hrakai	59.4	Dioscoreaceae	tuber	veg
Diplazium maxima	Chakawk	82.5	Polypodiaceae	tlf	veg
Elettaria cardamomum	Alaichi	47.2	Zingiberaceae	sd	spice, med
Elsholtzia communis	Lengser	86.9	Labiatae	lf, fl	fla
Ensete superbum	Saisu	53.8	Musaceae	st, yfl	veg, orn
Entada pursaetha	Kawihrui	92.1	Mimosaceae	tlf	veg
Eryngium foetidum	Bahkhawr	90.2	Apiaceae	lf	con
Fagopyrum dibotrys	Anbawng	68.3	Polygonaceae	lf	veg, fdd
Glycine max	Bekang	83.2	Papilionaceae	sd, wp	veg, med
Hedychium coronarium	Ainawn	74.9	Zingiberaceae	wp	orn
Helianthus annuus	Nihawi	35.1	Compositae	sd, wp	sd, orn

Hibiscus rosa sinensis	Banglapar	40.5	Malvaceae	wp	orn
Hibiscus sabdariffa	Anthur	73.9	Malvaceae	lf	spice
Hodgsonia macrocarpa	Khaum	43.2	Cucurbitaceae	sd	sd
Homalomena aromatica	Anchiri	53.2	Araceae	stalk	veg
Houttuynia cordata	Uithinthang	86.4	Saurauraceae	wp	veg
Ipomea batatas	Kawlbahra	60.4	Convulvu-laceae	tuber, lf	veg, med
Kaempferia rotunda	Tuktinpar	42.3	Zingiberaceae	fl	orn
Lablab purpureus (C)	Bepui	79.4	Papilionaceae	young pod, sd	veg
Lagenaria siceraria (C)	Um	43.9	Cucurbitaceae	fr	veg
Latuca indica	Khuanglawi	73.2	Compositae	ylf	veg
Luffa aegyptiaca (C)	Nawhfeawm-pawng	33.2	Cucurbitaceae	fr, fibre	veg
Lycianthes laevis	Vanian	50.3	Solanaceae	lf	veg
Lycopersicon esculentum	Sapbawkbawn	79.4	Solanaceae	fr	veg
Melocanna baccifera	Mautak	43.2	Poaceae	culm, sh	con, veg
Mirabilis jalapa	Artukkhuan	32.9	Nyctaginaceae	fl	orn
Momordica charantia (C)	Chhankha	65.4	Cucurbitaceae	yfr, lf	veg
Momordica mixta (C)	Maitamtawk	84.3	Cucurbitaceae	yfr, lf	veg
Mentha viridis	Pudina	66.3	Labiatae	wp	veg, med
Musa paradisiaca	Banhla	85.5	Musaceae	bud, fl, st pith	veg, med
Passiflora edulis	Sapthei	67.8	Passifloraceae	fr, lf	fr, veg, med
Phaseolus vulgaris	Bean	90.7	Papilionaceae	fr, pod	veg
Plantago major	Kelbaan	46.9	Plantaginaceae	lf	veg, med
Psophocarpus tetragonolobus (C)	Chawngbepui	32.8	Papilionaceae	fr	veg
Pueraria montana var. *chinensis* (C)	Zawngtur	45.3	Papilionaceae	tuber	tuber
Saccharum officinarum	Fu	76.3	Poaceae	st	juice, med

Sesamum indicum	Chhibung	58.9	Pedaliaceae	sd	oil, sd
Raphanus sativus	Buluih	80.7	Cruciferae	rt, lf	veg
Sansevieria zeylanica	Rullei	31.7	Agavaceae	orn	orn, med
Sechium edule (C)	Iskut	73.1	Cucurbitaceae	fr, lf	veg, fdd
Spilanthes acmella	Ansate	74.7	Compositae	lf, st	veg, fdd
Tagetes patula	Derhkenbuk	65.3	Compositae	orn	orn
Thysanolaena maxima	Hmunphiah	83.9	Poaceae	fl panicle	broom
Vigna unguiculata (C)	Behlawi	83.5	Papilionaceae	ylf, pod sd	veg
Vitis vinifera (C)	Grapethei	73.2	Ampelidaceae	fr, lf	fr, med
Zea mays	Vai mim	100.0	Poaceae	cob	fd
Zingiber officinalis	Sawthing	93.5	Zingiberaceae	rhz, lf	spice, med
Palm					
Areca cathechu	Kuhvakung	78.5	Palmae	nut	nut
Arenga pinnata	Thangtung	62.5	Palmae	lf, sh	veg
Calamus tenius	Thilte	37.9	Palmae	fr, sh	fr, veg
Caryota urens	Tum	44.3	Arecaceae	bud, fibre	veg, fibre
Cocus nucifera	Narialthing	53.1	Palmae	fr	fr
Daemonorops jenkinsianus	Raichhawk	23.3	Palmae	sh, fr, cane	veg, fr, basket

The most frequently reported species were *Parkia timoriana, Psidium guajava, Mangifera indica, Trevesia palata, Artocarpus heterophyllus* among trees, *Acacia pinata, Carica papaya, Murraya Koenigii* among shrub and. *Cucurbita maxima, Colocasia esculenta* and *Brassica juncea, Phaseolus vulgaris, Zea mays* dominated the herbs category. *P. timoriana* provides protein rich green pods and latter two species provide fruits that can be marketed locally. At the family level, Cucurbitaceae, Caesalpiniaceae,

Solanaceae, Poaceae, Papillionaceae and Euphorbiaceae demonstrated the highest floristic importance in homegardens. The most conspicuous characteristics of all homegardens irrespective of their size are their layered canopy arrangements and admixture of compatible species. Mohan Kumar et al.(1994) found 127 woody species across the homestead of 14 districts and 3 to 25 species per homestead in Kerela. However, Nair and Sreedharan (1986) reported 30 arboreal taxa from the selected home gardens of Kerala. High number of tree and shrub (301 species) have been reported also in Mayan home gardens of Yucatan, Mexico (Rico-Gray and Wienen 1963), 168 species in Santa Rosa in the Peruvian Amazon (Padoch and de Jong 1991) and 179 species in home gardens of Java (Soemarwoto 1987). Similarly, Tynsong and Tiwari (2010) reported 187 species in homegardens of War Khasi community in Meghalaya.

The farmers practiced no systematic intercropping, rather they practiced random intercropping and similar practice were recorded in Maya homegardens (Barrera 1980, Rico-Gray et al. 1990, Caballero 1992, Herrera-Castro et al. 1993, Montserrat et al. 1993, Ortega et al. 1993). An important characteristic of the Mizo homegardens (*Chuktuah huan)* is the animal component. The villagers reared cattle, fowls, and pigs mainly for domestic consumption and sometimes for sale. About 90% of the households practiced piggery.

The present study clearly reveals that species grown in the traditional homegarden systems are confounded by the livelihood requirements and traditional knowledge.

Vertical stratification of home garden*:*

The homegardens exhibit a complex structure, both vertically and horizontally. In the present study, the vegetation of the homegarden showed three to four different layers, viz. topmost layer (10 m or more), understory (5 to10 m), shrubs (1 to 5 m), and herb (less than 1 m) layer.The uppermost canopy usually consists of protein rich leguminous tree *Parkia timoriana, Artocarpus heterophyllus, Schima wallichii, Tectona grandis, Melocanna baccifera* etc which extends from 10-16 m. The canopy layer from 3-10 m were constituted by other fruit trees like *Psidium guajava, Carica papaya, Musa paradisiaca, Prunus, Citrus, Trevesia palmata*, etc and the lowest canopy is occupied by *Clerodendrum colebrookianum*, woody climbers like *Acacia pennata* and *Eleagnus latifolia* etc. up to 2-3 m. Herbaceous vegetables, tubers and climbers constituted the ground layer. In the studied home gardens, maximum species were found distributed

in second and first stories which resembled with the finding of many researchers over the world (Mohan Kumar et al. 1994, Nair and Sreedharan 1986, Michon et al.1983). The structural parameters of the homegardens in the study village were very similar to the other previously documented tropical homegardens (Shrestha et al. 2001, Peyre et al. 2006, Kumar et al. 1994). In the Kandyan homegardens of Sri Lanka, four layers were recorded (Perera and Rajapakse 1991) while in the homegardens of Andaman and Nicobar (Pandey et al. 2006) and in Assam (Devi and Das 2010) five stories were reported.

Horizontal zonation was also observed in some of the gardens, although these were not systematically arranged. These zones included vegetable growing area, bamboo groves, poultry/ piggery sheds, ponds and tanks used for fishery and irrigation, residential zone, ornamental zone etc. The structure and composition of homegardens can well be adjusted to various livelihood conditions such as size of landholdings, role of homegardens within the overall farming-system and degree of commercialisation (Wiersum 1982, Christanty et al. 1986, Soemarwoto 1987).

Homegarden plant use

All plant species in the homegardens were useful to farmers in some way or the other and eleven categories of uses were recorded. Although many of the plants had multiple uses only the major use of the plant as informed by the farmers were considered for allotting the category. The study shows that vegetables are the major component of the homegarden followed by fruit, medicinal, firewood and ornamental plants. The households cited most species as useful for vegetable (24%) followed by fruit (18%), firewood (12%), medicine (11%), ornamental (9.8%), fodder (9.2%), timber (6.7%) and others (9.3%) (Fig 1). The other utility class includes spice, beverage, broom, nut, although important, comprised only of a few species per category. Of the 198 recorded plants 86 have only one indicated use, while 112 had more than one attributed utility in the study area. *Parkia timoriana, Psidium guajava, Clerodendrum colebrookianum, Mangifera indica, Prunus domestica, Trevesia palmata, Citrus grandis, Schima wallichii, Artocarpus heterophyllus* etc. are the most important trees which provided multiple uses to the farmers (**Table 1**). Similarly, a good number of shrubs, herbs and climbers are a good source of multiple use and income to the farmers. Out of 82 tree species, 56 species fruit trees were cultivated. The most common fruit trees are *Emblica officinalis, Citrus grandis, Psidium guajava, Tamarindus indica, Prunus domestica* etc.

Besides the use of the fruits, *Artocarpus heterophyllus, Carallia brachiate* are mainly used for fodder, *Averrhoa carambola, Elaeocarpus floribundus* for construction, *Callistemon lanceolatus, Polyalthia pendula* for ornamental and *Spondias pinnata, Sterculia alata, Sterculia villosa* for making traditional drum. *Aegle marmelos, Garcinia lanceaefolia* are endangered and rare species that are present in the homegarden. *Murraya Koenigii, Elsholtzia communis* are commonly grown for flavour. Most plant products are used mainly for self consumption or for fodder but their surplus products are also sold in the market. In homegardens of Nicaragua, home consumption was 100% for most fruit trees and herbaceous food species. Cash crops like pineapple (*Anannas comosus),* maize *(Zea mays),* areca nut (*Areca catechu*) are income generating source and some common ornamental plants include *Callistemon lanceolatus, Allamanda cathartica, Bougainvillea spectabilis, Caesalpinia pulcherrima, Chrysanthemum indicum, Tagetes,*.

Homegardens are living gene banks and reservoir of plant genetic resources that preserve land races, obsolete cultivars, rare species and endangered species and species neglected in larger ecosystem (Daniaogbe et al. 1992, Eyzaguirre and Linares 2001). Many studies on home garden in other parts of the world (Agelet et al. 2000, Nair 2001, Vogl-Lukasser et al. 2001, De Clerck and Negreros-Castillo 2002, Gessler et al. 1998, Hoggerbrugge and Fresco 1993, Soemarwoto and Conway 1992, Padoch and De Jong 1991, Okafor and Fernandes 1987) revealed that rich species diversity of the homegarden system would be important for conservation of plant genetic resources. The composition of such species in a home garden is governed by many factors that make home garden a dynamic system (Daniels and Kirkpatrick 2006). By combining tree growing and horticultural cultivation, farmers have developed an integrated agricultural and tree production system which makes an optimal use of the soil production capacity, ensures multiple uses of natural resources, and provides multiple and sustained yields of different types of crops for subsistence and additional commercial use. They are therefore often considered as epitome of sustainability (Torquebiau 1992, Kumar and Nair 2004).

Conclusions

The practice of homegardening contributes not only in providing numerous direct benefits to the owners and to the users of home garden products but also promotes *in-situ* biodiversity conservation. The home gardens are dynamic systems and are highly acknowledged for retaining higher diversity that represents microenvironments within larger farming

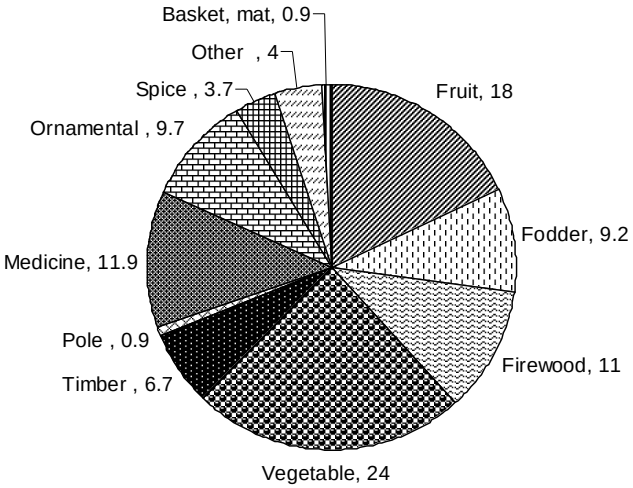

Figure 1: Plant use category of the homegardens in Aizawl district, Mizoram

systems; a mimics the natural, multi-layered ecosystem and is agro-ecosystem (Agelet et al. 2000, Nair 2001). They provide food, vegetables, fruits, fuel wood, small timber, herbs and spices etc for their daily requirement and also a source of income generation. In view of the fact that they also provide numerous ecological, economical and social benefits to the rural poor, the policy makers should promote home gardens in Mizoram to wean away pressures on the ongoing *jhum* (shifting cultivation). Probably some targeted and well-planned interventions may further be undertaken to strengthen the importance of this production system. It is further envisaged that through a better understanding of the role of farmers and their families as the producers of garden products, it will be possible to improve the management of genetic diversity in homegardens which in turn may result in a better and more sustainable production.

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Diversity of medicinally important weeds in a sub-urban town of West Bengal, India

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Abstract

This study was carried out to evaluate the composition, density, diversity, dominance, distribution and biomass of medicinally important weeds in Barasat – a congested sub-urban town near Kolkata. In this highly disturbed area, 20 medicinally important weed species were identified. While all species were typical of wasteland flora, 8 species showed preference for moist habitats which tend to dominate the vegetation. There were 16 aliens of which 12 were invasive alien species. Perennials (65%) outnumbered annuals. Majority of the plants were contagiously distributed (80%) and showed either allelopathic or anti-microbial properties. 19 species possessed medicinal usefulness of which 7 species were highly valued. Diversity and evenness indices were 3.08 and 1.03, respectively. Ratio of above ground to below ground biomass was 1.4 : 1. The clay-loam soil was nutrient rich. The disturbed settings with high proportion of aliens, still showed many utilizable species that tend to provide goods and services to the people. With a healthy soil and decent species diversity "passive re-vegetation" of wastelands might be achieved.

Keywords Urban disturbances, Alien weed species, Medicinal plant diversity, Plant biomass, Medicinal usefulness.

Introduction

Disturbance is a mechanism that negatively affects the survival, growth and production of plants. It was estimated that over 40% of the earth's vegetated land surfaces were directly disturbed (Daily 1995) and

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unfortunately for India, more than half of the land mass was degraded due to disturbances such as land use change, deforestation, grazing, industrialization, urbanization and scores of other human activities (Singh et al. 2008). Land use change (an adverse effect of tremendous population growth) was not only going to influence ecosystem functions (Gross et al. 2009) but would also change the biodiversity (Sala et al. 2000).

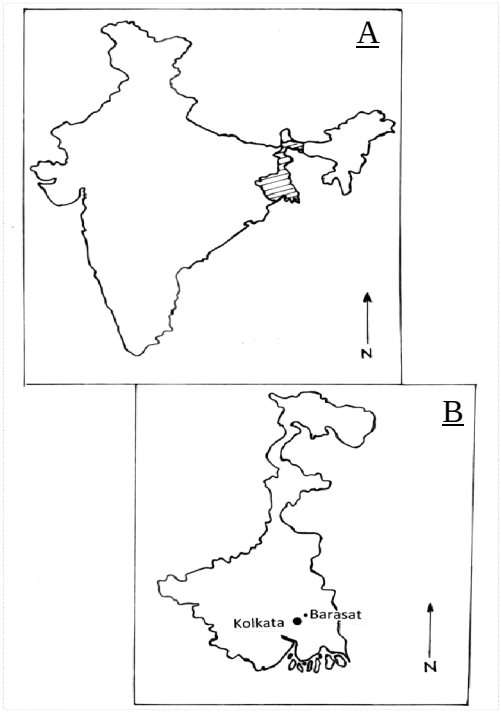
It was believed that next to habitat destruction, alien species were the second highest threat to biodiversity (Simberloff 1995). India in this respect was a bad sufferer. An earlier estimate commented that about 18% of its flora was made up of aliens (Nayar 1977). More recently, it was reported that 40% of its flora were alien species of which 25% were invasive (Raghubanshi et al. 2005). As to why aliens were better adapted to disturbed sites had already been thoroughly discussed by Simberloff et al. (2005) and Sharma et al. (2005) but it remains a fact that these species were very much an essential element of urban and sub-urban habitats (Honney et al. 2003). Quite interestingly it had been established that these habitats tend to show high species diversity due to greater spatial heterogeneity (Gilbert 1989, Roy et al. 1999).

While plant diversity studies in the disturbed regions of northern India have been carried out (Sharma et al. 2001, Gupta and Narayan 2006), there exists little or no quantitative ecological information pertaining to the vegetation around the city of Kolkata (formerly Calcutta) of West Bengal, India. (Majumdar 1965, Anonymous 2004, Bhattacharya et al. 2012). Thus with an aim to contribute to the base line ecological data, this study was carried out in the town of Barasat, located in the suburbs of Kolkata metropolis, to evaluate the species composition, density, diversity, dominance, dispersion, biomass estimation of the medicinally important weed layer. The properties of the soil layer were also evaluated. The place presented a picture of a thickly populated, congested, unplanned town with narrow roads, clustered houses, scattered water-bodies and occasional fallow fields that were grazed as well as used as dumping yards. Traditionally though, it was a low-lying land prone to water-logging that sustained a farming-business community, results presented below were the summer time data.

Materials and methods

Study Site

Barasat town ($22^0$42’57" N Lat. and $88^0$28’56" E Long.) is situated at a distance of 25km to the north-east of Kolkata (Figure 1a,b,c). It happens



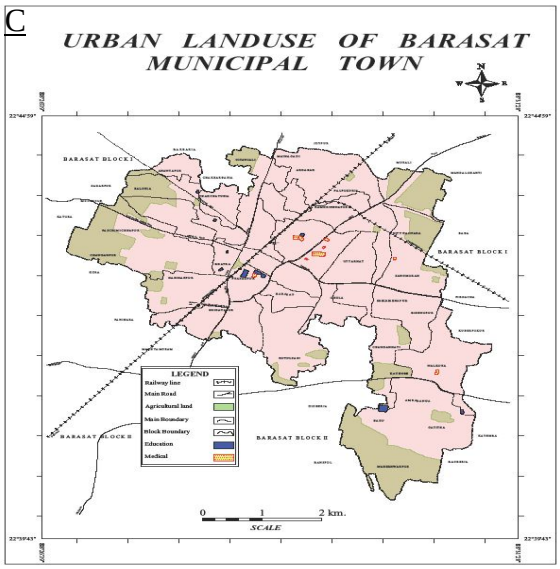


Figure 1 : (A) Map of India showing West Bengal in shade
(B) Map of West Bengal showing Kolkata and Barasat
(C) Map of Barasat town where the work was carried out

to be the headquarters of the North 24-Parganas district of West Bengal. It is a border district that has experienced a very high pace of urbanization both in terms of volume of urban-population as well as number of urban-centres in last several decades (Paul and Chatterjee 2012). It also has the distinction of being the second most populous district of the entire country. This has largely been due to mass migration following the partition and independence of India and later with the creation of Bangladesh. The town had population of 16,027 in the year 1951, when the area was merely 14.25 km^2. By 2011 the same had gone up to 2,78,435 and the area had expanded to 34.5 km^2. About 75% of the town is a built-up area showing concentric development pattern and where over 22% of its people lived in the 160 odd slums (Anonymous 2007). Concurrently there has been a boom in construction work, land-filling, vehicular traffic, waste matter dumping, grazing, land clearing and host of other man related activities. The study area was thus a highly disturbed and fragmented site.

The climate of the area was typically sub-tropical with three major seasons, for example, a hot humid summer (April - mid June), followed by a wet monsoon (mid June - September) and a cool dry winter (December - mid February). The mean maximum and minimum temperatures recorded were 43^0C (May) and 10^0C (January). It received an annual mean rainfall above 1500 mm and the relative humidity ranged from 55% (March) to 98% (July). [Data availed from the North 24-Parganas district headquarters].

Methodology

Plant sampling

The weed layer was analyzed by randomly laying one hundred quadrats of 60 cm x 60 cm dimensions all over the town at places like pond side, park-garden, fallow land, road-side and office-school and house back-yards. The size and number of quadrats needed were determined in the field by following Misra (1968) and Kershaw (1973). Using one foot nails and measuring tapes, the quadrats were marked out on the field and then the medicinally important weed species were listed, counted and identified using standard literatures (Hooker 1872 – 97; Prain 1903a). Graminae members were not part of the study. All the individual plants had their basal area measured out with vernier callipers. Frequency, density, abundance of species were determined by following Curtis and McIntosh (1950). The importance value index (IVI) was calculated as the sum of relative frequency, relative density and relative dominance (Curtis 1959). The ratio of abundance to frequency was used to interpret the distribution

pattern of species (Whitford 1949). If the ratio was <0.025, it indicated regular distribution, random distribution was between 0.025 and 0.05, while contagious distribution was > 0.05 (Curtis and Cottam 1956). Species richness – as indicated by the number of species was evaluated by following Whittaker (1975) and species evenness was evaluated following Pielou (1966). Species diversity and concentration of dominance were determined by following Shannon and Weaver (1949) and Simpson (1949), respectively.

Plant biomass sampling

The above ground biomass (ABG) of weed was estimated through ground level harvesting of fifty quadrates (60 cm x 60 cm) laid randomly across the town. The ABG was the collective summation of all living green, standing dead plants and litter. The fresh harvest was packed in air tight bags and weighed for fresh weight and then in the laboratory they were dried at 80^0C for 48 hours to get the dry weight. The moisture percentage was deduced from the difference of two weights. The below ground biomass (BGB) was estimated by digging out fifty soil monoliths of 15cmx15cmx15cm dimensions at random. Each monolith was then washed carefully within 24 hours in gentle running water to collect BGB in 0.5 mm sieve. By using blotting paper the surface water was removed from these and weighed to get fresh weight. The same was then dried at 80^0C for 48 hours to get the dry weight. The moisture percentage was deduced as above.

Soil analyses

Soil samples were randomly collected (0-10 cm depth) from nine representative localities of the town during the study period. They were thoroughly mixed and packed in air tight bags for analyses in the laboratory. Soil moisture content was immediately determined on dry weight basis (as the difference in weight of fresh and oven dry sample). Thereafter, the samples were air dried, sieved (2mm) and stored. Soil pH was determined by digital pH meter (1:5 soil water ratio) and the water holding capacity by following Misra (1968). The organic C was estimated by rapid filtration method of Walkley and Black (1934) while the available nitrogen (microkjeldahl's method), phosphorus and potassium (flame photometer) were determined by following Subbiah and Afija (1956), Bray and Kurtz (1945)and Hanway and Heidel (1952), respectively.

Results

Floristic composition

In the study area during the study period a total of 20 weed species under 18 genera and 12 family were recorded (Table 1). Amaranthaceae, Euphorbiaceae and Solanaceae were among the most numerous family represented by 3 species each. There were 7 annuals while the rest were perennials (9 herbs, 3 shrubs and 1 climber species). All the species were confirmed plants of disturbed wastelands and at least 8 of them showed preference for moist habitat or were downright semi-aquatic. A great majority of the plants – 16 species, had Tropical origin with 10 species from the Americas. As was true of wasteland flora there were 16 aliens of which 12 were invasive alien species.

The vegetation was dominated by 5 plants – *Xanthium strumarium*, *Amaranthus spinosus*, *Chrozophora plicata* and two species of *Polygonum* (Table 2). These species accounted for more than 60% of the importance values (183.25 index points) and over 70% of density values (15.05 individuals m^{-2}). Many species showed either allelopathic characteristics (14 species) or anti-microbial properties (16 species). There were at least 10 species that were noxious weeds but at the same time 19 species had some form of medicinal utility. The distribution of plants were predominantly contagious (16 species) while the rest were randomly dispersed. The species diversity and the concentration of dominance were found to be 3.08 and 0.205, respectively while the evenness index was 1.03.

Biomass estimation

The fresh above ground weight of plants ranged between 650.92 g m^{-2} and 1220.56 g m^{-2} and the dry weight (biomass) ranged between 250.11 g m^{-2} and 420.72 g m^{-2}. The fresh below ground weight of plant parts varied from 151.39 g m^{-2} to 1645.83 g m^{-2} while the biomass ranged from 43.06 g m^{-2} to 409.72 g m^{-2}.The average of these values are presented in Table 3. The average total biomass was 559.28 g m^{-2} and ranged between 293.17 g m^{-2} and 803.44g m^{-2}. Such wide range in weights occurred due to the study being carried out in diverse habitats of the town. However, the moisture content in both the above ground (57-67%) and below ground parts (61-75%) remained consistently high across the study site even for summer month.

Table 1 . List of plants recorded during the study period together with their habit, habitat and origin

SPECIES (FAMILY)	HABIT (+)	HABITAT	ORIGIN (++)
* *Achyranthes aspera* L. (Amaranthaceae)	PH	Wastelands	Tropical America
* *Amaranthus spinosus* L. (Amaranthaceae)	AH	Wastelands	Tropical America
* *Alternanthera sessilis* (L.) R. Br. ex. DC (Amaranthaceae)	PH	Disturbed lands, Agricultural fields and Marshy lands	Tropical America
Boerhaavia diffusa L. (Nyctaginaceae)	PH	Occurring in disturbed localities	Pan Tropical
Chrozophora plicata (Vahl) A. Juss. ex Spreng. (Euphorbiaceae)	PH	Moist Wastelands	Tropical Asia and Africa
Clerodendron infortunatum Gaertn. (Verbenaceae)	S	Disturbed Wastelands	Tropical Asia
**Croton bonplandianum* Baillon (Euphorbiaceae)	PH	Wastelands	South America
* *Heliotropium indicum* L. (Boraginaceae)	AH	Moist Disturbed lands	South America
**Parthenium hysterophorus* L. (Asteraceae)	AH	Disturbed Wastelands	Tropical America
Phyllanthus reticulatus Poir. (Euphorbiaceae)	S	Moist Disturbed lands	South and South East Asia
* *Physalis minima* L. (Solanaceae)	AH	Disturbed lands with high organic matters	Tropical America
* *Polygonum barbatum* L. (Polygonaceae)	PH	Semi-aquatic	Palaeotropical
**Polygonum plebejum* R. Br. (Polygonaceae)	AH	Semi-aquatic	
Pouzolzia indica (L.) Wight. (Urticaceae)	PH	Fallow lands	

**Solanum nigram* L. (Solanaceae)	AH	Disturbed lands	Tropical America
Solanum xanthocarpum Schard. and Wendl. (Solanaceae)	PH	Dry Wastelands	
Tephrosia purpurea (L.) Pers. (Papilionaceae)	PH	Wastelands and also grown in agricultural fields	Pan Tropical
* *Urena lobata* L. (Malvaceae)	S	Eroded Disturbed and poorly managed lands	Tropical America
Vitis trifolia L. (Vitaceae)	Cl	Common in thickets and mostly beside open water ways	Asia and Australia
* *Xanthium strumarium* L. (Asteraceae)	AH	Open disturbed lands high in moisture or flood prone areas	Americas

(*) Invasive Alien Species (IAS)

(+) PH – Perennial Herb; AH – Annual Herb; S – Shrub; Cl – Climber

(++) Recorded from several published literature

Table 2. The Density (m^{-2}), Importance value index (IVI), Distribution, Properties and brief Medicinal notes on the plants recorded in the study site

SPECIES	Density	IVI	Distribution (#)	Properties(##)	Medicinal Notes(##)
Achyranthes aspera	0.20	3.26	C	Anti-microbial and noxious weed	Entire plant is of high medicinal value and offer remedies to ailments
various					
Amaranthus spinosus	2.90	30.21	C	Anti-microbial and Allelopathic	Root is of some use in skin disorder
Alternanthera sessilis	1.40	19.45	C	Allelopathic and noxious weed	Entire plant is of high medicinal value and offer remedies to ailments
various					
Boerhaavia diffusa	0.50	5.97	C	Anti-microbial and Allelopathic	Entire plant is of high medicinal value and offer remedies to ailments
various					
Chrozophora plicata	1.30	27.05	Ra	Noxious weed not browsed by cattle	Leaf, root and seed offer limited medicinal value and offer few remedies to ailments
Clerodendron infortunatum	0.40	9.46	C	Anti-microbial, Allelopathic and noxious weeds	Leaf and root are of high medicinal importance and offer remedies to several ailments
Croton bonplandianum	1.10	15.71	C	Anti-microbial, Allelopathic and	Stem and seed are of some noxious weed value and offer few ailments
medicinal					
remedies to					

Heliotropium indicum	1.10	19.09	C	Anti-microbial, Allelopathic and noxious weed	Leaf and fruit are of some medicinal value and offer few remedies to ailments
Parthenium hysterophorus	0.40	14.62	Ra	Allelopathic noxious weed	Toxic weed and is avoided by man and beast
Phyllanthus reticulatus	0.25	7.07	C	Anti-microbial	Entire plant is of some value especially in stomach disorder and genito-urinary problems
Physalis minima	0.20	5.12	C	Anti-microbial and Allelopathic	Entire plant is of some medicinal value and offer remedies to various ailments.
Polygonum barbatum medicinal remedies to	1.70	36.01	Ra	Anti-microbial	Root and seed are of minor value and offer limited various ailments
Polygonum plebejum.	8.65	51.21	C	Anti-microbial and Allelopathic	Entire plant is of some value is used in general stomach disorder
Pouzolzia indica	0.20	2.07	C	Anti-microbial and noxious weed	Entire plant is of limited medicinal value and offer few remedies to ailments, notably anti-snake venom
Solanum nigram	0.10	2.63	C	Anti-microbial and Allelopathic	Entire plant is of high medicinal value and offer remedies to varies ailments
Solanum xanthocarpum	0.10	3.34	C	Anti-microbial and Allelopathic	Entire plant is of high medicinal value and offer remedies to varies ailments

Tephrosia purpurea.	0.10	2.44	C	Anti-microbial and Allelopathic	Entire plant is of some medicinal importance but is mostly used for extracting dye and as green manure
Urena lobata	0.10	2.66	C	Anti-microbial, Allelopathic and noxious weed not browsed by cattle	Root, stem and flower offer few remedies to ailments.
Vitis trifolia	0.15	3.86	C	Anti-microbial	Leaf, root of some medicinal value and offer remedies to ailments. It is edible
Xanthium strumarium	0.50	38.77	Ra	Allelopathic and noxious weed not browsed by cattle	Root, leaf, fruit, seed of some medicinal value and offer remedies to ailments.

(#) 'C' indicates Contagious distribution; 'R' indicates Random distribution

(##) Properties and Medicinal notes have only been briefly mentioned and were prepared from several published sources

Table 3. The average (±SD) above ground (gm^{-2}) and below ground (gm^{-2}) weights and moisture contents (%) in the plants during the study period.

Above ground weight			Below ground weight		
Fresh weight	**Dry weight**	**Moisture**	**Fresh weight**	**Dry weight**	**Moisture**
888.55 ± 193.38	326.50 ± 132.61	63.14 ± 3.81	821.67 ± 567.33	232.78 ± 141.21	70.27 ± 4.99

Soil properties :

The soil was mildly acidic, grayish-brown clay-loam (reported). The high proportion of clay particles ensured a relatively higher percentage of water holding capacity and moisture content (Table 4). The soil possessed extremely high organic C percentage together with high available N. However, low availability of P was because of the acidic nature of the samples which indulged in greater adsorption. The moderate level of available K was due to the nature of clay lattice configuration of the clay-loam soil.

Table 4. Physico-chemical properties of soil at the study site during the study period (Mean ± SD)

Parameters	
pH	6.40 ± 0.08
Water holding capacity (%)	43.19 ± 3.11
Moisture content (%)	10.60 ± 2.23
Organic C (%)	1.29 ± 0.01
Total N (mg g^{-1})	0.288 ± 0.006
Available P (mg g^{-1})	0.019 ± 0.004
Exchangeable K (mg g^{-1})	0.111 ± 0.009

Discussion

The study area was highly disturbed and the latter was considered a major factor capable of influencing species diversity. Depending upon the intensity and frequency, disturbances can create bare micro-site, reduce competition, promote invasion and alter growth-reproduction. As seen from the above results, alien weeds seemed to have over run the native flora. Of the 20 species recorded, 80% of them were aliens, 60% were invasive alien species and 50% were from the Americas. Such high proportion of alien plants had also been recorded elsewhere in India (Singh et al. 2010).

It had been argued that aliens tend to dominate wastelands as disturbance frees up resources, opens up space and changes the physical environment thereby creating opportunities for non native species (Hobbs et al. 1992). Besides, they usually lack natural predators and being less related to indigenous species, exhibit strong competitive ability and also use allelopathy as a weapon (Huang et al. 2009). In the study area, 70% of the plants had allelopathic potentials.

Though the species composition was typical of disturbed wastelands, there were many plants of moist-wetland habitats. In fact, such species dominated by having 68% of importance values (202 index points). It was a reminder to the fact that the town though a built-up urban area now, was originally a low-lying land with tendency for water-logging at some point of time. Most importantly this was still reflected in the floristic composition. The distribution patterns of the plants were mostly contagious (80%). This was either because of clumped distribution of resources (likeable micro-habitat) or for a general tendency of the off springs to remain in the vicinity of parents or as a result of social inclination of individuals to form groups.

The region experienced hot-humid climate with heavy rainfall. The moist-alluvial soil was rich in organic matters (both C and N) which emerged out of microorganism mediated mineralization of native organic fractions. The latter was provided by decomposing plant parts since the site possessed evidently high below and above ground biomass, animal dung (due to grazing) together with domestic degradable waste matters. In spite of the above the species richness and diversity were moderate, dominance low although evenness was rather high. These were reflected in the dominance-diversity curve (d-d) which had often been used to interpret community organization in terms of resource share and niche space (Whittaker 1975). When the species were arranged in a sequence from most to least importance (IVI), they would form a continuous progression from dominants through intermediates to rare ones (Shimwell 1971). The d-d curve in this study was flattened sigmoid type (Figure 2) that approached the Preston's log normal model (Preston 1948). This curve was typical of an area with few dominants, many co-dominants and a small number of rare species. It was in contrast to the geometrical pattern curves obtained in disturbed dry tropical environment of India by Gupta and Narayan (2006).

It is argued here that disturbance in the study area were several decade old so much so that species selection had ensured that only tough

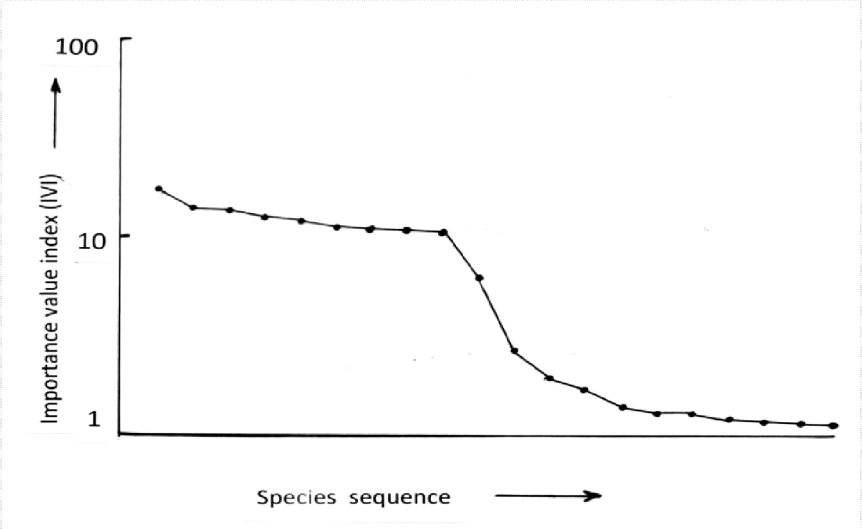


Figure 2 : Dominance – diversity curve in terms of Importance Value Index of species in the study area

species survive while the others were reduced or wiped out. There was a preponderance of perennials (65%) which was not in conformity with the observations of Grime (1974, 1979), who had proposed that species of ruderal life-history traits to be more abundant in disturbed sites. Here the perennials not only endured but also thrived well under stressful condition which was reflected in rather higher proportion of below ground biomass and an overall total biomass. This was in contrast to the findings of Gupta and Narayan (2010, 2011). Herbivory appeared to play its part. Fifty percent of the recorded plants were noxious weeds and another 4 species (*Amaranthus spinosus, Phyllanthus reticulatus, Solanum nigrum* and *Solanum xanthocarpum*) had inducible defense against herbivores. Grazing thus selectively suppressed favourable species and bolstered competitors that were less palatable. The competitors therefore could out-maneuver other species through physical occupation of space or by allelopathy. Occurrences of such combination of competitive–ruderal species in urban environment have also been observed elsewhere by Vallet et al. (2010). It must be added here that the dominance of unpalatable perennials and also the abundance of rapidly proliferating (unpalatable) ruderals like – *Amaranthus, Parthenium* and *Xanthium* indicated that dominance -diversity relationship was also influenced by the species response as illustrated by Huston (1979).

The population density of Barasat town was merely 1125 people km^{-2} in 1951 which had steadily increased and stood at 8071 people km^{-2}

in 2011 (Figure 3). Disturbances that obviously followed had still not prevented decent plant diversity and some species dominance albeit by aliens. However, all the aliens need not be detrimental (Mandal 2011), in fact some were downright useful (Table 2). In this study, 95% of the plants had been found to be utilizable, out of which 7 species possessed high medicinal values and 16 species had proven anti-microbial properties. *Vitis trifolia* was edible (leaf eaten as vegetable), *Tephrosia purpurea* improved soil fertility (green manure) and was also a source of dye, while *Pouzolzia indica* yielded anti-snake venom.

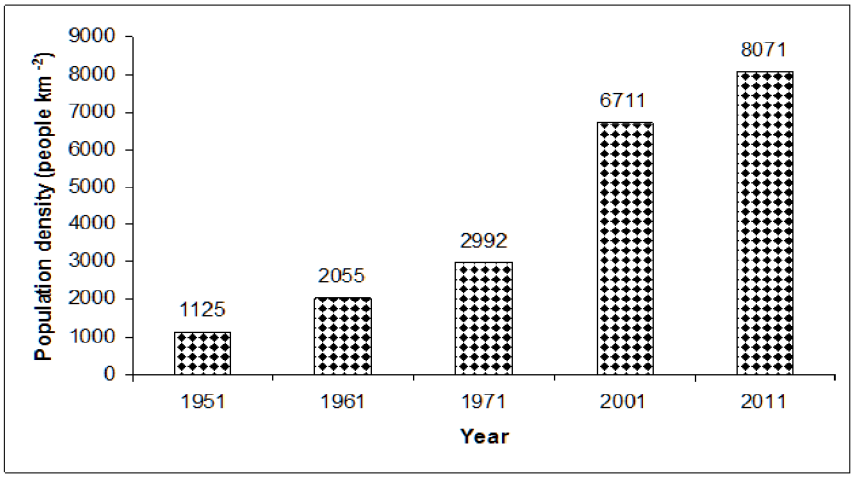


Figure 3 : Decadal increase in population density of Barasat town

Conclusion

It is concluded that the existing plant community in this disturbed site does provide goods and services to the people without any effort from their ends. So long that happens people are not unduly concerned. Since the soil is still healthy 'passive re-vegetation' of wastelands through these species might be welcome.

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Diversity of forest resource and its utility in service of mankind in Balasore district of Odisha

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Abstract

The study was carried out in Balasore district of Orissa. Effort was made to assess the diversity of forest resources and their utilization by the local inhabitants in the district. Various utility plants have listed out with their utilization in the district. Besides, the role of NGOs through training and participation programs in the livelihood of local population was presented.

Keywords: Diversity, forest resource, Balasore district, Orissa

Introduction

Balasore, the northern district of Orissa, is situated between latitude of 20° 48' and 21° 59' and longitudes of 86 °16' and 87°29'. It has total geographical area of around 3,70,000 ha and consists of 2 subdivisions, 12 blocks, and 3,087 villages. The district is bound by Bay of Bengal in the East which affects life and livelihood of the people of Balasore district. The district coast line is ~81 kms where 6 of 12 blocks (e.g. Balasore, Bhogarai, Baliapal, Remuna, Basta and Bahanaga) touches the Bay of Bengal. Mayurbhanj district is in the west, East Midnapur (West Bengal) in the North and Bhadrakh district is located to the South of the district. Five major rivers (e.g. Subarnarekha, Budhabalanga, Jalaka, Kansabansa and Sono) are crossing the district and falling in the Bay of Bengal (KVK Balasore, 2011). The changing environment has led the coastline to spread upto the present level.

Balasore has annual rainfall 150cm which is erratic and unpredictable. June to September receives 71% rainfall within 50 days. The district has more than 50% area under rain-fed. Mean Maximum temperature is 42°C. The district has 6 agro-ecological zones. The soil is red, lateritic, alluvial and saline soil.

Land utilization and forest coverage

As per land utilization statistics (Orissa Agriculture Statistics, 2011) Balasore district is endowed with forest area of 33,221 ha, miscellaneous trees and grooves of 25,000 ha, permanent pasture 16,000 ha, culturable wasteland 9,000 ha, barren and un-culturable land 10,000 ha, current fallow 16,000 ha. and other fallows 5,000 ha. Out of the total forest area reserve forest covers 20,269 ha, un-classed forest 19 ha, demarcated protected forest 2,154 ha and other forest under revenue department 10,779 sq. km. out of the total forest casuarina forest plays vital role in the sea coast. Some important *Casuarina* forests are Chandipur: 49.96 ha, Parakhi: 12 ha, Baunsa Adia: 30 ha, Debalagadi: 7 ha, Kharsahapur: 25 ha.

The entire district is controlled by one Divisional Forest Officer, Balasore followed by Assistant Conservator of Forests and 5 Range Forest Officers. Maximum forest area is observed in Nilagiri, Oupada, Jaleswar, etc. Kuldiha is a national sanctuary located within the district. Nilagiri, Oupada, Kuldiha and Raibania area of Jaleswar have prevalence of natural sal forest. Miscellaneous trees and groves are maximum in Jaleswar followed by Bhogarai than Baliapal than Nilagiri, etc. Maximum grazing land is observed in Nilagiri followed by Balasore, Khaira, than Soro. Maximum wasteland observed in Jaleswar followed by Bhogarai and Baliapal. Barren land and un-cultivable land is maximum in Baliapal followed Nilagiri block.

Forest resources

The District is endowed with the timber wood of gambhari (*Gmelina arborea*), sal (*Shorea robusta*), bijasal (*Pterocarpus marsupium*), kurum (*Kurumtotti kurunthotti*), sissoo (*Dalbergia sissoo*), siris (*Albizia lebbeck*), teak (*Tectona grandis*), acacia (*Acacia catechu*), jamun (*Syzygium cumini*) etc. In addition, variety of non-timber forest produce such as bhujapatra (*Betula utilis*), tendu (*Diospyros melanoxylon*) leaves, seeds of sal (*S. robusta*), mahua (*Madhuca longifolia*), *Bauhinia purpurea,* kusum (*Schleichera oleosa*), neem (*Azadirachta indica*), *Jatropha curcas*, fruits of cashew (*Anacardium occidantale*), *Strychnos nux-vomica*, myrobalans (*Terminalia chibula*), bael (*Aegle marmelos*), elephant apple (*Dillenia*

indica), Karanj (*Pongamia pinnata*), tamarind (*Tamarindus indica*), arjun (*Terminalia arjuna*), neem (*Azadirachta indica*) are available in abundance. Further, variety of grasses like broom (*Bermuda grass*), sabai (*Eulaliopsis binnata*), kusa (*Desmostachya bipinnata*), duba (*Cynodon dactylon*), para grass (*Urochloa mutica*), guinea grass (*Megathyrsus maximus*), elephant grass (*Pennisetum purpureum*), sudan grass (*Sorghum drummondii*), vetiver (*Chrysopogon zizaniodes*), lemon grass (*Cymbopogon*), palmarosa (*Cymbopogon martini*), citronella (*Cymbopogon winterianus*) are common occurring. Besides, number of common medicinal plants like Haridra (*Curcum longa*), aonla (*Emblica officinalis*), neem (*Azadirachta indica*), jamun (*Syzygium cumuni*) , bahada (*Terminalia bellerica*), *Nyctanthes arbotrytris*, ashok (*Saraca asoka*), gudmari (*Gymnema sylvestre*), sissoo (*D. sissoo*), siris (*A. lebbeck*), subabool (*Leucaena leucocephala*), gold mohur (*Delonix regia*), shatavari (*Aspergus racemosus*), guduchi (*Tinospora cardifolia*) , sadabihari (*Catharanthus roseus*), aswa gandha (*Withania omnifera*), sarpa gandha (*Rouvlfia serpentina*), piper mint (*Mentha arvensis*), basil (*Ocimum basilicum*), rukmini (*Nyctanthes arboritristis*), dalchini (*Cinnamomum*) are also available sporadically within the district. Among the bamboos the available potential species are kanta baunsa (*Bambusa arundinaceae*), Sundarakani baunsa (*Bambusa vulgaris*), badia baunsa (*bambusa nutans*) (Mohapatraautho *et al.*, 2006). Last two bamboos have been registered under Orissa State Bamboo Mission working under Orissa State Bamboo Development Authority. Other potential bamboos are *Bambusa palida, Oxytanenthera nigrociliata, Bambusa baccifera, Bambusa falcata* and *Melocana bambusoides*, etc. (Forest Department of Orissa, 2006). Forest type of Balasore is tropical semi-evegreen forest. The type along the beach is littoral forest on the ecosystem of drifting sand and accumulation by wind erosion. Plants are halophytes of evergreen and semi-evergreen in nature. Jhaun, karanj, paldhua, polanga, *Baringtonia asiata*, kia, bilati kanya (*Inga doelsis*), kansarilata, gudakanka (*Spinifex squarrosus*) are good sand binders (as cell sap has 16-48 mmhos/cm). Other forest type is tidal swamp forest (mangroves) which serve as wind break and ingression of tidal waves and save saline inundation which belong to 20-25 species of the family Rhizophoraceae, Verbenaceae, Euphorbiaceae and Sterculiaceae (Saxena, 1999).

Mangrove forests

Mangrove forests are composed of' trees and shrubs that grow in saline (brackish) coastal habitats. A wide variety of plant species can be found in mangrove habitat, but of the recognized 110 species, only about 54

species in 20 genera from 16 families constitute the “true mangroves”. Of which only few are observed within our district. Major mangroves are *Aegialitis*, *Acanthus*, *Avicennia* (black mangrove) and *Aegiceras*, *Rhizophora*, *Ceriops*, *Bruguiera* (red mangrove) and *Nypa* (Nympa). Manrove forest within Balasore district is appeared to be around 700 ha. Mainly within Bhograi right from Bhusundeswar to Udaipur. These are found in depositional coastal environments where fine sediments, often with high organic content, collect in areas protected from high energy wave action. They are found in tidal areas, and as such have a high degree of salinity. These overcome the problems of anoxia, high salinity and frequent tidal inundation. Once established, roots of mangrove plants provide a habitat for oysters and help to impede water flow, thereby enhancing the deposition of sediment in areas where it is already occurring. Usually, the fine, anoxic sediments under mangroves act as sinks for a variety of heavy (trace) metals which are scavenged from the overlying seawater by colloidal particles in the sediments. Red mangroves, which can live in the most inundated areas, prop themselves up above the water level with stilt roots and can then take in air through pores in their bark (lenticels). Black mangroves live on higher ground and make many pneumatophores. Mangroves protect the coast from erosion, storm surges (especially during hurricanes), and tsunamis. Their massive root system is efficient at dissipating wave energy. Wave energy is typically low in areas where mangroves grow. The roots also contain wide aerenchyma to facilitate oxygen transport within the plant. Mangroves provide environmental, social and economic solutions to food security and poverty reduction (Sukwong ,2003; Nagelkerken *et al.*, 2007).

Mangrove forests and coastal disturbances

In the past all natural calamities happened due to natural imbalance. Between 1900 to 1999 A.D., Orissa has witnessed furious coastal storms, tornadoes, cyclones, etc. Mangroves have storm resistance tendency. It has been observed that from 1900 - 1960 A.D. there was a good stocked mangrove forest over the coast which could protect the continent out of coastal disturbances. As a result, within last 60 years, there was only rare coastal disturbance i.e., only one storm happened on 14th October 1942. In due course of time of 1960 A.D., people started disturbing the forests as a result of pre-dominance of foreign migrants, encroachment of the areas and converting the areas into agriculture lands during onset of green revolution during that decade. The deforestation of saline forests along coastlines consequently resulted an increased ecological disturbance. The regions became more prone to storm, cyclone and tsunami. Besides, phailin

touched in 12, October, 2013 there were 10 serious storms, cyclones which appeared between 1960 upto 1999 few of which are mentioned Table 1.

Table 1. Frequency of coastal disturbances and their impact in Orissa during last century.

Period	Date of Oceanic disturbances	Details of loss of lives and properties
1900-1960 A.D.: 60 years (good existence of saline forests) only one storm	14/10/1942	Some people of Orissa and West Bengal were died.
1960-1999 A.D.: 40 years (loss of saline forests including mangroves across the coast) 10 storms/cyclones few are mentioned herewith.	8/9/1963	Cyclone affected 5 lakh people of Orissa, W.B. and Punjab.
	8/10/1967	Cyclone resulted death of 1,000 people.
	29/10/1971	Cyclonic storm caused loss of shelter of 3 lakh families.
	3/6/1982	Storm affected 1 lakh 40,000 sq. k.m.
	November 1990	Affected 15 lakh people of Orissa, 8 lakh sq. k.m area.
	17/10/1999	Disturbed 4 coastal districts of Orissa.
	29/10/1999	Orissa cyclone where thousands of people were died.

Agro-forestry systems prevalent

Agroforestry is the deliberate scientific integration of woody perennials with herbaceous crops and/or animals which proves to be ecologically viable and economically more sustainable than a sole cropping system. Following common agro-forestry systems are available within the district based on spatial or temporal arrangements.

Boundary planting

Farm is bounded by a peripheral plantation of single row or double rows called boundary plantation. This gives an additional income as well as protective boundary against extreme temperature and stray cattle and strangers. Major species observed are *Acacia auriculiformis*, *Eucalyptus* hybrid, *Bambusa vulgaris*, *Bambusa nutans*, *Leucaena leucocephala*,

Casuarina equisetifolia, Azadirachta indica etc.

***Silvi-Horticultural* system**

Thorny bamboo (*Bambusa arundinaceae*) based boundary plantation is observed at Ujuda village of Basta block. Where, farmers practice cucurbitaceous vegetables at the vicinity of bamboo plants. Bamboo gives protective covering towards sponge gourd, ridge gourd, bitter gourd, etc. Other than bamboo the trees grown at the periphery is neem.

Shelter belt

Shelter belt is the plantation of 3-4 rows made against extreme temperature, cold wave, salt spray, sand spray. Species used for this purpose are *Casuarina equisetifolia*, *Heritiera, Eugenia jambolana, Acacia auriculiformis,* etc. Shelter belt protects the farm, inhabitation, cattle against salt spray, coastal storm, water spray, etc. It also harbours good biodiversity and improves the ecological niche.

Balasore has some important estuaries e.g., Chaumukh, Kankadapal and Kirtania. Where, river Subarnarekha touches the Bay of Bengal. It is rich in a good ecological niche with Casuarina, Heritiera which shelters the inhabitation and farmlands against coastal wave and soil erosion and encourages marine fisheries.

Wind break

Wind break is planting of 1-2 rows of trees perpendicular to the direction of wind which provides mechanical stability and checks the wind velocity both on windward and lee ward sides. This is carried out at coast and other areas where wind velocity is high. Species observed are *Casuarina equisetifolia, Acacia auriculiformis, Eucalyptus tereticornis, Gmelina arborea, etc*

Aqua-forestry

Fresh water

Pond based integrated farming system is observed within the district. Within the water area cat fish, mrigal, rohu, catla, silver, carp, grass carp are observed. Within the dyke areas, arjun, bamboo (*Bambusa bambos*), teak, *Acacia auriculiformis*, kadamba, jamun, etc. are observed. At its vicinity banana, pine apple, papaya are noticed. This system becomes self sustainable which maintains temperature of the pond and supports the aquatic lives by supplying nutrients.

Marine

The muds are used in mangrove forests for other bottom feeders by mulching the mangrove leaves. In at least some cases, export of carbon fixed in mangroves is important in coastal food webs. The habitats also host several commercially important species of fish and crustaceans. Mangrove plantations are grown in coastal regions for the benefit and they provide to coastal fisheries and other uses. Red mangroves are the most commonly grown of all species, used particularly in marine aquariums in a sump to reduce proteins and other minerals in the water. Leaves of mangrove are better feed to nourish the shrimp cultivation.

Block plantation

Plantation carried out within a big patch of land either Govt., community or of private land is called block plantation. These type of plantation observed of the species are *Acacia auriculiformis, Acacia mangium, Tectona grandis, Shorea robusta, Pterocarpus marsupium, Anthocephalus kadamba, Bambusa vulgaris, Bambusa tulda, Bambusa nutans,* Mahogany, *etc.* The spacing maintained is dependent of species and soil.

Acacia auriculiformis plantation is dominant in the blocks of Jaleswar, Balasore, Basta, Bhograi, Baliapal. It is grown for the purpose of hard timber, fodder, soil binder and nitrogen fixer. It can withstand long drought spell or submergence. Once established it does not need any maintenance. It does not have infestation, its wood is durable for long period too. It can perform good over river banks, wastelands and conserve the soil. Following plants can better grow at its vicinity as pine apple, turmeric, zinger, elephant foot yam, yam, black pepper. Sal and teak tree are better performed in the lateritic soils rather than alluvial one. Many farmers became however successful over introducing sal along the alluvial areas on the off coast. Teak is performing very well at Lakshannath, Jaleswar where 30 acres of area is observed over teak of single farmer. Kadam is planted in both upland, medium and lowlands. It is used for paper, pulp, match industry and plywood manufacture. Mahogany and *Acacia mangium* (Australian teak) needs intensive care. Thus they fetch high profits as compared to other species.

Farm forestry

Farm forestry is the biggest component of Social forestry which involves “Forestry by the people, for the people and of the people”. Perennial (trees, shrubs and grasses) of importance observed within, across

the farm area or peripheral village area is farm forestry. It not only fulfils the household need of the farmers/villagers like timber, fodder, firewood and minor forest produce including medicinal and aromatic plants. Major species within these areas are *Dalbergia sissoo, Dalbergia latifolia, Albizia lebbek,* kia, juna (*Koeleria macrantha*), kusa (*Desmostachya bipinnata*), Ikada (*Andropogon muricatus*), sabai (*Eulaliopsis binata*), beta (*Calamus* sp.), mat stick, *Ceiba pentandra, Samania saman, Terminalia arjuna, Bambusa vulgaris, Ferrhonia nidica. Acacia auriculiformis, Syzygium cumini, Pongamia pinnata, Schleichera oleosa, Acacia nilotica, etc.*

Khadi (Ikada) farming

Betel (*Piper betel* L.) is a creeper for which khadi *(Andropogon muricatus*) or bamboo sticks serve as host (Anon, 2008). Ikada is however more popular for this purpose within the district and commercially cultivated. Ikada is a perennial plant of family gramineae. It is propagated through rhizome. It is a good coppicer. It takes one year for harvesting after planting. It has 2 commercial types tall *(Uda)* and dwarf *(Chhancha)*. For harvesting it is cut leaving 2-3 inches above the collar region. After harvesting the new sprouts emanate out of coppice which is harvested quarterly as sprouts grow faster. It is resistant to long drought spell or submergence. It is disease or pest free and can grow without fertilization. Farmers of Bhogarai block take it as a promising cash crop and cultivate hundreds of hectares and fetch annually Rs. 50,000/- per acre. Long drought or submergence has resulted converting the paddy fields into ikada lands in large numbers.

Molashes from Palmyra and date palm

During winter molashes are extracted out of phloem of palmyra-palm and date palm. The sap is collected the day following injuring the phloem portion. The sap is very delicious to drink from which gur is prepared in *Bhatta*. Gur of this type worths 3 to 4 times more than sugarcane gur. The training Instiyute within this state for this purpose is located at Jagat Pur, Cuttack.

Canes (Calamus sp.) in rural livelihood

Beta (*Calamus* sp.) a palm called bent as well. It is a climbing palm growing in clumps from underground rhizome, the upper part is covered with 1.5 to 2.5 feet long sheaths, culm prolongs to many metres long. Leaflets are many, equidistant and gradually smaller towards the top. Petioles are with straight spines. Spathes are lower 6-10 inches long. Flowers are small in pairs, fruits edible (0.5 inch long elliptic), seeds ovoid, oblong, 0.4 inch

long. It is generally observed in the marshy alluvial areas of Baliapal, Bhogarai, Balasore blocks. It affects livelihood of many farmers as they manufacture chairs, cots, sofa, morahs, arm chair, dinning table, stool, umbrella sticks, pedestrial sticks and considered sacred thus used in different holy festivals. Orissa Small scale Industries, Forest Deptt., TRIFED, ITDA promote cane craft which is undergoing at Balasore, Jaleswar, Baliapal towns.Cane (*Calamus tenius, Calamus longipathus)* forest as observed sporadically at Jayarampur village, Bhogarai which is used by the farmer for preparing morahs, chairs, sofa, stools, cots, etc. Leaves are browsed by buffaloes.

Rural Crafts

Artisans prepare various items out of bamboo, canes, grasses (juna, sabai, bena, kasatanti, ikada), leaves of tal and khajur. Mats, furnitures, brooms, baskets, toys etc.

Catchment area Plantation

Canal bank areas e.g., Orissa Coast Canal are very much prone to loss of top soil along with soil biota. The species observed are of deep rooting or binding or of soil stabilizer. Out of the five rivers of this district 4 pass by 4 townships. Budha Balanga near Balasore town, Subarnarekha Jaleswar, Jalaka Basta and Kansa Bansa Soro town near Jamujhadi. 1st three affect much however the last one affects approach road though it does not look perennial due to soil erosion. Soil erosion has become typical phenomena which has devastatingly affected the riverian ecosystem. Which could expand the rivers horizontally with blockage of usual passage and vertical depth through siltation. River turns its usual route to new direction. The species are *Acacia auriculiformis*, Palmyra palm *(Borasus flavellifera)*, Casuarina, *Eucalyptus tereticornis, Eucalyptus hybrid , Eugenia jambolana, kia (Pandanus sp.), grasses*, bamboos like salia and kanta bauns, *etc* are planted at river and canal bank areas.

Avenue plantation

For roadside plantation, the species chosen could be able to adsorb the vehicular dusts, check intensity of noise released out of automobiles, could develop good shade, with good vertical growth less crown spread. The tree species observed are *Peltoforum ferruginum, Cassia siamia, Delonix regia, Eucalyptus* hybrid, *Samania saman, Michelia champaka, Mimoceps elongi, Bauhinia variegata, etc.*

Lac cultivation

Lac is a natural resin secreted through deposition of sap by lac insects within some forest plants. The insect responsible for lac deposition is *Kerrya lacca* which has two strains. i.e., Kusumi an Rangeeni. Kusumi strain has host trees kusum (Figure 1), ber, *Acacia auriculiformis, Cucurbita maxima, Flemingia semialata, Flemingia microphylla, Annonas sp., Cajanus cajan,* etc. On the other hand, Rangeeni crop is observed within the host species of palas, ber, *Acacia nilotica, Albizia lucida, Prosopis juliflora, Prosopis cineraria, Ficus semicordata, Ficus infectoria, Ficus bengalensis, Acacia catechu, Albizia lebbek,* etc. Two crops per year harvested in both rangeeni (katwki, Baisakhi) and kusumi (Jethwi and Aghani). A trivoltine insect (*Kerrya sarada*) has been identified by Indian Institute of Natural Resins and Gums (I.I.N.R.G.), Ranchi from our district only growing on rain tree (*Samania saman*). This can produce lac three times per year. Kusum trees are observed within the blocks of Nilagiri, Oupada, Bahanaga, Basta and Jaleswar. Palas (*Butea monosperma*) within Basta, Bahanaga, Soro, Nilagiri and Oupada blocks. Ber (*Zizyphus mauritiana*) is randomly scattered throughout the district. *Acacia auriculiformis* is available within the blocks of Bhogarai, Baliapal, Jaleswar, Basta, Balasore, etc. Though all the species mentioned are available within the district, lac naturally is observed within ber, kusum and *Samania saman*. Despite huge availability of *Acacia auriculiformis* it is not cultured with lac.

Fig-1 *Kerrya lacca* in the host tree kusum (*Schleichera oleosa*)

Sericulture:

Tassar larvae feeds on leaves of asan (*Terminalia tomentosa*), arjun (*Terminalia arjuna*) (Figure 2), bahada (*Terminalia bellerica*), and tassar on ratanjot (*Jatropha curcas*), castor (*Riccinus communis*), silk worm on mulberry (*Morus alba*). Asan, bahada are available within natural forests with good laterite content. Arjun loves alluvial soils. Hence, predominant within all the 6 coastal blocks. Ratanjot and castor sporadically distributed within the village forests. The climate suits mulberry too. Thus, there is good scope for rearing of of tassar and silk. Makidia a village of Jaleswar block where more than 200 farmers are engaged in reeling and weaving of tassar and silk of export quality. They are encouraged by Sericulture Deptt., Orissa. The only need is rearing for cocoon production. It is grown within 200 ha. of area within Nilagiri blocks like Jamuna, Bholanala, Desabandha, Tasar Ada, etc. villages.

Fig. 2 Arjun (*Terminalia arjuna*) tree naturally growing within the district where rearing of tassar made

Live fencing

The protective aspect of a farm or shelter in no way can be ignored. A suitable fence can save the farm against stray cattle, monkeys, elephants, strangers, bears, etc. Without protection the productivity of a farm hampers many fold. Stone /brick wall fence or barbed wire fence are too expensive that farmers unable to afford. On the other hand, fencing with bamboo thorn year by year is cost ineffective and labour consuming. Fencing with green hedge becomes a permanent protective one, reduces fencing cost many fold. Species used within the district in the form of live fencing are *Jatropha curcas, Acacia cassia, Bambusa arundinaceae, Acacia arabica, Gliricidia sepium, Prosopis juliflora,* etc.

Bio-diesel

To minimize the pressure on fossil fuel the scientists are harnessing

options to produce diesel out of plants like gaba (*Jatropha curcas),* polang (*Calophyllum innophyllum),* neem (*Azadirachta indica),* mahua (*Madhuca indica),* mahatil (*Simaruba glauca),* karanj (*Pongamia pinnata),* castor *(Riccinus communis).* Jatropha, polang, neem and karanj are hugely available within the district within the coast. Mahua is available beyond the the coast. Simaruba has been recorded at the roadside plantation. The carnels of seeds of these plants release oil out of which diesel is extracted through the process of trans-esterification. Besides biodiesel, the carnel oil, cakes, leaves, etc. of these species are used for biological control of insects, pests and diseases and for preparing medicines.

Case studies of forest for livelihood security

Income generation through agroforestry nurseries

Vocational training on "Nursery technology for raising of quality planting materials in forest crops." was imparted at the end of winter to enable the farmers to encourage their nursery activities during Summer and planting during monsoon. Many enthusiastic youngsters/ farmers expressed their interest for starting agroforestry nurseries. Bimal Chandra Patra, Basulipat of Bhogarai, Sambhunath Mita, Hasinpur of Baliapal and Rabindra Nath Pradhan, Chaumukh of Baliapal came with good success.

Nursery success of Sambhunath Mita

Sambhunath Mita a resource poor farmer of Hasinpur village of Baliapal block. He is having a big family and resides in a Indira Awas house. It was observed that he was having some preliminary idea on nursery management. After getting training out of K.V.K., Balasore he was encouraged and initiated the nursery raising of agro-forestry tree species taking the help of his family labour. The soil he used out of forest soil which did not require sand being sand rich. Seeds he aggregated out of the local area. Fym he added out of own compost pit. Only he put his expenses for purchasing polythene bags and fungicides/insecticides as desired. Thus, there was not great risk of loss of the scheme. At the very outset of out break of winter Mita put Eucalyptus seeds for germination within the naked bed along with sand and pesticides. 15 days after radicle emergence he transferred these towards 9 x 21 cm polybags. These were allowed to grow upto disposable stage. Acacia (*Acacia auriculiformis*) was grown directly in the polybags. After 3 months out of 3 thousand seedlings he got Rs. 10,000/-. He was very much happy. Through this amount he generated more seedlings. The time to time technological idea along with emotional make up was supported by the K.V.K. scientist. He developed a nursery

unit with 30,000 seedlings where not only Eucalyptus but also acacia, *Acacia mangium*, mahogany, sal, champak, patal garuda, kachnar (kanchan), teak, gamhar were included. *Acacia mangium*, sal and teak saplings he could freshly introduce. For sal within 7 days of fall of seeds it was put for germination, for teak seeds were put within raw cow dung to break dormancy. *A. mangium* was germinated in the same way as that of acacia. Jhaun *(Casuarina equisetifolia)* seedlings he developed on waste papers (dairy milk packets after milk removing used for raising seedlings). The produce of the nursery he sold at the market of Baliapal, Langaleswar and Debhog initially. The farmers coming to the K.V.K. were suggested about Mita's nursery. He got a good publicity and developed a good repute. For his outstanding contribution for environment he woned Baliapal block level "Prakruti Bandhu Award" during this years's World Environment day celebration (5th June, 2009). Now he sells saplings at his door point. Upto mid of July he got a profit of Rs. 50,000/-. His sorrowful face of poverty was replaced with cheerful expression. Now he has planned to expand his nursey to a model one for which he has applied for Govt. aid. He became a role model for income generation with promoting the environment. Many NGOs including Jeevanyas, Baliapal are now coming forward to strengthen his potential.

Maintenance of agro-forestry

Silvi-horticultural

Afarmer named Subhendu Behera of Ghantua village, Baliapal block had developed a 6 months old plantation of *Acacia mangium* by February, 2009. This was observed by S.M.S. (Forestry) of this K.V.K. He immediately suggested him to undertake inter-cropping of greens and vegetables on experimental basis. The farmer initially denied but finally got agreed. Within the gap of 2m plantation spacing he was advised to grow brinjal, lady's finger or Indian spinach of one line at 60 cm spacing. There was only additional work with the farmer of inter-cultural operations of vegetables. He could grow all these successively with timely irrigation, weeding and pesticides application. The out put he obtained within 3 months by selling the vegetables at Baliapal, Debhog or Mangala Munda weekly market. He became happy of getting an additional income Rs. 8,000/- out of about 3,000 sq. metres of area besides the standing saplings. The inter-cultural operations made to vegetables allowed the trees to grow vigorous. For which, pruning was recommended to allow sun light at the vicinity and bring straightness of tree stems. The saplings were supported with big stakes to protect from bending or breakage due to wind speed. The lops

and tops were good browsable which became good feed for cattle and goats. *Acacia mangium* being a nitrogen fixing one soil was enriched and became a protein rich fodder. Subhendu was happy and hopeful of undertaking this tree-crop interaction programme to larger areas. The classical idea of competition for light, water and nutrients was replaced by complementarity within the system. Many farmers visited this place to generate their idea.

Silvi-pastoral System

This system involves spatial arrangement of trees and fodders/ grasses towards producing timbers and feed for cattle. A farmer namely Kamala Kanta Barik of Ujuda village of Basta block was observed to be having homestead growing of cattle. He has a plantation of acacia saplings too. There was scarcity of grasses; he had neither fodder trees nor grasslands due to year round agriculture activities. The cows were appearing lean and thin. The K. V. K. scientists suggested for intercropping of grasses within the plantation. The farmer grew fodder grasses after purchasing seeds and the produce was fed to the cattle. This could result a significant increase in milk production daily from 1 litre to 1.5 litres per cow. This gave him an additional return from milk of Rs. 10,000/- from 3 cows from 3,000 sq. meter of agro-forestry area. This grass was a perennial one giving year round production; which not only conserved the soil but also generated surplus income and encouraged the dairy. It proved a good proposition for river catchment area for economic and environment development. Furthermore, the farmer has also decided to introduce kusumi lac insects within the acacia branches to promote lac cultivation as per the scientist's suggestion; which no doubt will provide additional remuneration along with wood and milk and soil conservation.

Conclusion

Balasore district is endowed with multifarious group of soil and forest diversity. Its head of Western end is bestowed with lateritic soil with wet tropical semi-evergreen forests while its tail of Eastern end is wet with Bay of Bengal and rich with alluvial soil and Swamp or littoral forests. Soil erosion is severe due to land slides, sand dunes or gullies or siltation which caused serious flooding and drought otherwise. Thus, it needs massive plantation across the coast, river banks, canal banks or hill beds for environment stabilization which is the basis for agriculture, life and livelihood. Immense of grazing lands, waste/ fallow lands which can serve as a big platform for massive afforestation by efforts of Govt., non-govt. or any

individuals. Further, to bridge the gap as per recommendation of The National Forest Policy 1988 for 1/3 rd of forest coverage and simultaneous need of food security there is need of intermingling of annuals and perennials within same patch of lands on spatial or temporal basis to bring economic sustainability and environmental stability. Local rural population depends critically on forests for subsistence and livelihood needs. They should be the basic unit for management of forests (Saxena, 1999). Which will not only promote the livelihood but also will maintain the district for healthy inhabitation to mitigate drought, flood, coastal submergence, soil erosion, high temperature desiccation, storm, cyclones, tornadoes, etc.

Future thrust

The following recommendations can be made towards stabilizing environment and promoting farmer's income (All India Coordinated Research Project in Agroforestry and Krishi Vigyan Kendra, Balasore, O.U.A.T.):

Purposes	**Systems to be followed**
1. Stabilization of coastal ecosystem:	Plantation of mangroves at the juncture of sea and land mass, following this Casuarina plantation for sand dune stabilization, than bamboo planting.
2. Canal bank planting :	Grasses, kasatanti, bena, sabai, beta than *Casuarina* than *Acacia*
3. Submerged area planting:	Planting during dry period by making mount. Species suitable are Bamboo, *Acacia, Eucalyptus*, Arjun, etc
4. Hill area planting:	Making trenches and holes of high dimension filling with more FYM than planting with teak, gamhar, sal, sissoo, etc.
5.Agroforestry :	Agroforestry systems may be practiced are
	Teak + rice, teak + green gram, teak + black gram, *Eucalyptus* + pine apple, *Eucalyptus* + vegetables, *Eucalyptus* + ground nut, *Acacia* + pine apple, Acacia + grasses, Acacia + yam, Acacia + elephant yam, *Acacia mangium* + vegetables, *acacaia mangium* + black pepper, Acacia mangium + pulses, mangrove + fishes, integrated farming with teak, acacia, bamboo within dykes and fishes within water, etc.
6. Lac cultivation	lac insects with kusum, ber, palas, Samania, *Ficus, Acacia, Albizia*, etc. trees can be made cultured.

7.Sericulture	Tassar insects to host with arjun, asan, castor, gaba, etc. silk worm can be reared on leaves of mulberry on trial basis.
8.Other non-timber forest produce	:kendu leaves, mahua flowers, jhuna, medicinal and aromatic plants, varieties of bamboo, grasses, beta, ikada for craft and other uses traditionally made can be commercialized.

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Microbial diversity distribution in the lower belt of eastern Himalaya

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Abstract

North-East India, a physiographically categorized zone located along the lower belts of eastern Himalayas falls within the realm of one of the mega-biodiversity hotspots of the world. The region is characterized by the presence of pristine natural ecosystems which are yet to be exposed to anthropogenic disturbances. The pristine niches along with some extreme habitats are bound to provide scope for discovery of novel organisms yet to be known to the scientific community and waiting to be bioprospected for human benefits. The undulating topography with great variation in altitude, soil types, and vegetation leads to marked variation in edapho-climatic conditions, the main reason behind the richness in diverse groups of flora and fauna provided by a plethora of habitats harbouring a genetic treasure house of plant, animal and microbial resources. Although there have been substantial amount of scientific literature generated on flora and fauna of the region, the microbial documentation and exploration still is very scarce and calls for a concerted attention of microbiologists. The microbial diversity from the diverse ecological niches of the Indo-Burma biodiversity hotspot holds promise for isolation of biotechnologically significant strains as well as novel species, and provides vistas for studies on the microflora of the biodiversity rich region of the lower belt of eastern Himalayas.

Keywords: Microbial diversity, natural forest, diverse niche, northeast India, eastern Himalaya

Introduction

The debate about the significance of biodiversity and the field of

ecology into intense research was spurred by the provocative publications of R. H. MacArthur and G. E. Hutchinson (MacArthur 1957, Hutchinson 1959, MacArthur and MacArthur 1961) during the mid-1900s. Biodiversity is a measure of important ecological processes such as resource partitioning, competition, succession, and community productivity and is also an indicator of community stability (Morris et al. 2002). In the 1960s, microbiologists impel investigating the impingement of biodiversity on the function and structure of microbial communities by following in the footsteps of plant and animal ecologists (Hariston et al. 1968, Swift 1974, Morris et al. 2002). As vouchsafed by Erwin, the term biodiversity is related to the number of species, or species richness, along with 'the richness of activity each species undergoes during its existence through events in the life of its members, plus the non-phenotypic expression of its genome' (Erwin 1991). By some other researchers, biodiversity is referred to the variability among living organisms from all sources, including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part. This includes diversity within species (genetic diversity), between species and of ecosystems (Global Environment Outlook 3, 2002).

Microorganisms are the pervasive concierge of the Earth, occurring in all climate areas, including those once considered to be most unlikely to support life - the cold of the Arctic and Antarctic, the heat of geysers and oceanic hot vents and deep within rocks (Colwell 1997). According to Heywood and Watson (1995), an estimated 1,000,000 bacterial and 1,500,000 fungal species exist on this planet, yet fewer than 4,000 and 70,000 have been described in case of bacteria and fungi respectively. "Microbes orchestrate life on earth" seems more of a philosophical than a methodical contends (Kowalchuk et al. 2008). Since more than three billion years, they have been living on this planet and their capabilities to acclimatize to several environments make them still the prominent organisms.

Natural microbial diversity encompasses a broad spectrum of microorganisms that exert a strong influence on global processes such as the carbon, nitrogen and sulphur biogeochemical cycles (Balvanera et al. 2006, Golubiewsk and McGinley 2010). Knowledge of microbial diversity is scarce in spite of their importance to human welfare. As the enormity of microbial diversity becomes apparent, the dilemma of how to preserve microorganisms and their gene pools asserts itself ever more forcibly. Although there have been swift rise in the strategies recommended for conservation of biodiversity but none seem to consider microorganisms.

(Bhattacharjee and Joshi 2012). North-East India, located in the Eastern Himalayan region, one of the megabiodiversity hotspots of the world, has pristine natural ecosystems which offer scope for the bioprospection of novel organisms hitherto unknown to scientific world (Bhattacharjee et al. 2014). Exploration of microbial diversity from diverse ecological niches of the Indo-Burma biodiversity hotspot holds promise for the isolation of biotechnologically significant strains and novel species (Myers et al. 2000).

Microbes in diverse niches of North-East India

India's North-east, consecrated with a wide range of physiographic and eco-climatic conditions is regarded as one of the biodiversity hotspots on earth (Rao 1994). This region falls in a distinctive part of the Indo-Burma mega biodiversity hotspot, featuring diverse biota with a high level of endemism and being considered as prime one amongst the two identified in Indian sub-continent. Highly undulating topography with great variation in altitude leads to marked variation in edapho-climatic conditions, the main reason behind the richness in diverse groups of flora and fauna which have been documented (Myers et al. 2000). The North-East India sprawling over 2,62,379 sq.km, with a latitude of 21° 34' N and longitude of 97°52' E is unique in providing a plethora of habitats thus, a genetic treasure house of plant, animal and microbial resources. It comprises of the states of Arunachal Pradesh, Assam, Meghalaya, Manipur, Tripura, Mizoram, Nagaland and Sikkim that can be physiographically categorized into the Eastern Himalayas, Northeast hills (Patkai-Naga Hills and Lushai Hills, Garo, Khasi and Jaintia hills) and the Brahmaputra and Barak Valley plains (Devi et al. 2012).

Microbes in edaphic, aquatic and aero-environments

Soil is an alluring biological system with the microorganisms indwells soil responsible for much of its generous metabolic sufficiency (Nannipieri et al. 2003). Microbial resource is a new area which provides a huge potential yet to be exploited in agriculture and this area is attracting scientists in recent years. Microbes have been well studied for their vital roles in biogeochemical cycles and recycling dead and decayed plant materials. The most significant and resourceful organisms in agriculture are the bacteria, algae and fungi playing important roles in nitrogen fixation, phosphate solubilization, producing plant growth promoting hormones and also the decomposing organisms making organic matter and carbon available to plants. A wide range of microbes are being identified for their characteristic properties which are being investigated for agricultural beneficence. For an improved growth, yield and quality of agricultural produce it is important

to identify and recognize the best soil and crop management practices for a more sustainable form of agriculture. Saikia et al. (2011) recognized the bio-control potential of *Brevibacillus laterosporus* strain BPM3 which showed characteristic antifungal behaviour against a number of phyto-pathogenic fungi like *Fusarium oxysporum* f.sp. *ciceri*, *F. semitectum*, *Magnaporthe grisea* and *Rhizoctonia oryzae* and a Gram-positive bacterium, *Staphylococcus aureus*. This isolate was obtained from a hot spring in Assam.

Cherrapunjee, in the state of Meghalaya is reported to be one of the world's rainiest places on earth. Banerjee et al. (2012) carried out an interesting study in this highest recorded rainfall area by studying the bacterial community composition involved in biofilm formation. The study targeted to find if the incessant rainfall has any effect on nature and colonization of biofilm bacteria. The samples were obtained from immersed water bodies and biofilm forming bacteria isolated by growing on different culture media followed by estimation of protein and carbohydrate content of bacterial exopolysaccharides. The results reflected the change in bacterial biodiversity with the change of the substratum like stainless steel surface than on glass surfaces. But there was no distinct difference in biofilm forming bacterial compositions from other water bodies. Several niches like the caves, pristine forests, lakes, rivers and other wetlands and other ecosystems and endophytic niches are promising targets for surveying bioactive actinomycetes. The state of Manipur comprises of different niche habitats like the Loktak lake, the largest freshwater lake in North east India, river habitats of Nambul, salt springs like Ningel and Shikhong in the Thoubal district and caves like Khangkhui in Ukhrul district, forest areas like Shirui Jungle and Shirui Lily Hills in Ukhrul district and Amamlok Hills in Imphal. The soil samples and the lake sediment samples from the above habitats were analyzed and found to be rich source of antimicrobial actinomycetes population. The niche habitats in Manipur especially wetlands show great promise for discovery of bioactive actinomycetes. The report shows 36 actinomycete genera of which *Streptomyces*, *Micromonospora*, *Actinoplanes*, *Actinomadura*, *Nonomuria*, *Nocardia* and *Streptosporangium* were the most abundant (Ningthoujam et al. 2009a). A *Streptomyces* strain, reported from Loktak Lake, showing broad spectrum activity against some bacterial pathogens like *E. coli*, *Bacillus pumilus* and *Candida albicans* was reported. The isolate was identified as *Streptomyces sindenensis* (Ningthoujam et al. 2009b). Manipur is an underexplored zone falling in the Indo-Burma biodiversity hotspot, in microbiological aspects. A total of 156 actinomycetes were isolated from

three samples of Nambul River of Manipur. Seven strains were identified as *Streptomyces* spp. while one strain each was identified as *Nocardia* sp. and *Micromonospora* sp. Three strains showed promising antifungal activities against human and plant pathogens (Ningthoujam et al. 2011). Investigating the soil microbial community composition is important in explaining the soil ecological processes during vegetation succession. The composition of soil microbiota should be evaluated to understand the mechanism of the improvement in soil properties during vegetation succession. Understanding the biodiversity of soil fungi and its relationship with ecosystem is crucial for the maintenance of a sustainable ecosystem. Below-ground communities, like soil mycorrhizae, play an important role in many ecosystem services, such as decomposition and nutrient cycling, as well as influencing nutrient uptake by plants (Heijden et al. 2008). Fungi are an essential part of soil microbial community and comprise most of soil biomass and their distribution is determined by the availability of organic nutrients in the soil, its texture, vegetation and surrounding climate. Fungi have often been classified based on their morphological characteristics, however a number of fungi with indistinguishable morphological features (cryptic) species have been recently differentiated .The identification of various groups of fungi at species level has been made possible in the past decade by molecular techniques especially the phylogenetic approach. One such study by Devi et al. (2012) targeted phylogenetic diversity of culturable fungi isolated from soil samples obtained from 24 m above sea level to 2,000 m above sea level altitudes of North-East India falling under the Eastern Himalayas. The fungal isolates were characterized by PCR amplification of 18S rDNA using universal primers and a phylogenetic analysis exposed rich biodiversity of soil fungi spread over a wide range of altitudes. The characterized isolates corresponded to 7 orders of fungal kingdom with *Eurotiales* and *Hypocreales* being the most abundant and diverse group. Species of *Penicillium* and *Aspergillus* were found to have the highest diversity index followed by *Talaromyces* and *Fusarium*. This study also indicated that the distribution of fungi has a negative correlation with altitude and moisture content of soil, and showed positive correlation with temperature, pH and humidity. The diversity of fungi associated with bamboo litter from Bambusetum of Rain Forest Research Institute, North-East India, was assessed by Kumar et al. (2013). The study reported the presence of 45 and 39 fungal taxa belonging to 22 genera, in gradeI and grade II litter respectively, with 24 fungal taxa common to both grades. The collection of macrofungi in different seasons revealed 16 macrofungi species of which 3 belonged to family *Entolomataceae* and *Agaricacea*, two to *Tricholomataceae* and *Geoglossacea*, and one species belonged to each

family *Dacrymycetaceae, Pluteaceae, Coprinaceae, Marasmiaceae Lycoperdaceae* and *Phallaceae*. The study was carried out since bamboo vegetation is prevalent and is of economic importance in North-East India. Fungi that have the ability to decompose wood, causing it to rot, known as wood-rotting fungi, a good number of which produce large and conspicuous fruiting bodies. These constitute at least 10% of total fungal diversity, of which 16 - 41% have been described to date (Rossman 1994, Mueller et al. 2007). The study of fungal diversity in forests is incomplete without understanding the role wood-rotting fungi play in recycling of wood in forest environment. This in turn has attracted the interests of mycologists' to survey these fungal types and investigate for their potential applications in pollutant purification, soil bioremediation and antibiotic production (Blanchette 1995, Kotterman et al. 1994, Smânia et al. 2003). Eight forest stands of Meghalaya, India was surveyed by Lyngdoh and Dkhar (2014), where 78 wood-rotting fungi belonging to 23 families were collected and identified. Tree logs were found to harbour the maximum number of wood-rotting fungi with 59.7 % whereas living trees sheltered the least with 7.8%. The species of *Microporus xanthopus* was found to be most abundant (87.5 %) followed by *Cyclomyces tabacinus*, *Microporus affinis* and *Trametes versicolor* with 62.5 %. White-rot fungi were found to be most prevalent contrasting to the presence of few brown-rot. A rare species of wood-rotting fungus, *Heterobasidion perplexa* was also found growing on logs of *Pinus kesiya* and this fungus has never been reported to be found in India. The knowledge of wood-rotting fungi will provide a valuable insight to the fungal biodiversity and help strengthen initiatives to protect and sustainably use our natural resources (Rossman et al. 1998).

Similarly Kalita et al. (2009) investigated the effects of plant growth promoting rhizobacteria (PGPR) and arbuscular mycorrhizal fungi (AMF) on *Fusarium oxysporum* causing wilt in brinjal. They recorded that after the application of these bioinoculants both alone or in combination could increase chlorophyll content, total number of leaves, shoot height and so on. Fungal isolates obtained from soil samples of Kaziranga National Park Assam, India by Kumar et al. (2010) showed anti-Candida and antibacterial activity. These isolates were evaluated for their antagonistic activities which were higher against Gram-positive bacteria but showed less inhibition against Gram-negative bacteria. *Aspergillus, Scopulariopsis, Curvularia, Phoma, Lasiodiplodia, Fusarium, Acremonium* and *Aureobasidium* were further identified as potent antibiotic strains. *Fusarium* spp., and *Rhizoctonia solani* has been noted to cause serious diseases like wilting and damping-off in French beans in North-East India. A study was conducted on isolates

obtained from French bean growing fields of Manipur out of which only one isolate identified as *Burkholderia cepacia* exhibited characteristic inhibition zone depicting very high antagonistic activity against both the pathogens. Besides, it produced extracellular hydrolytic enzymes like protease, secondary metabolites like siderophore and HCN, plant growth promoting hormone (IAA) and solubilized organic phosphate. This can further lead to the development of a highly effective bio-inoculant preventing the crops against soil borne fungal pathogens (Indira et al. 2012).

The presence of fungi in air is proposed to cause adverse health effects thus regarded as detrimental (Bush and Portnoy 2001, Ren et al. 2001). A number of allergic diseases, such as asthma, rhinitis, and eczema are on the rise in both developed and developing countries. Allergic problems in India is rising at an alarming rate where over 25% of the population is approximated to suffer from major allergic problems with respiratory allergy constituting about 70% , while allergic rhinitis about 3–4% (Vishwanathan 1964, Shaikh 1997). The most common causative agent of these allergic diseases worldwide is recognized as the *Aspergillus* fungi which are dominant constituent of air (Blackley 1873, Austwick 1965, Millins et al. 1976, Sarma 2002, Bisht et al. 2003). Various strains of *Aspergillus* and *Penicillium* also seem to play a role in asthma and allergic alveolitis (pulmonitis because of hypersensitivity) (Kanny et al. 1996). A wide spectrum of airborne fungi has been reported in various aeromycological studies. There is a need for intensive studies on aeromycology and the clinical implications associated with it. A survey carried out by Sharma et al. (2007) focused on biochemical and immunological study of airborne *Aspergillus* moulds with the aim to identify their common allergenic species that are prevalent in the Southern region of Assam, North-East India. At least 16 different species of *Aspergillus* were isolated from air of which *A. fumigatus* was found to be most dominant followed by *A. flavus, A. humicala, A. niger, A. nidulans, A. terreus* and *A. versicolor*. The concentration of *Aspergillus* was recorded to be higher during dry seasons i.e., from September to March. *A. fumigatus, A. flavus* and *A. humicola* were found to have more protein content and were more allergenic as compared to the other tested species. This supports the findings of Bhattacharya (2000), according to whom samples having high protein content have greater potential to become allergenic. Several aeromycological surveys carried out proved the dominance of *Aspergillus* species in Assam and various parts of North-East India (Singh 1979, Devi and Singh 1992, Sharma and Dutta 2001, Sharma et al. 2004). Sharma et al. (2010) attempted to evaluate the qualitative and quantitative fungal

constituents of indoor air of five important working environments in South Assam, which would help predict the possible negative implications of airborne fungi to employees and stored products. Several fungi of clinical importance, like *Aspergillus, Botrytis, Candida, Calcarisporium, Cunninghmela, Geotrichum, Meria, Penicillium,* and *Stachybotrys,* were identified in the indoor air, the most common genera being *Aspergillus, Penicillium, Geotrichum, Cladosporium* and *Humicola*. The concentration of fungi was recorded to be twice as high indoors as compared to that of outdoor air, which could be attributed to various factors such as dampness, humidity, indoor temperature, and hygiene setting indoors and the surrounding environment favouring propagation of fungi including the pathogenic strains (Bornehag et al. 2001). The incidence of such fungal species in levels above threshold limits could be hazardous to people working in such indoor environments (Prasad et al. 1994).

Plant associated microbes

The organisms endemic to various habitats including the plant tissues have opened a new area of interest for scientists in search of novel properties. The study on ethnomedicinal plants with fungicidal properties has gained importance for the screening of new bioactive compounds. *Centella asiatica* an ethnomedicinal plant known for its use as a liver tonic, blood purifier, antidysenteric, antiseptic, increasing memory power and treatment of high blood pressure traditional medicine is one of the many traditional herbal medicine used by the tribal people of North east India. Bacterial endophytes were isolated from various parts of this plant and screened for their antifungal activity using agar well diffusion assay. Scanning electron microscopy was used to observe the structural deformities caused while inhibiting the fungal pathogens by the methanolic extracts of the endophytic bacteria. *Bacillus subtilis* cenB an isolate from the host plant was observed to cause morphological distortions and alterations in sclerotia of the fungal pathogen, thus exhibiting most prominent antifungal activity. The bioprospection of the endophytic bacteria prevalent in ethnomedicinal plants can open vistas for their utilisation as microbial cell factories for production of bioactive compounds as an alternative to chemically synthesised compounds (Nongkhlaw et al. 2014).

Increase in demographic pressure has led to over-exploitation of forest resources leading to an enormous species loss. This has in turn led to most of the medicinal plant species to be endangered. Threat to natural populations of medicinal plants has increased because more than 90% of medicinal plants being used as raw materials for herbal industries in India

and for export are drawn from natural habitat (Dhar et al. 2002). Their extinction will deprive us the benefits of yet uncharacterized fungal endophytes associated with the respective plants. Medicinal plants are reported to harbour endophytes which in turn provide protection to their host from infectious agents and also provide adaptability to survive in adverse environmental conditions. Endophytic fungi produce a wide range of biologically active compounds such as antioxidants, antibiotics, and exploring such endophytes obtained from specialized habitats may help pave a way to discovering beneficial novel metabolites. Most plants having medicinal usage among the ethnic tribes of North-East India are known to harbour endophytic fungi. A study carried out by Bhagobaty et al. (2007) targeted endophytic fungi associated with the medicinal plant *Osbeckia stellata* found in pine forest undergrowth of Shillong, Meghalaya, which lies in the fringes of the Eastern Himalayan ranges and is also a part of the Indo-Burma mega biodiversity hotspot. The endophytic fungi isolated from the plant were found to have characteristics similar to *Mortierella hyalina*. This fungus is generally found in forest soils particularly under pine and grasslands (Domsch and Gams 1972) and produced metabolites that may aid in techniques like Thin layer Chromatography (TLC) and Gas Chromatography (GC). Bhagobaty et al. (2011) assessed the diversity of fungal endophytes associated with ethno-medicinal plants of the traditionally preserved 'Sacred forests' of Meghalaya where 703 fungal endophytes reported were characterized morphologically. Most of the endophytic fungal species isolated belonged to the genera *Penicillium*, *Talaromyces* and *Paecilomyces*, which fall under the phylum ascomycetes. These species of endophytes are said to be 'creative' and could be the actual producers of medicinal compounds. Diversity analysis of fungal endophytes associated to the medicinal plant *Emblica officinalis* of Meghalaya was studied by Nath et al. (2012) whereby four endophytic fungi were isolated from various parts of the plant which were then assessed for their antimicrobial and antioxidant activity. *Emblica officinalis* was selected for traditional usage owing to its medicinal properties. The fungal endophytes *Phomopsis* sp. and *Xylaria* sp. isolated were characterized morphologically and assayed for their antioxidant activity by 2, 2-diphenyl-1-picrylhydrazyl (DPPH) method, whereas the total phenolic content was evaluated using ethanolic-extract of the endophytes. High antioxidant activity and phenolic content was observed for the endophytes which also showed antimicrobial activity against strains. Nath et al. (2013) investigated the biological activity of endophytic fungi associated with an ethnomedicinal plant *Rauwolfia serpentina* Benth used as anti-hypertensive remedy by tribal populations of North-East India. A total of 15 endophytes isolated

were identified as *Colletotrichum gloeosporioides*, *Penicillium* sp., *Aspergillus awamori* and *Fusarium oxysporum* using biochemical and molecular tools. *C. gloeosporioides* was found to be the dominant colonizer of the plant, followed by *Penicillium* sp. and *A. awamori*. Of the isolates obtained *Penicillium* sp. showed better hypocholesterolemic activity and antimicrobial activity against test pathogens, than the rest. *Fusarium oxysporum* showed promising antagonistic ability whereas the highest antioxidant potential and phenol content was exhibited by *A. awamori*. This study revealed various beneficial innate properties of the endophytic fungal extracts that can have significant pharmaceutical applications. Endophytic fungi associated with *Potentilla fulgens* L. were assessed for their bioactivity like antioxidant and anti-inflammatory activity by Nath et al. (2013). The endophytes were screened for presence of phytochemicals and the use of molecular approaches characterized the isolates as *Bulgaria* sp., *Paraconiothyrium* sp., *Penicillium* sp., *Chaetomium elatum, Aspergillus* sp. and *Sirococcus conigenus*. Ethanolic extracts of *Aspergillus* sp. and *Sirococcus conigenus* showed high antioxidant activity and also possessed potent anti-inflammatory activity. A number of phytochemicals like cardiac glycosides, steroids, flavonoids, terpenoids, phenols and saponins were found to be present in the fungal extracts thus encouraging the exploration of fungal endophytes for bioactive properties. Fungi help in bioremediation of toxic metals through reduction of metal ions and this property of fungi has been channeled for the environment friendly synthesis of metal nanoparticles which are emerging as novel antimicrobial agents. These filamentous fungi are said to be ideal for metal nanoparticles synthesis as they are easy to handle and cultivate on a large scale (Mukherjee et al. 2001) and can accumulate metals through physicochemical and biological mechanisms. However few studies have reported the use of endophytic fungi for the synthesis of metal nanoparticles (Verma et al. 2010, Qian et al. 2013). One such study was carried out by Devi et al. (2013), whereby a plant *Gloriosa superba* L. known for its medicinal properties, was used for the isolation of two endophytic fungi *Alternaria solani* and *Penicillium funiculosum*, which were utilized for in vitro biosynthesis of silver nanoparticles. According to another study carried out by Devi and Joshi (2014), a rare endophytic fungi *Cryptosporiopsis ericae* was isolated from an ethno-medicinal plant of Northeast India, *Potentilla fulgens* L. then employed for the biosynthesis of silver nanoparticles. The use of this endophytic fungus for the synthesis of silver nanoparticles was reported for the first time through this study. These biosynthesized nanoparticles were characterized using various techniques and when tested against test pathogenic strains were found to be potent antimicrobial agents. Endophytic

fungi can thus be explored for the mycosynthesis of metal nanoparticles and hence eliminate the different problems related to various chemical synthesis protocols.

Microbes from extreme environments

Over a quarter of a century ago, MacElroy (1974) coined the term extremophile (lover of extremes) for the organisms which inhabit extreme environmental conditions. Life in extreme environments is dominated by microorganisms. The word has been interpreted in a number of ways and perhaps understandably has become associated with those microorganisms that inhabit environments unsuitable to mammals. Conditions that are 'extreme' to one organism may be essential to another's survival, so the concept of extremophily is a relative one. Researchers who were looking for organisms that eke out a living in some of the most inhospitable soils on Earth have found hardly a few. From limestone quarry at Hundung, Manipur, India, various novel actinobacterium were isolated namely *Streptomyces manipurensis* sp. nov., *Streptomyces hundungensis* sp. nov., *Rhodococcus canchipurensis* sp. nov. and *Micromonospora kangleipakensis* sp. nov. and *Streptomyces muensis* sp.nov. (Nimaichand et al. 2012, Nimaichand et al. 2013a, Nimaichand et al. 2013b, Nimaichand et al. 2013c, Ningthoujam et al. 2013). Similarly from warm spring located in Assam, India, a number of novel bacterial strains were isolated such as *Aquimonas voraii* gen. nov., sp. nov., *Paenibacillus assamensis* sp. nov., *Aeromonas sharmana* sp. nov. and *Flavobacterium indicum* sp. nov. (Saha et al. 2005a, Saha et al. 2005b, Saha and Chakrabarty 2006a, Saha and Chakrabarty 2006b). *Brevibacillus laterosporus* strain BPM3, a potential biocontrol agent isolated from a natural hot water spring of Nambar Wild Life Sanctuary, Assam, India (Saikia et al. 2010). *Caldimonas meghalayensis* sp. nov., a novel thermophilic betaproteobacterium was isolated from a hot spring of Meghalaya in northeast India (Rakshak et al. 2013). One hundred and thirty uranium tolerant isolates including both Gram-positive and Gram-negative bacteria comprised *Firmicutes*, *Actinobacteria*, *Betaproteobacteria*, *Gammaproteobacteria* and *Bacteroidetes* were obtained from soil samples collected from the site Uranium ore deposits sites at Domiasiat, North-East India (Kumar et al. 2013). Fluorescent *Pseudomonas aeruginosa* and three metal tolerant *Serratia* spp. were isolated from sediments of pre-mined uranium ore deposit of Domiasiat, Meghalaya, India (Sarman et al. 2014). A total of 210 Psychrotolerant *Streptomyces* were isolated from the soil samples of Tawang, India where temperature varied from 5°C during daytime to -2 °C during night (Debnath et al. 2013). 12 strains of bacterial isolates

comprising of *Pseudomonas aeruginosa , Microbacterium, P. ûuorescens, Bacillus licheniformis, B. circulans, B. subtilis w*ere isolated from crude oil-contaminated soil samples collected from three different oil ûelds of Assam: Lakuwa, Gelekey and Rudrasagar (Bordoloi and Konwar 2007). *Acinetobacter junii, Achromobacter* sp. and *Alcaligenes faecalis* were isolated from soil samples collected from the crude oil contaminated site of Digboi Crude oil Refinery Assam (Mazumdar and Deka 2013). *Streptomyces* sp.VITPK1 was isolated from soil sediment collected from the brine spring at Thoubal District, Manipur, India (Sanjenbam et al. 2014).

Conclusion

The study of biodiversity is motivated by interest in the heterogeneity and variability of organisms. Because of the immense number of microorganisms on Earth and the wide range of habitats they occupy, the potential heterogeneity and variability of microorganisms are probably larger than for any other group of organisms. Microbiologists are well aware of this potential. Nevertheless, the trends illustrated in this chapter suggest that the field of microbial biodiversity has not attraction due to attention on the larger heterogeneity and variability especially to the described region. In order to best exploit microorganisms, we need to know what is there and what we can use. Studies of related organisms may yield potential products. For example, species of the actinomycete *Kitasatospora* have been found that produce a herbicide, and an antibiotic (setomimycin) (Bull 1991). Microbial and fungal secondary metabolites may be sources of new chemical and pharmaceutical products (Porter and Fox 1993). Antibiotics have been the major products from microbial screening, with some 10000 discovered in the last 50 years (Nisbet and Fox 1991). More recently, microbes are being probed for compounds with antifungal, antiviral, or antitumor activity. Other drugs, like mevinolin, which reduces cholesterol in humans, have been found through microbial screening (Nisbet and Fox 1991). Fungi are a potentially rich source of active molecules. Some fungi produce toxins that protect the plants on which they live from predation (Nisbet and Fox 1991). Other fungi produce insect toxins that are potential biological control agents.

Unless we find ways to continue screening and studying microorganisms and preserving their habitats, there is no way to know the functions of these organisms within their natural habitats and the richness of life. Microbiology is on the rise. The number of papers dealing with microbes and published in Nature and Science has increased during the last few years, with emphasis on geo-microbiology and metagenomic studies.

Table 1: Bacteria isolates reported from North-Eastern India.

Isolate name	Isolated from	Location	Reference	Remarks
Citrobacter youngae, Bacillus thuringiensis, Raoultella ornithinolytica, Enterobacter soli	*Rubia cordifolia,* Host plant	Meghalaya	Nonghkhlaw and Joshi (2014)	Biofilm formers and plant epiphytes
Bacillus tequilensis, Bacillus aryabhattai, Bacillus thuringiensis, Pantoea eucalypti,	*Centella asiatica,* Host plant	Meghalaya	Nonghkhlaw and Joshi (2014)	Biofilm formers and plant epiphytes
Serratia marcescens Bacillus subtilis, Serratia sp.	Endophytes of *Centella asiatica*	Meghalaya	Nonghkhlaw and Joshi (2014)	Showing antifungal activity
Bacillus thuringiensis, Pseudomonas palleroniana, Serratia nematodiphila, Stenotrophomonas maltophilia, Pseudomonas mosseli, Pantoea eucalypti, Pseudomonas putida, Bacillus thuringiensis, Lysinibacillus xylanilyticus, Bacillus thuringiensis, Enterobacter asburiae, Acinetobacter johnsonii	*Potentilla fulgens,* Host plant	Meghalaya	Nonghkhlaw and Joshi (2014)	Biofilm formers and plant epiphytes
Kocuria rosea,	Stalactite of Mawsmai Cave	Meghalaya	Banerjee and Joshi (2014)	Cave biofilms
Lysinibacillus macroides	Column of Mawsmai Cave	Meghalaya	Banerjee and Joshi (2014)	Cave biofilms
Acinetobacter johnsonii	Wall deposit of Mawsmai Cave	Meghalaya	Banerjee and Joshi (2014)	Cave biofilms

Bacillus cereus	Wall deposit Mawjymbuin Cave	Meghalaya	Banerjee and Joshi (2014)	Cave biofilms
Lysinibacillus parviboronicapiens	Column of Mawjymbuin Cave	Meghalaya	Banerjee and Joshi (2014)	Cave biofilms
Bacillus halodurans	Wall deposit of Mawmluh Cave	Meghalaya	Banerjee and Joshi (2014)	Cave biofilms
Brevibacillus agri	Wall deposit of Dam Cave	Meghalaya	Banerjee and Joshi (2014)	Cave biofilms
Bacillus thuringiensis	Stalagmite of Labit Cave	Meghalaya	Banerjee and Joshi (2014)	Cave biofilms
Streptomyces sp.	*Centella asiatica*, Host plant	Meghalaya	Dochhil *et al.*, (2013)	Seed germination enhencing activity
Staphylococcus equorum, Enterobacter sp., *Bacillus subtilis,*	contaminated soil	Meghalaya	Bhattacharjee *et al.*, (2014)	Pesticide degrading
Streptomyces spp.	Soil sample	Arunachal Pradesh	Bhattacharjee *et al.*, (2012)	Soil forms
Anaerobaculum mobile, Garciella nitratireducens, Coprothermobacter sp., *Thermodesulfobacterium* sp., *Thermosediminibacter oceani, Caldanaerobacter* sp., *Clostridium sporogenes, Thermodesulfovibrio* sp., *Thermodesulfotobacterium* sp.,	Kathloni Oil Fields	Assam	Kaur *et al.*, (2009)	Sulphate Reducer
Burkholderia. Cepacia	Rhizosphere soil from French bean field	Imphal, Manipur	Devi *et al.*, (2012)	Bio-control agent

Bacillus subtilis subsp. *Subtilis, Serratia marcescens* subsp. *Sakuensis, Chromobacterium piscinae, Proteus vulgaris, Pseudomonas aeruginosa, Achromobacter ruhlandii*	Cherrapunji	Meghalaya	Banerjee *et al.,* (2012)	Biofilm formers
Ralstonia solanacearum , Ralstonia syzygii, Polynucleobacter difficilis, Polynucleobacter sp. *Nitrosomonas* sp., *Halomonas pacifica, Acidobacteria* sp.	Agricultural fields	Brahmaputra valley, Assam	Bhattacharyya *et al.,* (2014)	Uncultured bacteria
Proteobacterium sp.	Undisturbed forest	Brahmaputra valley, Assam	Bhattacharyya *et al.,* (2014)	Uncultured bacteria
Acidobacteria sp., *Pelobacter* sp., *Proteobacterium* sp., *Xanthomonas* sp.,	Tea garden	Brahmaputra valley, Assam	Bhattacharyya *et al.,* (2014)	Uncultured bacteria
Wautersia basilensis, Rhodocyclus sp., *Nitrosomonas* sp., *Xanthomonas* sp.,	Disturbed forest	Brahmaputra valley, Assam	Bhattacharyya *et al.,* (2014)	Uncultured bacteria
Burkholderia sp., *Delftia acidovorans, Dokdonella* sp. *Xanthomonas* spp.	Active flood plain soils	Brahmaputra valley, Assam	Bhattacharyya *et al.,* (2014)	Uncultured bacteria
Serratia sp.	Sub-surface soils of uranium deposits	Domiasiat, Meghalaya	Kumar *et al.,* (2011)	Uranium tolerant

Pseudomonas aeruginosa	Uranium ore rich sites	Domiasiat, Meghalaya	Sarma *et al.*, (2012)	Metal tolerant
Serratia nematodiphila Serratia. marcescens subsp. *sakuensis*	Uranium ore deposit, Kylleng	Domiasiat, Meghalaya	Sarma *et al.*, (2013)	Metal tolerant
S. marcescens, Pseudomonas ficuserectae	Subsurface soils of Uranium ore site	Domiasiat, Meghalaya	Kumar *et al.*, (2013)	Heavy metal tolerance behaviour
Bacillus cereus ,Bacillus subtilis	Soil sample	Meghalaya	Devi *et al.*, (2010)	Thermostable alpha amylase producers
Bacillus. subtilis, Pseudomonas aeruginosa	Petroleum contaminated soil	Assam	Das and Mukherjee (2006)	Indigenous bacteria degrading crude petroleum-oil.

Table 2: Fungal isolates reported from North-Eastern India.

Isolate name	Isolated from	Location	Reference	Remarks
Exobasidium vexans	Tea leaf	North-East India	Borthakur (2011)	Blister blight disease of Tea leaves
Corticium thea	Tea leaf	North-East India	Borthakur (2011)	Black rot of Tea leaves
Cephaleorus mycoidae blight, red rust of leaves	Tea leaf	North-East India	Borthakur (2011)	Grey blight, brown
Fusarium solani	Tea stem	North-East India	Borthakur (2011)	Die back disease of Tea Stem
Cephaleorus parasiticus	Tea stem	North-East India	Borthakur (2011)	Red rust of Tea Stem
Poria hypobrunnea	Tea stem	North-East India	Borthakur (2011)	Red rust, thorny stem Blight disease of tea
Ustulina zonata	Root of tea	North-East India	Borthakur (2011)	Charcoal stump root disease
Corticium thea	Tea leaf	North-East India	Borthakur (2011)	Black rot of Tea leaves
Cephaleorus mycoidae	Tea leaf	North-East India	Borthakur (2011)	Grey blight, brown blight, red rust of leaves
Fomes lamoensi	Root of tea	North-East India	Borthakur (2011)	Violet root rot of tea
Trichoderma spp.	Soil	North-East India	Agnihothrudu and Barua(1962)	Biocides from tea against thorny stem blight and branch canker disease of tea

Beauveria bassiana	Soil	North-East India	Agnihothrudu and Barua(1962)	Prevents tea mosquito bug disease
Chalara terrestris	From roots of *Camellia sinensis*	Tocklai, Assam	Agnihothrudu, and Barua(1962)	-
Glomus aureum	Rhizosphere soil of Alnus nepalensis	Upper Shillong, Meghalaya	Panna *et al.*, (2009)	Arbuscular mycorrhizae
Glomus clavisporum	Rhizosphere of *Michelia champaca*	Umiam, Meghalaya	Panna *et al.*, (2009)	Arbuscular mycorrhizae
Glomus fuegianum	Soil from potato field	Swer, Meghalaya	Panna *et al.*, (2009)	Arbuscular mycorrhizae
Glomus glomerulatum	Michelia champaca	Meghalaya	Panna *et al.*, (2009)	Arbuscular mycorrhizae
Glomus macrocarpum	rhizosphere soils of Michelia champaca	Meghalaya	Panna *et al.*, (2009)	Arbuscular mycorrhizae
Glomus microaggregatum	potato field	Meghalaya	Panna *et al.*, (2009)	Arbuscular mycorrhizae
Glomus rubiforme Glomus taiwanense	Michelia champaca	Meghalaya	Panna *et al.*, (2009)	Arbuscular mycorrhizae
Talaromyces flavus Mortierella hyalina Penicillium verruculosum	Endophytes from *Potentilla fulgens*	Nongkrem, Meghalaya	Bhagobaty and Joshi (2011)	Present in Roots and stem of medicinal plant
Mortierella hyalina Syncephalastrum racemosum	Endophytes from *Osbeckia stellata*	Cherrapunji Meghalaya	Bhagobaty and Joshi (2011)	Present in Roots and stem of medicinal plant
Acremonium sp. *Paecilomyces* sp.	Endophytes from Camellia caduca	Mawphlang, Meghalaya	Bhagobaty and Joshi (2011)	Present in Roots and stem of medicinal plant

Aspergillus chrysogenum . *Penicillium* sp	Endophytes from Schima khasiana	Mawphlang, Meghalaya	Bhagobaty and Joshi (2011)	Present in Roots and stem of medicinal plant
Sporisorium assamensis	In the inflorescence of *Digitaria* sp.	Jorhat, Assam	Bag and Agarwal (2001)	Plant associated fungi
S. agropyri sp. nov.	On *Agropyron strigosum* L.	Assam	Bag and Agarwal (2001)	Plant associated fungi
Acremomium cerealis, Acremonium furcatum, Acremonium fusidioides, Acremonium kiliense, Acremonium strictum, Aspergillus fumigates, Absidia spinosa , Aspergillus oryzae, Aspergillus wentii, Aspergillus versicolor, Beltrania sp., *Chaetomium* sp., *Cladosporium cladosporioides, Cladosporium herbarum, Cladosporium macrocarpus, Cochliobolus sativus, Curvularia pallascens, Cylindrocladium scoparium, Aspergillus oryzae, Aspergillus wentii Aspergillus versicolor, Curvularia pallascens, Cylindrocladium scoparium,*	Organically Amended Agricultural Soil	Meghalaya	Swer *et al.,* (2011)	Agricultural soil microbes
Bulgaria sp., *Paraconiothyrium*	*Potentilla fulgens,* Host plant	Shillong Peak in	Nath and Joshi (2013)	Endophytic fungi

sp *Penicillium* sp. *Chaetomium elatum* *Aspergillus* sp. *Sirococcus conigenus.*		Meghalaya		
Phomopsis sp., *Epacris* sp.	Stem of Host plant	Meghalaya	Nath *et al.*, (2012)	Endophytic fungi
Diaporthe sp., *Xylaria* sp.	Root of Host plant	Meghalaya	Nath *et al.*, (2012)	Endophytic fungi
Colletotrichum gloeosporioides *Penicillium* sp., *Aspergillus.*	Stem and leaves of *Rauwolfia serpentina Awamori*	Meghalaya	Nath *et al.*, (2013)	Endophytic fungi
Penicillium verruculosum	Potentilla fulgens, Host plant	Shillong, Meghalaya	Bhagobaty *et al.*, (2010)	Ethno-medicinal properties
Cryptosporiopsis ericae PS4	*Potentilla fulgens*, Host plant	Shillong, Meghalaya	Devi and Joshi (2014)	Silver nanoparticle synthesizer with antimicrobial potency
Alternaria solani Penicillium funiculosum	*Endophytes of Gloriosa superba*	Shillong, Meghalaya	Devi *et al.*, (2013)	Antimicrobial property via silver nanoparticle production
Aspergillus sp., *Aspergillus versicolor, Penicillium* sp., *Chromocleista* sp., *Thysanophora longispora Talaromyces leycettanus Fusarium* sp., *Nectria lugdunensis Hypocrea koningii, Cladosporium* sp.,	Soil from various altitudes	Eastern Himalaya	Khaund *et al.*, (2012)	Edible mushroom

Trichoderma viride
Pleurostomophora richardsiae
Mortierella wolfii
Thysanophora penicillioides
Chromocleista malachitea
Chamaeleomyces granulomatis
Absidia glauca Umbelopsis sp.,
Apiospora montagnei

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An overview on fungal diversity in North East India: options for research and development

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Abstract

North Eastern India encompasses "eight" states (Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura) and is known for its rich biodiversity with substantial endemic species. The region has been identified as the Indo-Burma Hotspots of biodiversity. This region is believed to have enormous microbial diversity including an array of organisms that would be important for agriculture, nutrient management and industry, which has not been fully explored, particularly microbial diversity. Therefore, existence of agriculturally and industrially potential microorganisms especially fungi and actinomycetes should not be under estimated and proper documentation is needed. Recently, scientists have started working on diversity of endophytic and soil fungi from this region and showed that this region is having vast scope for agriculture and industry through microbial management. Endophytic and soil fungi has been isolated and characterized for antifungal, antibacterial and P-solubilization potentials from some parts of North East India. A number of Arbuscular Mycorrhizal fungi (AMF) has been reported and documented which are beneficial for the agricultural crops against biotic and abiotic stresses. Mushroom diversity is also undertaken in some parts. This chapter highlighted the work done in this region on fungal diversity and how it could be potentially exploited.

Keywords Fungal diversity, secondary metabolites, North East India, Mizoram, Mushroom.

Introduction

The Kingdom Fungi consists exclusively of species that are hyphal or clearly associated to hyphal species. Most of them all the way through their life cycle possess walls which normally contain chitin but not cellulose and they are solely absorptive in their nutrition. They are divided into divisons- Chitridiomycetes, Zygomycetes, Ascomycetes, Basidiomycetes and Mitosporic Fungi. The Chytridiomycetes are the only group with motile cells, known as zoospores. The sexual process leads to the production of characteristic spores in different groups. The fungi that form zygospores are classified as Zygomycetes, those that form ascospores as Ascomycetes and those forming basidiospores as Basidiomycetes. Many of Ascomycetes and Basidiomycetes, in addition to producing spores by a sexual process form other types of spores asexually. These are known as Mitosporic Fungi, as their spores are produced following mitosis but none by meiosis. They were formerly termed the Deuteromycetes or Fungi Imperfecti (Charlile et al. 2005)

Fungi are the group of organisms responsible for breakdown of complex dead organic material into simpler inorganic forms and play an important role in the cycling of nutrients within ecosystems. The Kingdom Fungi includes organisms which are important in terms of their ecological and economic roles. For example, mycorrhizal fungi associated with plant roots use carbon and in turn facilitate supply of essential nutrients to plants. Other fungi provide numerous drugs (such as penicillin and other antibiotics), foods like mushrooms, bread, Cheese, champagne and beer. Besides, many beneficial effects, fungi also cause a number of plant and animal diseases in humans, ringworm, athlete's foot and several more serious diseases. Since fungi are more genetically similar to animals than any other organisms and thus, fungal diseases are very difficult to treat. Plant diseases caused by fungi include wilt, powdery mildew, downy mildew, canker, anthracnose, early blight and leaf, root and stem rots that may cause severe damage to crops. However, a number of fungi, particularly yeasts are important "model organisms" for studying problems in genetics and molecular biology. This article reviewed information on the diversity of fungi in northeast region, their application and needs further research in the area.

Diversity of fungi in North East India

North Eastern India has topography consist of stretches of hilly forest areas as well as plains of Assam. Sikkim and Arunachal Pradesh come under Himalayan hills whereas Manipur and Nagaland fall under

Naga hill and Meghalaya is covered by Garo, Jaintia and Khasi hills; State of Mizoram is surrounded by Lusai hills. Topographical range of the region varies from tropical foot hills up to snow clad alpine hills. North-East India at 21° 34' N latitude and 97°52' E longitude is a vast gene pool of plant, animal and microbial resources. This region falls in a distinctive part of the Indo-Burma mega biodiversity hotspot (Myers et al. 2000) and being one amongst the two identified in Indian sub-continent. This active centre of speciation is also a centre of genetic diversity of domesticated crops and a secondary centre for many ecologically and economically important plant and animal resources (Bhattacharya et al. 2011). Research have been done on fungi from this part of India on their ecological occurrence, their nutritive values particularly in case of Mushrooms, role in soil fertility, solubilizing phosphorous and their antimicrobial potential.

Although there is vast opportunity lying in field of mycology in this region, it is still poorly explored. In North East India, there is a tremendous opportunity for mycologist to explore fungi and their habitat that may lead to many novel compounds from the region using which several human and plant diseases might be cured and the plants might also get a form of phosphorous of their need or that suits them the most. Research work from North East India has been more focused on endophytic, mycorrhizal and soil fungi; though, some research has been also performed from this region on mushrooms and their nutritive values.

Diversity of endophytic fungi in North East India

Endophytic Fungi: An overview

Endophytic fungi generally belong to Ascomycetes and fungi imperfecti, and they spend whole or part of their lifecycle colonizing inside the healthy host plant tissue without causing any apparent symptoms of disease. In natural ecosystems, symbiotic association of many plants with mycorrhizal fungi or fungal endophytes has profound effect on ecology, fitness and evolution of plants (Rodriguez et al. 2009, Petrini 1986). These symbionts have been reported to have intense effects on ecology of plants (Rodriguez et al. 2009, Brundrett 2006) by bestowing abiotic and biotic stress tolerance, increasing biomass, decreasing water consumption and increasing overall fitness of the plants (Rodriguez et al. 2009). Endophytic fungi associated with living tissues and in some means contribute to the health of the plant. This sets them apart from saprophytic fungi. In endophytic association with the plant, the host plant is thought to supply nutrients to the microbe, while the microbe may produce factors that protect the host plant from attack by animals, insects and microbes (Huang et al.

2001, Yang et al. 1994).

The possibility of biosynthesis of associated plant compounds by endophytes was first comprehended and published by Stierle et al. 1993 (Zhao et al. 2010). Taxol produced by an endophytic fungi *Taxomyces andreanae* (Xu et al. 2008, Stierle et al. 1993), isolated from *Taxus brevifolia* was an important discovery, inspired from which numerous efforts made to identify endophytes as sources of associated plant natural products. Plant hormones like Gibberellins and Indoleacetic acid produced by endophytic fungi have emerged as a new phenomenon which promotes plant growth during stress (Waqas et al. 2012). In last two decades, numerous valuable bioactive compounds classified as alkaloids, terpenoids, steroids, quinones, lignin, phenols and lactones having with antimicrobial, insecticidal, cytotoxic and anticancer activities have been successfully isolated from endophytic fungi (Xu et al. 2008, Zhang et al. 2006, Zhao et al. 2010). Endophytic fungi are also producers of some important extracellular enzymes including pectinases, xylanase, cellulose, lipase, proteinase, phenol oxidase etc. (Wang et al. 2006, Tan et al. 2001).

Plant roots are also known to colonize by dark septate endophytes (DSE) that forms a mutualistic association similar to mycorrhizas. According to Barrow, (2003) they are observed most commonly growing inter and intracellularly within the cortex, epidermis and on root surfaces. Several studies support the fact that dark septate endophytes co-colonize some host plant root along with arbuscular mycorrhizal fungi (Songachan and Kayang (2011), Jumpponen and Trappe (1998) and can be distinguished from arbuscular mycorrhizal fungal hyphae by their dark brown to dark red brown colour, thick lateral wall and repeatedly occurring septa (Kai and Zhiwei 2006, Songachan and Kayang, 2011)

Status of research on endophytic fungi in North East India

Variations of climatic zones lead to changes in occurrence of medicinal plants in different hills. Population density in the region shows it to be less compared to the other part of the country and most of the land is unutilized which needs to be protected to enrich the medicinal plant flora (Shankar and Rawat 2013). Many people in North East India specially the people of Mizoram use traditional medicinal plants to treat and cure many diseases including cancer, black water fever, malaria and respiratory syndromes (Sharma et al. 2001). Endophytic fungi isolated from these medicinal plants may also offers natural products useful to combat many such diseases. Numbers of researches have also been done to accumulate information regarding their distribution in different parts of plants which

may in turn prove to be significant, in describing the possible reason behind their certain ecological functions.

Endophytic fungi isolated from medicinal plants of North East India has potential for production of novel antimicrobial compounds in particular. In addition to that they have been reported as potent antioxidant producers and enzyme inhibitors (as in Cox assays). An endophytic *Fusarium oxysporum* isolated from rhizome of *Zingiber zerumbet* (L.) Sm. found to inhibit free radicals and cyclooxygenase activity. The tested extracts, of isolated endophytic fungi showed DPPH radical scavenging activity and COX II inhibition with IC50 value of 41.68 µg and 14.27 µg/100 mg respectively (Nongalleima et al. 2013) (Table 1).

Bhagobati and Joshi in 2011 have examined crude metabolite extracts derived from the culture broths of endophytic fungi of five ethnopharmacologically important plants, *Potentilla fulgens, Osbeckia stellata, Osbeckia chinensis, Camellia caduca* and *Schima khasiana* of Meghalaya in North-East India (Table 1). They were found to produce broad range of toxins, growth hormones and antibiotics upon searching in the mycotoxin database Myco_DB (Senyuva et al. 2008) , used for tentative identification of the fungal metabolites from the obtained mass values. The isolated endophytic fungus showed a wide range of metabolomic diversity which in future can be explored as potential microbial cell factories for production of varied range of biomolecules. Using analytical techniques like LC-MS, bio-prospection of useful fungal metabolites from potential fungal isolates can be made possible.

In 2012, Bhagobati and Joshi have isolated some more endophytic fungi from same medicinal plants as mentioned above and determined their antimicrobial and antioxidant potency. Antimicrobial properties were ascertained against human pathogens *Bacillus cereus, Salmonella typhi, Escherichia coli, Staphylococcus aureus,* and *Candida albicans* (Table 1). Crude ethyl acetate extracts of fungal metabolites have been found to show minimum inhibitory concentration (MIC) ranged from 13-45 µg/ml against the test bacterial and yeast pathogens. The endophytic fungi also showed high antioxidant activity. Ferric reducing antioxidant power (FRAP) and 1, 1-diphenyl-2-picrylhydrazyl (DPPH) free radical assays were used for estimating the total antioxidant power and free radical scavenging activity.

The fungal endophytes *Phomopsis* sp. and *Xylaria* sp. of *Emblica officinalis* from various parts of Megahalaya have shown high antimicrobial and antioxidant activities. The extacts from fungal endophytes were found to inhibit growth of both bacteria (*Enteroccocus faecalis, Salmonella*

enterica ser. Paratyphi, Streptococcus pyogenes) and yeast, *Candida albicans* (Nath et al. 2012). In another instance *Quambalaria* sp. an endophytic fungi from *Ipomea carnea* showed considerable antimicrobial activities against pathogens such as *Shigella dysenteriae* followed by *Escherichia coli* and *Candida albicans (Table 1)*. Optimum metabolite production from the crude extract of *Quambalaria* sp. required a 15 day incubation period and neutral pH in Czapek Dox broth amended with leaf extracts of the host. RNA secondary structure study revealed two hinges and a 5' dangling end which found to be unique to the isolate and may also be used as barcode for *Quambalaria* sp. (Padhi and Tayung 2013).

In the line of researches going on determining antimicrobial activity of isolated fungi, an endophytic *Fusarium* sp. isolated from *Taxus wallichiana* of Arunachal Pradesh also showed antifungal and antibacterial properties (Table 1). Antibacterial activity was tested against *Bacillus subtilis*, *Staphylococcus aureus* and *Escherichia coli* with maximum antagonism found against *Pseudomonas aeruginosa.* The fungus was also optimized for favoured growth conditions along with maximum production of the antimicrobial agent. Media composition of 5% leaf extract (w/v) supplemented with 0.1% dextrose (carbon source) and yeast extract (nitrogen source), optimum temperature, 25 ± 2°C, pH 6 with incubation period of 10 days was observed optimum for favoured growth conditions. Production of antimicrobial agent was maximized by Phenylalanine and dextrose enriched basal medium, whereas higher biomass accumulation was achieved by methionine amended in combination with glucose (Gogoi et al. 2008).

Kayini and Pandey, in 2010 have isolated and identified 24 endophytic phyllosphere fungi along with some epiphytic fungi and assessed their distribution in leaves of *Alnus nepalensis, Castanopsis hystrix* and *Schima walichii* respectively at bimonthly intervals during July, 2008 to May, 2009. *Alternaria alternata, Cladosporium cladosporioides, Fusarium oxysporum and Pestalotiopsis sp*. were found to be the dominant colonizers of the three forest tree leaves among all the isolated fungi. Whereas, *Gliocladium fimbriatum* an endophytic fungi was isolated only from leaves of *Schima wallichii* (Table 1).

Besides**,** antimicrobial fungi that reside asymptomatically as endophytes in the tissues of medicinal plants are also known to produce diverse array of bioactive metabolites and enzymes. Endophytes from medicinal plants of Meghalaya have found to validate this by their ability to produce amylase, cellulase, protease, lipase, and xylanase (Bhagobati

and Joshi 2012) (Table 1).

An important report was obtained from this region about *Penicillum verruculosum* an endophytic fungi isolated from tap roots of *Potentilla fulgens* L. (a medicinal plant widely used to treat various ailments in Meghalaya). The isolate was found to be a potent IAA producer and plant growth promoter. Metabolites of *Penicillum verruculosum* was found to promote seed germination of *Vigna radiate* (green gram) and *Cicer arietinum* (Chick Pea) (Bhagobati and Joshi 2009) (Table 1).

Diversity of soil fungi

An overview

Decomposition of organic matter is an important factor that regulates the process of nutrient cycling in the ecosystem which is mainly governed by the activity of soil microorganism (Pandey et al 2007). Additionally, these soil fungi synthesize growth factors like vitamins and auxins that help in binding soil-aggregating substances (Went and stark 1968). Nearly half of the decomposition products are transformed by fungi into cell materials which is many times more than that of the role of bacteria to degrade those products. Although fungi accomplish a range of important ecological functions, yet understanding of fungal diversity in soil is limited. Community profiling techniques including denaturing gradient gel electrophoresis (DGGE), temperature gradient gel electrophoresis (TGGE), single strand conformation polymorphism (SSCP), terminal restriction fragment length polymorphism (T-RFLP), amplified rDNA restriction analysis (ARDRA), amplified ribosomal intergenic spacer analysis (ARISA) and cloning, can reveal taxonomy and functional characteristics of soil fungi (Anderson and Cairney, 2004). Soil fungi also include mushrooms as well as mycorrhizal fungi, which we will discuss in next sections.

Diversity of soil fungi of North East India

Fungal soil microfloras are the most studied fungi along with endophytic fungi from North Eastern Region of India. Soil fungi are phosphate solubilizers (Kanakala and Singh, 2013), potential producers of antimicrobials (Mishra et al. 2013, Chutia et al. 2012), enzymes (Jha et al. 1992, Jha et al. 1992), showed that soil degradation and loss of vegetation in forests of North east India has adverse effect on microbial population number and enzyme activity. Soil fungi isolated from forest of different stages of regeneration from different altitude showed variations in population number and enzyme activity. Fungal population numbers and enzyme activity of dehydrogenase, urease and phosphatase were found to be higher in the

Table 1: List of Endophytic Fungi isolated from north east India having bioactive potential

Sl. No	Endophytic Fungi	Host Plant	Place of Collection	Biological Activity	Reference
1.	*Fusarium oxysporum*	*Zingiber zerumbet* (L.)	Chavangphai village, Chandel District, Manipur	Found to inhibit free radicals and cyclooxygenase activity	Nongalleima et al. 2013
2.	*Talaromyces flavus*	*Potentilla fulgens*	Nongkrem, Cherrapunji, Mawphlang,and Umsaw forests, Meghalaya	Antimicrobial and antioxidant activity	Bhagobati and Joshi, 2012
3.	*Mortierella hyalina*	*Osbeckia stellata*	Nongkrem, Cherrapunji, Mawphlang,and Umsaw forests, Meghalaya	Antimicrobial and antioxidant activity	Bhagobati and Joshi, 2012
4.	*Paecilomyces variabilis*	*Osbeckia chinensis*	Nongkrem, Cherrapunji, Mawphlang,and Umsaw forests, Meghalaya	Antimicrobial and antioxidant activity	Bhagobati and Joshi, 2012
5.	*Penicillium* sp.	*Camellia caduca*	Nongkrem, Cherrapunji, Mawphlang,and Umsaw forests, Meghalaya	Antimicrobial and antioxidant activity	Bhagobati and Joshi, 2012
6.	*Penicillium* sp.	*Schima khasiana*	Nongkrem, Cherrapunji, Mawphlang,and Umsaw forests, Meghalaya	Antimicrobial and antioxidant activity	Bhagobati and Joshi, 2012
7.	RS07PF(Unidentified)	*Potentilla fulgens*	Nongkrem	Aflatoxicol I, Aflatoxin B2, Cytochalasin H, Dihydrojasmonic acid, Indolacetic acid, oleic acid, penicillic acid,	Bhagobati and Joshi, 2011

				etc. (Tentative metabolite profile generated by LC-MS)	
8.	RS07OS (Unidentified)	*Osbeckia stellata*	Cherrapunji	Aflatoxin G2, Abscisic acid, Austdiol, Fusicoccin, Antimycin A5, Gibberellic acid, Verrucine A, Verruculotoxin, etc. (Tentative metabolite profile generated by LC-MS)	Bhagobati and Joshi, 2011
9.	RS07OC (Unidentified)	*Osbeckia chinensis*	Cherrapunji	Aflatoxicol I, Aflatoxin B2, Bezophenone, Diaportin acid, Indolacetic acid, Ochratoxin a, Walleminone, etc. (Tentative metabolite profile generated by LC-MS)	Bhagobati and Joshi, 2011
10.	RS07CC (Unidentified)	*Camellia caduca*	Mawphlang	Aflatoxin M1, Abscisic acid, Antimycin A3, Ascorbic acid, Trichodermin, etc. (Tentative metabolite profile generated by LC-MS)	Bhagobati and Joshi, 2011

11.	RS07SK (Unidentified)	*Schima khasiana*	Umsaw Nongkhrai	Aflatoxin G2a, Antimycin A5, Diaportin acid, Riboflavin, Dihydroxysterigmatocystin, Trichoverrol A, Verrucine A, etc. (Tentative metabolite profile generated by LC-MS)	Bhagobati and Joshi, 2011
12.	*Penicillum verruculosum*	*Potentilla fulgens*	Meghalaya	IAA production and promotes seed germination of *Vigna radiate* and *Cicer arietinum*.	Bhagobati and Joshi, 2009
13.	*Xylaria* sp.	*Emblica officinalis*	Meghalaya	Antifungal and Antibacterial activity	Nath et al. 2012
14.	*Diaporthe* sp.	*Emblica officinalis*	Meghalaya	Antibacterial activity	Nath et al. 2012
15.	*Phomopsis* sp	*Emblica officinalis*	Meghalaya	Antifungal activity	Nath et al. 2012
16.	*Quambalaria* sp.	*Ipomoea carnea*		Antifungal and Antibacterial activity	Padhi and Tayung, 2013

less degraded forests than in the more degraded ones. Dehydrogenase and urease activity varied with fungal population numbers at both high and low altitude whereas at lower altitude forest favoured phosphatase activity (Jha et al. 1992). (Table 2).

Trichoderma spp. are known as efficient biocontrol agent from soil fungal community. Many commercial preparations of the genera are available in the market. *Trichoderma pseudokoningii* (NCBI acc. No.-JX500737) from soils of Mizoram has been found to have antifungal activity against *Fusarium oxyspoum* f.sp. *pisi*, a cusative agent of pea wilt and thus can act as biocontrol agent which may help in reducing this disease in plants (Mishra et al. 2013) (Table 2). *Penicillium* sp. isolated from soils of different forests in Brahmaputra Valley, Assam, India, also showed significant antimicrobial activity against bacterial pathogens *Streptococcus bombycis*, *Aeromonas salmonicida*, *Staphylococcus aureus* and *E. coli* having inhibition zone of about $\geq$10mm (Chutia et al. 2012). With such high antibacterial activity, *Penicillium* sp. from virgin forest floors may have the ability to produce novel compounds of antimicrobial potential. Chutia et al. 2012 analyzed diversity of soil fungi from different undisturbed forests and seasonally flooded forests of Brahmaputra Valley. They have isolated species of *Penicillium*, *Alternaria*, *Aspergillus*, *Chaetomium*, *Cladosporium*, *Cunninghamella*, *Curvularia*, *Drechslera*, *Fusarium*, *Gliocladium*, *Humicola*, *Mucor*, *Paecilomyces*, *Periconia*, *Pestalotiopsis*, *Rhizoctonia*, *Rhizopus*, *Scelerotium*, *Sepedonium*, *Trichoderma* etc. *Penicillium*, *Aspergillus* and *Fusarium* species were found to be the most dominant fungal genera among all isolated soil fungi population in all the seasons.

Similar efforts made by Kumar et al. (2010), showed fungal isolates from the soil of the Kaziranga National Park, Assam, were having antibacterial and anti–*Candida* activity (Table 2). The most potent strains having antimicrobial activity, isolated belong mainly to the genera *Aspergillus*, followed by *Scopulariopsis*, *Curvularia*, *Phoma*, *Lasiodiplodia theobromae*, *Fusarium*, *Acremonium* and *Aureobasidium pullulans* (Kumar et al. 2010).

Plectosphaerella cucumeria has emerged as a new root rot pathogen and phosphate solubilizer from Mizoram (Table 2). *P. cucumeria* found to cause root rot to *Musa paradisiaca* an important fruit crop of tropical and subtropical countries. This is the first report of the *P. cucumeria* as both new root rot pathogen and P-solubiliser (Kanakala and Singh 2013).

One of the few studies on soil fungi isolated from Northeast India was done by Devi et al. (2012). *Aspergillus, Chromocleista, Penicillium, Trichoderma, Talaromyces, Nectria, Fusarium, Hypocrea, Pleurostomophora, Cladosporium, Mortierella, Thysanophora, Chamaeleomyces etc*. were characterized belonging to the phyla Ascomycota and Zygomycota corresponding to seven orders (Eurotiales, Hypocreales, Calosphaeriales, Capnodiales, Pleosporales, Mucorales, and Mortierellales) and Incertae sedis in which eurotiales and hypocreales were designated as the most varied and abundant group of fungi along the entire altitudinal stretch (Devi et al. 2012).

Fungal population and their species composition have been reported to be influenced by factors like soil depth, seasonal variation, organic fertilizers, vermin-compost (Bhattacharya and Jha 2011, Swer et al 2011). Fungal soil microflora from Nameri forest of Assam recovered from all depths of soil with highest fungus population in spring. *Aspergillus* and *Penicillium* were most dominant and abundant genera found there while Phycomycetes were the dominant fungal group (Bhattacharya and Jha 2011). Swer et al. (2011) showed that vermin-compost has more negative effect on fungal population number than different organic fertilizers like farm yard manure, plant compost and integrated compost (i.e. a combination of FYM, VC and PC in a 1:1:1 ratio). It further proved that organic matter level in the organically managed soil systems has a pivotal role to play in fungal growth, sporulation and diversity.

Malabranchea Gypsea a saprophytic fungal species (Sharma and Arunachalam 2007) from Arunachal Pradesh can produce extracellular enzymes of industrial importance such as protease and xyloglucanase and several amino acids.

Table 2. **Soil fungi from North East India and their biological potential**

S. No.	Identified Soil Fungi	Place of Soil Sample Collection	Biological Potential	Author
1.	*Plectosphaerella cucumeria*	Root of *Musa paradisiaca* Mizoram	Phosphate-solubilizer	Kanakala and Singh, 2013
2.	*Trichoderma pseudokoningii*	Soil samples, Aizawl, Mizoram	Antifungal Activity	Mishra et al. 2013
3.	*Penicillum* sp.	Soil Samples from Burhi Dihing (Tinsukia), Silapothar	Antibacterial activity	Chutia et al. 2012

		(Dhemaji), Majuli (Jorhat), Giban Wildlife Sanctuary (Jorhat), Bura Pahar (Golaghat), Titabor (Jorhat), Bogibeel (Dibrugarh), Assam		
4.	Unknown soil fungi		Dehydrogenase, urease and phosphatase activity	Jha et al. 1992

Diversity of mycorrhizal fungi

An overview

Mycorrhizal association is a mutualistic association that exists between a group of soil fungi and higher plants. The plant provides carbohydrates and other essential organic compounds to the fungi which colonizes both the root and the adjacent soil. Fungi in return help the plant uptake of nutrients by extending the reach of its root system with the help of its hyphae. Among many associations found in nature, there are two major types of mycorrhizal association viz. ectomycorrhizal and endomycorrhizal of the vesicular-arbuscular (VA) type that has economic and ecological significance (Harley and Smith 1983). The ectomycorrhizal fungi invade the cortical region of the host plant root without penetrating cortical cells. The main characteristic features of this type of mycorrhizal association are: (1) the formation of Hartig net around cortical cells which is nothing but hyphal network of fungi and (2) a thick hyphal mat on the root surface covering feeder roots. In endomycorrhizal associations of the vesicular-arbuscular (VA) type, the fungi hyphae arranged in finely divided pattern known as arbuscules which penetrate the cortical cells. Arbuscules are alleged sites of exchange of materials between the host plant and the fungi. These fungi also forms vesicles that generally serve as storage structures and when they are old they can serve as reproductive structures. Some researchers now prefer the designation arbuscular mycorrhiza (AM) over the term vesicular-arbuscular (VA) mycorrhiza since vesicles are not always found in such association (Habte 2000).

Symbiosis of arbuscular mycorrhizal fungi found frequently associated with improved plant growth attributed to nutritional and non nutritional effects of fungi. According to many researchers arbuscular mycorrhizal fungi affects the evolution of the plant, microbial communities, soil nutrient status, alleviation of drought and heavy metal stresses etc. In addition it also influences antagonism to pathogens increased phytohormone

levels, uptake of phosphorous, ammonium, copper, zinc, potassium, calcium and sulfur (Saranya and Kumutha 2011, Bethlenfalvay et al. 1989, Allen et al. 1980). Arbuscular mycorrhizal fungi also found to promote symbiotic N fixation (Saranya and Kumutha 2011, Barea et al. 1987).

Both Arbuscular and ectomycorrhizal fungi extend hyphae from the site of their association into the soil and these external hyphae are responsible for translocating nutrients from the soil to the root, and thus helping the host plants to improve their nutrient uptake from soil. Recently, Talbot et al. 2013, have hypothesized that ectomycorrhizal fungi influences the breakdown of nutrient-rich biopolymers in soil while saprotrophic communities primarily regulate the breakdown of carbon-rich biopolymers. Ectomycorrhizal fungi also found to contribute to larger-scale soil C and nutrient cycling occurring primarily via extramatrical hyphae outside the rhizosphere. Most ectomycorrhizal falls within the class basidiomycetes, while some belong to the zygosporic zygomycetes and ascomycetes. On the other hand, arbuscular mycorrhizal fungi belong to six genera within the azygosporous zygomycetes (Habte 2000).

Arbuscular mycorrhizal fungi colonizing plant root systems found to modulate plant growth even in salt stress which is a major threat to proper plant growth and productivity in various ways (Evelin et al. 2011). Arbuscular mycorrhizal fungi employ various mechanisms to improve the salt tolerance of host plants such as enhanced nutrient acquisition (P, N, Mg and Ca), maintenance of the K:Na ratio, biochemical changes (accumulation of proline, betaines, polyamines, carbohydrates and antioxidants), physiological changes (photosynthetic efficiency, relative permeability, water status, abscissic acid accumulation, nodulation and nitrogen fixation), molecular changes (the expression of genes: PIP, Naþ/ Hþ antiporters, Lsnced, Lslea and LsP5CS) and ultra-structural changes (Evelin et al. 2011). N-fixing capability of *Rhizobium* is believed to enhance if the host plant is also in symbiosis with arbuscular mycorrhizal fungi (Mohammadi 2011, Harrisson 1999). Various biological and physical mechanisms have been proposed to relate low metal toxicity to plants colonized by arbuscular mycorrhizal fungi including adsorption onto plant or fungal cell walls present on and in tissues (Mohammadi 2011, Mehrag and Cairney 2000, Joner 2000), exclusion by precipitation onto polyphosphate granules, dilution by increased root or shoot growth and compartmentalization into plastids or other membrane-rich organelles (Entry et al. 2002).

An arbuscular mycorrhizal (AM) fungus *Glomus fasciculatum* is found to increase salt tolerance in tree species *Gmelina arborea*.

G. fasciculatum treated plant showed increase in fresh and dry weight, greater percentage of mycorrhizal colonization, higher accumulation of proline and chlorophyll content and also antioxidant enzymes like peroxidase, catalase and superoxide dismutase along with increasing levels of salinity (Dudhane 2011). Another mycorrhizal endophyte, *Hymenoscyphus ericae* showed proteinase activity (Leake and Read 1990). *Glomus mosseae* is also known to possess a complex of pectolytic enzymes including pectinesterase, polymethylgalacturonases, polygalacturonases, pectin and pectate lyases (Garcia Romera et al. 1991).

DNA barcode region for fungi is not yet defined. The internal transcribed spacer (ITS) region has been recommended as a primary barcode candidate but closely related species of arbuscular mycorrhizal fungi does not resolve by ITS barcode. By comparing different regions to resolve fungi up to closely related species level, Stokinger, 2010 suggested a 1500 bp fragment comprising small subunit (SSU), ITS region, and large subunit (LSU) nuclear ribosomal DNA as a basis for AMF DNA barcoding.

Status of Mycorrhizal fungi in North East India

Arbuscular mycorrhizal fungi in their symbiotic association with plants benefit them by increased resistance to environmental stresses, enhanced plant nutrient acquirement, water relations, improving soil quality and resistance to diseases (Smith and Read 2008). Mycorrhizal fungi effects plant diversity and productivity and hence are an essential component for functioning of the ecosystem (van der Heijden et al. 1998). The identity and diversity of AMF have an immense influence on plant community structure (Scheublin et al. 2004) therefore, it is important to study and investigate composition of AMF community in different plant species.

In North East India many research works have been performed taking different plant species from different altitudes and diverse conditions, studying their biodiversity, community structure and species richness. Arbuscular mycorrhizal fungi (AMF) have been investigated for their species composition and diversity in many plants such as *Crotalaria anagyroides*, *Eupatoriumadenophorum,* and *Hedychium coronarium* from subtropical pine forest of Meghalaya (Songachan and Kayang 2011), *Solanum khasianum, Solanum sisymbriifolium,* and *Solanum torvum* from NEHU campus, Meghalaya (Songachan and Kayang 2012), rhizospheric soils of *Flemingia vestita* (Songachan and Kayang 2011), *Alnus nepalensis, Michelia champaca Solanum tuberosum* (Panna and Highland 2009) etc**.** *Glomus* and *Acaulospora* were found to be dominant in all the cases (Songachan and Kayang 2011, 2012, Panna and Highland

2009).

Effort has also been made in this region to assess species diversity and the regeneration pattern of vesicular-arbuscular mycorrhizal (VAM) fungi in shifting cultivated abandoned land (jhum fallow) and natural forest soils of Arunachal Pradesh, North-Eastern India (Singh et al. 2003) and to assess the impact of forest conversion to agricultural land AMF microbial diversity in undisturbed forests ,slash-and-burn fields and monoculture forests of Karbi Anglong hill district of Assam (Sharmah and Jha 2011). The dominant tree species from both jhum and natural forest soils were *Ailanthus grandis, Altinga excels, Arthocarpus chaplasha, Bombax ceiba, Gmelina arborea, Manglieta caveana, Tectona grandis* etc. while *Acaulospora, Enterophospora, Gigaspora, Glomus, Sclerocystis* and *Scutellospora* were found to be dominant genera of VAM fungi, recorded from soils of jhum fallow and natural forest sites (Singh et al. 2003). Glomus sp. was found to be dominant species of undisturbed forests, Slash-and-Burn Fields and Monoculture Forests (Sharmah and Jha 2011). The jhum fallow contains lower VAM fungal population species richness than the natural forest. This may attributed to (i) repeated slash-and-burn agriculture (ii) loss of host plants and (iii) unfavourable conditions for regeneration of VAM fungi in the jhum fallow land (Singh et al. 2003). Arbuscular Mycorrhizal fungi meet the same fate, as species richness was distictively higher in undisturbed forests (Sharmah and Jha 2011). Songachan and Kayang (2011) reported that AMF colonization, spore density, species richness and diversity were higher in Shifting plantation when compared to that of continuous cropping plantation (Table 3).

Arbuscular mycorrhizal fungi (AMF) develops symbiotic association with the plant ubiquitously, but sometimes they colonize rhizospheric region of root associated with dark septate endophytic (DSE) fungi. Diversity and colonization of arbuscular mycorrhizal fungus together with dark septate endophyte have been investigated on some species of bamboo from Northeast India. *Acaulospora tuberculata, A. rehmii, Glomus intraradices* and *G. tortuosum* were the most dominant species (Das and Kayang 2013). A case study of DSE and AMF associations in a potato field at Meghalaya, indicated that the colonization of arbuscular mycorrhizal fungi and dark septate endophyte fungi progressed at the same rate with no significant difference found. *Glomus tortuosum, Pacispora boliviana and Gigaspora margarita* were dominant fungal species recorded (Panna and highland 2010).While in another case study of *Solanum* sp. from NEHU (North Eastern Hill University), colonization rate of AMF and DSE differs (Songachan and Kayang 2011).

Mushrooms of North East India

There have been reports of mushrooms as wood decaying fungi from Mizoram. The fungi which mainly grows on wood are defined as wood decaying fungi. They may be grow on living tree where these fungi cause diseases (*Laetiporus sulphureus*) or, mycorrhizal association (*Cantharellus tropicallis*) or, on dead trees, logs where they help in their decomposition and discharge of nutrients into the soil. Mostly they categorize in basidiomycetes group under polyporales and agaricales but few ascomycetes such as are also found to grow on decayed wood. These fungi usually occurs when forest sites are disturbed to some extent. Wood decaying fungi proved to be essential for the functioning of forest ecosystem where they provide habitat for many other organism and facilitate the regeneration of forests (Bisht 2011). Decompositon of wood play a very important role in nutrient recycling, carbon formation etc. 50 of them have been reported and described from Mizoram of which 3 are ascomycota-*Daldinia concentrica, Xylaria hypoxylon, Xylaria longipes*., 44 are polypores and 6 belong to various orders of agaricle along withsome some unidentified sp. *Cerrena consors,Coriolopsis aspera, Cyclomyces tabacinus, Daedalea incana, Ganoderma applanatum,Lenzites elegans,Microporus xanthopus, Oxyporus ravidus, Polyporus Squamosus, Schizophyllum commune ,Termitomyces* sp. etc. have been reported from different forests of Mizoram (Bisht 2011) (Table 4).

Mushrooms are widely distributed in North eastern forests of India. Besides their nutritive value, their medicinal and antimicrobial potential can't be denied. But most reports on mushrooms from North East India are on their nutritive values (Table 5). In North-eastern region of India mushrooms are highly demanded as food. But the knowledge of edible mushroom in Assam is confined only to the ethnic tribes of the state. Adantages of mushroom production also includes recycling of agro-wastes which leads to the diversification of agriculture based microbial technology and eases the pressure on lands for cultivation (Sarma et al. 2010).

Mushrooms grow in a particular habitat, greatly influenced by light, temperature and relative humidity of the place. Many mushroom sp. belonging to different genera like *Ganoderma lucidum* followed by *Cantharellus tubaeformis, Agaricus bisporus, Schizophyllum commune, Auricularia delicata, Boletus luteus, Cantherallus cibarius, Lycoperdon cladopus, Termitomyces clypeatus, Auricularia auricula, Lentinus edodes,*

Table 3- Occurrence and colonization of Major genera of Mycorrhizal Fungi and Dark Septate Endophytes from different geographical regions of Noth East India

S. no.	Mycorhizal fungus type	Host Plant/ Type of soil	Major genera/ species of Identified fungus	Place of Collection	Location	Elevation (Above sea level)	Coloniza-tion Rate	Spore Density	Author
1	AMF	*Crotalaria anagyroides* Rhizospheric soil	*Acaulospora*, *Glomus*	subtropicalpine forest of North Eastern Hill University campus, Meghalaya, India	25°36' 40"N, 091°53' 57 4"E	1424 m	71%	659 per 25 gm soil	Songachan and Kayang, 2011
		Eupatorium adenophorum Rhizospheric soil	*Acaulospora*, *Glomus*				69%	661 per 25 gm soil	
		Hedychium coronarium Rhizospheric soil	*Acaulospora*, *Glomus*				66%	319 per 25 gm soil	
2	AMF	*Solanum khasianum* Rhizospheric soil	*Acaulospora*, *Glomus*	North Eastern Hill University Campus, Meghalaya	25.36.40N, 091.53.57E	1,424 m	39 %	681Spores per 25 gm soil	Songachan and Kayang, 2012
		Solanum sisymbriifolium Rhizospheric soil	*Acaulospora*, *Glomus*				42%	498 spores per 25 gm soil	
			Acaulospora,						

			Glomus						
		Solanum torvum Rhizospheric soil					36%	740 spores per 25 gm soil	
3.	DSE	*Solanum khasianum* Rhizospheric soil	-	North Eastern Hill University Campus, Meghalaya	25.36.40N, 091.53.57E	1,424m above sea level	0.79%(mean)	-	Songachan and Kayang, 2012
		Solanum sisymbriifolium Rhizospheric soil	-					-	
		Solanum torvum Rhizospheric soil						-	
4.	VAM	Soil	*Acaulospora , Enterophospora, Gigaspora,, Glomus , Sclerocystis* and *Scutellospora*	The Banderdewa forest range in Papumpare district of Arunachal Pradesh	27.62 N latitude and 93.492 E	350 m	-	-	Singh et al. 2003
5.	AMF	soil samples from the rhizosphereregion of plants	*Glomus, Acaulospora, Ambispora*	undis turbedforests (UF) , slash-and-burn fields (SBF) andmonoculture	(92.45’ and 93.54’ East Longitude and 25.45’ and 26.35’	232 MSL	-	UF(879± 19.5 spores per 100g soil), SBF (174±5.3 spores per	Sharmah and Jha, 2011

				forests (MF) In Karbi Anglonghill district, Assam	North Latitude)			100g soil) and MF (103±4.4 spores per 100g soil)	
6.	AMF	soil samples from rhizosphere of *Michelia champaca, Alnus nepalensis* and *Solanum tuberosum*	*Glomus rubiforme*	Umdihar,. Umsaw, Mawlein, ICAR, Upper Shillong,, Swer					Panna and Highland, 2009
7.	AMF	Potato (*Solanum tuberosum*) plots, root and soil sampling	*Glomus tortuosum* Schenck and Smith, followed by *Pacispora boliviana* Sieverd. andOehl, and *Gigaspora margarita* Becker and Hall	in Swer villagein the EastKhasi Hills District of Meghalaya	(latitude 25°25 N and longitude 91°47E)	1910 - 1975 m	6.98 (±3.13)– 12.4 (±3.53)%		Panna and Highland, 2010
8.	DSE	Potato (*Solanum tuberosum*) plots, root and soil sampling		in Swer villagein the East Khasi Hills District of Meghalaya	(latitude 25°25 N and longitude 91°47E)	1910 - 1975 m (±1.65)%	7.9(±2.9) –13.2	-	Panna and Highland, 2010

9.	AMF	rhizosphere soils of *Flemingia vestita*	*Aculospora, Glomus*	shifting system of plantation (SP) located at Mawprem and continuous cropping system of plantation (CCP) located at Thangsning East Khasi Hills, Meghalaya	SP-(25°32´ - 33.2´´N, 091°45´ 05.5´´E) and CCP-(25°28´ 57.1´´ N, 091° 55´00.9´´E)	1275 in SP and 1261 in CCP	-	Songachan and Kayang, 2011
10.	DSE	rhizosphere soils of *Flemingia vestita*	*Aculospora, Glomus*	shifting system of plantation (SP) located at Mawprem and continuous cropping system of plantation (CCP) located at Thangsning East Khasi Hills, Meghalaya	SP-(25°32´ - 33.2´´N, 091°45´ 05.5´´E) and CCP-(25°28´ 57.1´´ N, 091°55´ 00.9´´E)		-	Songachan and Kayang, 2011

Laetiporus sulphureus, Morchella esculanta, Termitomyces mammiformies, Auricularia polytricha, Calvatia gigantean, Cantharellus cibarius, Russula integra, Gomphus floccosus, Lactarius quieticolor, Lepiota magnispora, Auricularia auricula-judae, Boletus aestivalis, Cantharellus cibarius, Hypsizygus tessulatus, Pleurotus pulmonarius etc. have been identified and thir frequency of occurrence have been recorded. Although from north east India almost all major groups of mushrooms have been reported, emphasis has been given to identify edible mushrooms and analysis of their nutritional (both macro and micro-nutrients) components. (Bisht 2011, Agrahar-Murugkar and Subbulakshmi 2005, Sarma et al. 2010, Kumar et al. 2013, Khaund and Joshi 2013, Longvah and Deosthale 1998).

The mushrooms consumed by the tribals of North East India are harvested wild and although progress in this region has been made to analyze nutritional parameters of mushrooms; commercialization of the edible mushroom and studies on identification of wild and toxic mushrooms is still lacking in this region. Mushrooms are also known to produce array of extracellular enzymes, antimicrobial and anticancer compounds, therefore, it is important to explore and document more species which could be novel source of bioactive compounds.

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Table-4. List of Mushrooms from North East India and their Nutritional Information (Proximate / Macronutrients)

S. no.	Identified Mushrooms	Place of Collection	Dry Matter	Moisture	Protein	Fat	Carboh-ydrate	Fibre	Ash	Author
1.	*C. gigantean*		4.37 %		27.3 %	1.0 %		22 %	6.3 %	Agrahar-Murugkar and Subbulakshmi, 2005
2.	*C. cinerea*		13.0 %		27.5 %	2.5 %		8.4 %	13.9 %	
3.	*C. cibarius*		15.9 %		21.1 %	1.6 %		12.8 %	13.2 %	
4.	*R. brevispora*		10.5 %		24.1 %	1.3 %		8.8 %	10.9 %	
5.	*R. integra*		9.7 %		21.1 %	4.5 %		6.4 %	11.5 %	
6.	*G. floccosus*		13.0 %		21.2 %	5.3 %		9.2 %	8.0 %	
7.	*L. quieticolor*		8.2 %		19.0 %	2.6 %		14.4 %	6.6 %	
8.	Agaricus arvensis	Lahorijan, Puliebzie, Zakhama, Pherma, Mankoi, Chungtia, Nongkham, Namcha, And Tigit forest, Nagaland	4.20±0.60 per 100gm	94.90±1.80	32.87±1.69		32.91±1.80	0.14±0.02	0.18±0.01 2013	Kumar et al,

9.	*Agaricus langei*	4.10±0.65	84.82±1.72	35.14±1.04	34.83± 1.8214	3.28±0.05	34.83±1.82 14.10±0.61	Kumar et al, 2013
10.	*Lepiota lilacea*	4.20±0.67	83.20±1.73	28.12±1.40	49.33±1.94	11.98±0.64	8.09±0.77	
11.	*Lepiota magnispora*	2.40±0.53	93.31±2.02	27.55±1.25	35.00±1.58	5.20±0.29	3.05±0.57	
12.	*Auricularia auricula-judae*	95.17±2.03	2.20±0.59	36.30±1.33	33.23±1.67	2.81±0.04	7.07±0.52	
13.	*Boletus aestivalis*	77.01±1.25	4.10±0.65	32.76±1.47	52.07±2.81	12.13±0.58	14.97±0.73	
14.	*Cantharellus cibarius*	87.82±1.63	2.20±0.51	34.17±1.26	47.00±2.24	1.40±0.28	7.78±0.63	
15.	*Hypsizygus tessulatus*	83.40±1.39	3.10±0.87	37.80±1.25	51.20±2.27	12.90±0.35	9.09±0.78	
16.	*Pleurotus pulmonarius*	95.13±1.83	3.90±0.64	37.63±1.24	43.40±2.15	4.12±0.64	10.17±1.26	
17.	*Panus fulvus*	52.11±1.14	2.10±0.63	27.06±1.62	33.04±1.28	6.08±0.52	3.11±0.47	
18.	*Lactarius hygrophoroides*	70.00±1.28	3.30±0.86	44.93±1.79	42.00±1.64	10.58±0.35	2.00±0.29	
19.	*Cookeina sulcipes*	88.48±1.51	2.30±0.58	28.93±1.65	50.20±2.38	0.16±0.02	6.55±0.58	
20.	*Schizophyllum commune*	87.30±1.29	12.90±1.74	22.50±0.67	32.43±1.21	6.50±0.67	10.10±1.14	

21.	*Lepista irina*		83.82±1.58	2.10±0.47	26.12±1.50		50.20±2.34	6.08±0.52	3.16±0.59	
22.	*Melanoleuca grammopodia*		67.34±1.89	3.10±0.84	36.27±1.52		33.04±1.43	8.12±0.64	4.13±0.68	
23.	*Schizophyllum commune*	Manipur	5.3per100g		15.9	2.0	68.0	68.0	8.0	Longvah and deosthale 1998
24.	*Lentinus edodes*		4.7		22.8	2.1	64.0	64.0	6.0	

Table-5. Mineral Composition (Micronutrient Profile) of Mushrooms from North East India

S.No.	Identified Mushrooms	P	Mg	Ca	Fe	Zn	Cu	Cr	Na	K	Mn	Se	Vit.C	Author
1.	*C. gigante*	0.33 gm%	150 mg%	0.03 gm%	10.7 mg%	10.3 mg%	1.39 mg%		0.18 mg%	22.3 mg%	4.41 mg%	91.2 µg/kg	14.9 mg%	Agrahar-Murugkar and Subbulakshmi, 2005
2.	*C. cinerea*	0.42 gm%	43.8 mg%	1.91 gm%	75.2 mg%	11.1 mg%	23.9 mg%		0.33 mg%	52.1 mg%	6.79 mg%	0.17 µg/kg	41.8 mg%	
3.	*C. cibarius*	0.58 gm%	46.2 mg%	0.42 gm%	53.5 mg%	6.83 mg%	4.36 mg%		0.29 mg%	47.9 mg%	7.68 mg%	295 µg/kg	41.9 mg%	
4.	*R. brevispora*	0.51 gm%	217.2 mg%	0.53 gm%	7.17 mg%	6.76 mg%	16.7 mg%		0.31 mg%	35.5 mg%	11.4 mg%	5.28 µg/kg	28.0 mg%	
5.	*R. integra*	0.24 gm%	327 mg%	1.27 gm%	56.2 mg%	10.5 mg%	3.33 mg%		0.56 mg%	41.0 mg%	7.28 mg%	26.9 µg/kg	19.6 mg%	

6.	*G. floccosus*	0.34 gm%	136 mg%	1.37 gm%	22.3 mg%	13.0 mg%	3.48 mg%		0.14 mg%	18.7 mg%	7.04 mg%	Neglig-ible	25.8 mg%	
7.	*L. quieticolor*	0.42 gm%	25.31 mg%	1.46 gm%	19.4 mg%	39.4 mg%	1.91 mg%		0.21 mg%	17.0 mg%	5.32 mg%	975 µg/kg	18.1 mg%	
8.	*Schizophyllum commune*	P408 mg	MG227 mg	CA188 mg	Fe12.3	Zn5.7	Cu0.9	Cr 133 micro gm	-	-	-	-	-	Longvah and deosthale 1998
9.	*Lentinus edodes*	493	200	127	20.1	4.3	0.9	140 micro gram	-	-	-	-	-	

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Diversity of microfungi on decaying leaves of *Alnus nepalensis* and *Castanopsis hystrix* in subtropical plantation forests of Manipur, North East India

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Abstract

Microbial population and species composition of culturable filamentous fungi, their seasonal occurrence and successional patterns on decaying leaves of *Alnus nepalensis* and *Castanopsis hystrix* in subtropical mixed plantation forest of Manipur were studied (from June, 2010 to August, 2011) at monthly interval. Bacterial and actinomycetes populations were higher at *A. nepalensis* leaves throughout the study, whereas, fungal count was higher in *C. hystrix* leaves during early decay phase. Total eighty five fungal species belonging to 44 genera and 1 sterile mycelial form were isolated from both litter types by employing 3 cultural methods. Marked successional changes in fungal assemblages were observed during decomposition. Composition of litter fungi was significantly affected by sampling months and isolation techniques. Microfungi showed differential seasonal preferences during the course of litter decomposition. Most frequent species recorded from both litter samples by all three isolation methods were: *Cladosporium cladosporioides, Cylindrocladium parvum, Fusarium oxysporum, Trichoderma koningii* and *T. viride*. *Penicilium* was the most abundant genus with 21 species. Litter fungi of both trees showed highest similarity index during rainy season and about 37% of the microfungi were overlapping between two litter types.

Keywords Microfungi, decaying leaves, Alnus, Castanopsis, subtropical plantation forest

Introduction

In natural ecosystems a variety of microorganisms including fungi, bacteria and actinomycetes are the major decomposers of dead organic matter and play a key role in redistribution of mineral elements released into soil in the form suitable for plant uptake (Gadd 2004). Microbial activities and various physico-chemical agencies bring about change in chemical constituents of plant detritus which determine the species composition of successive colonizers and this trend continues until all organic substrates are mineralized (Holland and Coleman 1987). Inherent to each system a unique microbial flora exist among which, saprobic fungi represent the largest proportion of litter biomass in terms of diversity and physiological activities and are able to degrade the lignocellulose matrix in litter thus contributing to the maintenance of global carbon cycle (Kjøller and Strewe 1982, Herman et al. 2008). Attempts have been made to explain the underlying principles of fungal occurrence by studying the species composition of mycoflora on various plant substrates during different stages of decomposition (Hudson 1968, Frankland 1998, Hyde and Soytong 2007, Osono 2006, 2007). However, it appears that each decomposition system has its own characteristic species assemblage and successional pattern depending on substrate quality, fungal reservoir of the site, abiotic factors and environmental constraints (Swift, 1976). Research on fungal diversity therefore provides a basis for estimating their functional properties and level of redundancy in the ecosystem.

Estimates of global fungal diversity vary from 0.7 to 9.9 million species but only 80,000 species have been described to date (Schmit and Mueller 2007). In addition to tropical forests, the numbers of unexplored habitats which have proven rich in specialized and unique mycoflora are still enormous (Suryanarayanan and Hawksworth 2005), though they may have restricted distributions to a particular habitat type (Manoharachari et al. 2005). The indispensable roles that fungi play in nutrient cycling in natural forests, there is a clear imperative to better understand the structure of litter inhabiting microfungi in poorly studied areas and the hosts. High species diversity and spatial heterogeneity of decomposer fungi on decaying leaves in tropical forests have been reported (Bills and Polishook 1994, Santana et al. 2005).

North East India is regarded as one of the biodiversity hotspots of the world (Myers 2000) and blessed with a wide range of physiography and eco-climatic conditions, representing the transition zone between the Indian, Indo-Malayan and Indo-Chinese biogeographic regions and a meeting place of the Himalayan mountains and Peninsular India (Devi et al. 2012). This region is unique in providing a profusion of habitats which

features diverse biota with a high level of endemism. Highly undulating topography leads to marked variation in edapho-climatic conditions and altitudinal gradients due to which diverse flora and fauna have been well documented but the microbial groups have not received much attention as yet (Ramakantha et al. 2003). Different forests of the region that follow the foothills of the Himalaya to the west and extended into southeast China in the east, still remains systematically unexplored in relation to fungal diversity (Devi et al. 2012). Several studies on the saprobic fungal community and their succession on decaying leaf litters of forest and plantation trees in the tropics have been conducted in recent years (Tang et al. 2005, Duong et al. 2008, Osono 2008, Shanthi and Vittal 2010, Seephueak et al. 2010), however only a few published reports have established the nature of microbial population and diversity of fungi on litter types of forest trees in North East India till date (Kshattriya et al. 1994, Pandey et al. 2007, Sharma et al. 2011, Sharma and Pandey 2012).

Alnus nepalensis D. Don. (Family-Betulaceae) and *Castanopsis hystrix* A. DC. (Family-Fagaceae) commonly known as Himalayan alder and chinkapins, respectively' are the parts of evergreen subtropical plantation forest trees in Manipur mainly confined to lower and middle altitudes ranging between 1000 to 1300 m. a.s.l. and forming a climax vegetation type (Yadava 1990). In this region the forests are over-exploited for timber, fuel wood and common agricultural practices like shifting cultivation which has led to decrease in the forest area and are responsible for degradation of natural forests, thus reducing the fertility of soils (Pandey et al. 2007). In degraded areas, large-scale plantations of commercial plant species have been raised in the past to fulfill the needs of human beings. These changes in natural ecosystems may directly or indirectly affect the vital functions of the soil such as decomposition and mineralization that can alter the species composition or may have negative effect on the diversity of decomposer fungi (Lodge 1997).

Therefore, the aims of the present study were to investigate the microbial populations, fungal diversity, their seasonal distribution and successional patterns on *A. nepalensis* and *C. hystrix* leaf litters during different stages of decomposition in the mixed subtropical plantation forests of Manipur, North East India.

Materils and methods

Study site

The present study was conducted at two mixed plantation forest

stands located adjacently on gentle slopes of the hillock at Taphau Pudunamei along the Taphou Naga Hill range (25^0 17' 13" N Latitude and 94^0 01' 25" E Longitude), having elevations between 1132-1154 m a.s.l., at a distance of 2 km north-west of Senapati District Headquarter and 62 km north of Imphal, the capital city of Manipur, Northeastern India. The study site falls under eastern Himalaya subtropical wet hill forest as classified by Champion and Seth (1968). Manipur hills along with Naga and Mizo hill ranges consists of mainly tertiary strata and came into existence as a result of Tertiary folding of sedimentary strata in the shallow Tethys Sea, about 40 - 90 million years ago (Yadava 1990). The climate of the area is typically monsoonic. The year is divisible into three distinct seasons viz. summer (April to June), rainy (July to September) and winter (November to February). March and October are the transitional months between winter and summer and rainy and winter seasons, respectively. The summer and rainy seasons are characterized by high temperature and humidity. Low temperature and sort photoperiod of clear sunny days followed by frosty nights are common in winter. The mean minimum and maximum temperatures during the study period (June, 2010 to August, 2011) ranged between 1.1 to 14.2 ^{0}C and 24.4 to 34.1 ^{0}C, respectively (Figure 1). The maximum relative humidity (RH) varies from 51.7 to 89.4% with an average RH of 35.8 to 62.2%. Monthly rainfall ranged from 0.4 to 235.3 mm, with mean annual precipitation of 896.8 mm and a total rainfall of 1337.9 mm during the study period. The soil of *A. nepalensis* stand (A) was 10-20 cm deep, rocky type, blackish in colour and loamy sand (sand 70.4%, silt 22.7 %, clay 6.7%), while that of *C. hystrix* stand (B) was 20-30 cm deep, greyish in colour and loamy sand in texture (sand 74.3%, silt 20 %, clay 5.3 %). Both soils were slightly acidic (5.1-6.1) in nature. The temperature and moisture content of the two soils ranged from 13.3 to 22.7 ^{0}C and 8.2 to 66.2 %, respectively whereas, soil organic carbon varied between 2.98 to 6.29%. The vegetation of Stand-A and B was mainly dominated by *A. nepalensis* and *C. hystrix* along with several other woody associates viz., *Quercus serrata, Schima wallichii, Albizia lebbeck, Emblica officinialis* and *Ficus hispida*. Ages of the trees at both stands ranged between 35 to 60 years. The ground flora was better developed and formed by abundant herbaceous cover and woody species seedlings. Details of soil properties of both stands are shown in Table 1.

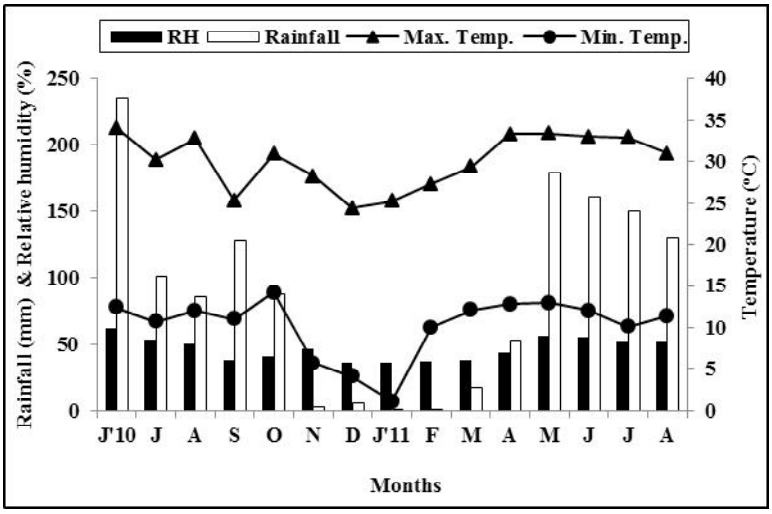


Fig. 1. Changes in monthly relative humidity (%), rainfall (mm) and maximum and minimum temperature (°C) during the study period.

Table 1. General characteristics of vegetation and soil at *A. nepalensis* and *C. hystrix* forest stands.

Parameters	***A. nepalensis* stand**	***C. hystrix* stand**
Vegetation*		
Tree age (years)	55 - 60	35 - 40
Range of tree height (m)*	10 - 18	6 - 13
Mean girth (cm)	65.3 ± 2.2	67.9 ± 3.1
Density (tree ha^{-1})	1370	1430
Tree basal cover (m^{-2} ha^{-1})	76	94
Soil**		
Soil type	Loamy sand	Loamy sand
Organic Carbon (mg g^{-1})	32.1 - 56.4 **(96077.3)**	24.0 - 39.6 **(73434.7)**
Total N (mg g^{-1})	21.6 - 24.8 **(51424)**	14.1 - 19.0 **(37912)**
Available P (mg g^{-1})	1.08 - 1.42 **(2851.2)**	0.53 - 0.81 **(1505)**
Exchangeable K (mg g^{-1})	40.8 - 84.9 **(16320)**	28.9 - 52.8 **(9606.8)**

***Height of *A. nepalensis* and *C. hystrix* only. ****Values of soil properties are reported as the range of variations during study period in upper 10 cm soil depth. Values in parenthesis with bold letters show organic Carbon and nutrient concentrations (kg ha^{-1}).

Study materials and estimation of lignocellulose contents

Leaf litters of *A. nepalensis* and *C. hystrix* were used as the study materials. The leaf litter sizes were measured and their cellulose and lignin contents were determined. Dried litter samples of each were ground separately and sieved to get fine powder. Cellulose content was analyzed by the procedure outlined by Jermyn (1955), while that of Klason lignin as described by Van Vurren and Van der Eerden (1992) by subtracting the ash content of the acid digested residual materials.

Sample collection and decomposition studies

Mature senesced leaves of *A. nepalensis* and *C. hystrix* were collected separately during February-March, 2010 over the large nets when maximum litterfall occurred, then brought to laboratory and properly air-dried. The leaf litter decomposition study was carried out by nylon mesh bag technique. A total of 175 nylon net bags (10 × 15 cm size; 1 mm mesh) containing 5 g air-dried leaves of each of the two plant species were prepared separately and placed randomly at seven different locations in a bunch of 25 bags on 1st May, 2010. On each sampling date at least seven litter bags containing the decomposing litter were randomly recovered from each location of the study sites at monthly intervals. After recovery, the bags were placed in separate polythene bags and brought to the laboratory. The leaf litter of each bag were brushed carefully to remove the adhering soil particles and other debris. Three litter bags each of the two tree species were weighed fresh and then oven dried at 80 ^{0}C till a constant weight to assess the moisture content. The remaining recovered litter bags were used for biological properties. The per cent moisture was calculated as: Litter moisture content (%) = (fresh weight-dry weight/dry weight) × 100. The collection and observation of *A. nepalensis* litter bags was performed up to May, 2011 while, for *C. hystrix* it was continued up to August, 2011 till maximum litter decay occurred. A total of 12 and 15 collections were made in case of *A. nepalensis* and *C. hystrix*, respectively.

Estimation of microbial population from litter

Dilution (suspension) plate technique was employed for the selective isolation of fungi, bacteria and actinomycetes colonizing both the decaying leaf types (Parkinson et al. 1971, Pandey et al. 2007). One gram litter pieces (5 mm diam.) of each, punched out from leaves using sterile Cork borer, was suspended separately into 250 ml Conical flask containing 100 ml sterilized distilled water and then shaken on horizontal shaker to detach the microbial propagules. Suspension was diluted further

to 10^{-3} and 10^{-4} by adding sterile distilled water. One ml aliquot of 10^{-3} dilution for fungi and 10^{-4} dilution for bacteria and actinomycetes was inoculated in five replicated Petri dishes. Twenty ml molten and cooled (40 ^{0}C) Czapek-Dox + Yeast Extract agar [CDA] (Onions et al. 1981), Thornton's agar (Thornton 1922) and Jensen's agar (Jensen 1930) media was poured separately into each Petri dish for the selective isolation of fungi, bacteria and actinomycetes, respectively. The dishes were rotated clockwise and anticlockwise to mix the homogenates. After solidifying, the dishes were incubated at 25±1^{0}C for fungi and 30±1^{0}C for bacteria and actinomycetes. The microbial colonies were counted after 2, 5 and 7 days of incubation for bacteria, actinomycetes and fungi, respectively and the average number of colony forming units (CFUs) were calculated as: [Average number of microorganism's g^{-1} oven dry litter = (Average no. of colonies appeared in the culture plate × Wet weight of litter/Weight of oven dry litter) × Dilution].

Isolation of microfungi from litters

After counting the fungal population, individual colony developed on agar media in Petri dishes was identified further for examining the qualitative nature of microfungi. Besides dilution plating, two more cultural methods viz. washed disks (Sharma et al. 2011) and surface sterilization method (Kinkel and Andrews 1988) were applied to obtain precise information regarding the species composition of fungal communities colonizing the two litter types.

In washed disk method, 25 pieces (5 mm diam) of each leaf substrate prepared as above were washed serially in 10 changes of sterile distilled water (1 min/ washing) and blotted dry in folds of sterilized blotting papers. The disks were placed in 5 Petri dishes (5 disks/ plate), each containing 20 ml solidified CDA medium. The plates were incubated at 25±1 ^{0}C for 7 days and the fungal colonies developed on the leaf disks were identified.

In surface sterilization method, 25 disks of each litter type were prepared as above and submerged in 70% ethanol for 1min, then transferred into 15% H_2O_2 for 1 min and again kept into 70% ethanol for another 1 min followed by serial washing in 10 changes of sterile distilled water. After washing, disks were blotted dry for 30 minutes, inoculated in each of 5 Petri dishes (5 disks/plate) containing solidified CDA medium and incubated as above. After incubation, fungal species appeared on litter pieces were identified.

Based on the number of months and the seasons in which litter fungi of both trees occurred by different methods were categorized into various groups i.e. ubiquitous (occurred in 6 or more months), summer (recorded in at least 3 months during March to June), rainy (occurred in 3 months during July to October), winter (occurring in 3 or more months during November to February), nonspecific (recorded in 3 or more months but not included in any categories) and accidental (recovered in less than 3 months) species. Besides these, the fungi were also classified as early colonizers (occurring in at least 3 or more months in the first 4-5 months), mid-stage colonizers (occurring in at least 3 or more months in middle sampling period) and late colonizers (recorded in at least 3 or more months in latter sampling months).

Identification of fungal isolates

The fungal colonies were identified based on keys and descriptions provided by various authors (Barnet and Hunter 1972, Ellis 1971, 1976, Pitt 1979, Subramanian 1971,Watanabe 2002). The identities of several isolates were later confirmed at Indian Type Culture Collection, Indian Agricultural Research Institute, New Delhi (ITCC ID Nos. 8248.11-8267.11, 8268.11, 8269.11, 8271.11, 8272.11, and 8274.11) and National Fungal Culture Collection of India, ARI, Pune (Accession Nos. NFCCI 2035- 2042, 2045 – 2047, 2064, 2065, 2225, 2227- 2229, 2233, 2235 and 2873-2877).

Data analysis

Relative abundance (RA %) of each fungal species isolated by dilution plating was calculated as: (Number of colonies of a fungal species/ Total number of fungal colonies) ×100. The observations made on washed disks and surface sterilization methods were expressed in terms of percent Frequency of occurrence (FO %) of the individual species and were calculated as: (Number of leaf disks on which a fungal species occurred/Total number of leaf disks observed) ×100. Mean annual percentages of RA or FO of each fungus were calculated by dividing the sum of RA or FO of individual species by the number of observation i.e. 12 in case of *A. nepalensis* and 15 for *C. hystrix*. The overlap and complementarity of microfungi from two litter types were calculated using the Sørenson's quotient: Overlap (%) = (Number of taxa shared between A and B/ Total number of taxa observed in A and B) ×100, and Complementarity (%) = 100 Overlap in which A denotes the number of fungal species in one kind of litter and B denotes the species in another litter type. Similarity index (SI) (Sørensen 1948) of the isolated fungi was calculated using the formula: SI = 2C/(A+B), where A is the number of

species in one sample, B is the species number in other sample and C is the number of fungal species co-existing in two samples. The diversity indices of the fungal communities were calculated using Shannon-Weiner information (Shannon and Weiner 1963) as follows: $H' = \Sigma - \left(\frac{n_i}{N}\right) \log_e \left(\frac{n_i}{N}\right)$ Where, H′ is the Shannon index of general diversity, n_i is the importance index value of each fungal species and N is the total importance value of all the species.

Results

Leaf area index and ligno-cellulose contents

Leaf sizes of *A. nepalensis* ranged from 8-15 cm in length and 4-8 cm width, while that of *C. hystrix* were 6-12 cm × 3-5 cm. Initial cellulose and lignin contents of *A. nepalensis* and *C. hystrix* were 36.6% and 39.8% and 15.6% and 18.2%, respectively.

Changes in microbial population on decaying litters

Monthly variations in fungal, bacterial and actinomycetes populations isolated from *A. nepalensis* and *C. hystrix* leaves are depicted in Figs. 2 and 3. Freshly fallen air-dried leaves of both litter substrates were colonized by lesser number of microorganisms which increased consistently as the decomposition progressed showing highest fungal counts (22.2×10^{-3} and 22.8×10^{-3} g^{-1} litter dry mass of *A. nepalensis* and *C. hystrix*, respectively) during the fourth sampling (in September). However, the maximum population of bacteria and actinomycetes in *A. nepalensis* leaves were recorded in fifth sampling (in October) revealing the corresponding values of 57.2×10^{-4} and 40.6×10^{-4}, respectively whereas, the highest peak in counts of these two microbial groups (34.2×10^{-4} for bacteria and 28.2×10^{-4} for actinomycetes) in *C. hystrix* litter were obtained in September i.e. fourth samping. After this, the microbial population in both litter types decreased gradually in the successive months to a low level till the ninth sampling (up to February) and thereafter, again showed increasing trends till the end of decay period except in case of *A. nepalensis* leaves where actinomycetes count decreased further in last sampling (May). As compared to *C. hystrix* litter, *A. nepalensis* leaves revealed higher bacterial and actinomycetes populations throughout the study period, while the fungal population was slightly higher in *C. hystrix* leaves during early decay period i.e. from second to fifth sampling months (July-October).

All the test climatic variables (viz. rainfall, relative humidity, average mean temperature) and moisture contents of *A. nepalensis* and *C. hystrix*

litters were insignificantly correlated with fungal, bacterial and actinomycetes counts except that the bacterial population and moisture percentage of *C. hystrix* litter were found to be positively correlated (r = 0.49, $p < 0.05$).

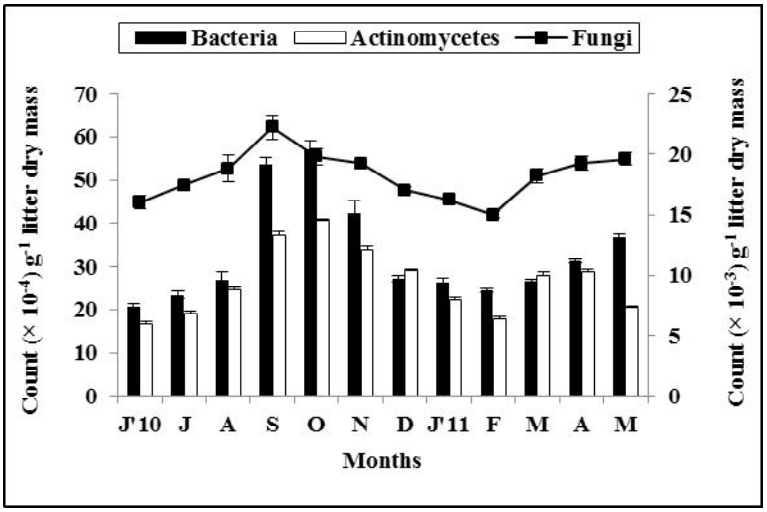


Fig. 2. Monthly changes in microbial population on decomposing leaf litter of *A. nepalensis.* Values of bacterial and actinomycetes counts are plotted on left y-axis and of fungi on right x-axis.

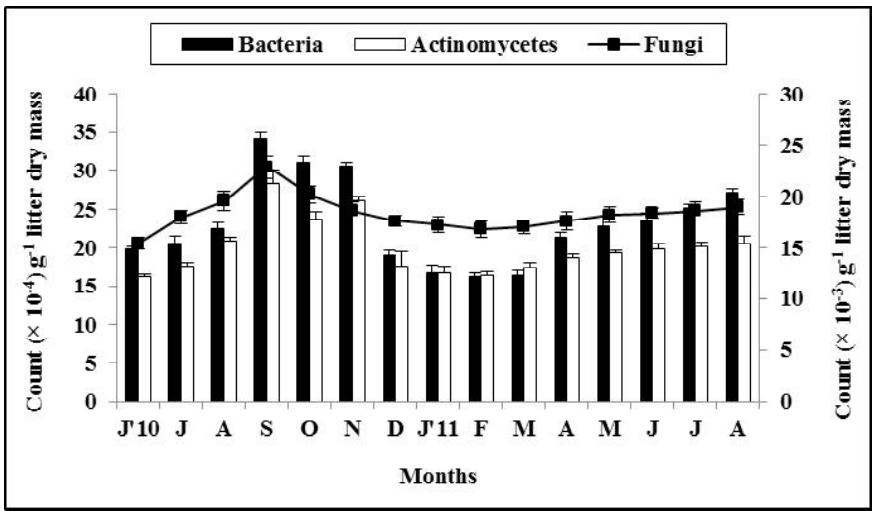


Fig. 3. Monthly variations in microbial population on decaying leaf litter of *C. hystrix*. Values of bacterial and actinomycetes counts are plotted on y-axis and of fungi on x-axis.

Diversity of litter colonizing fungi

A total of 85 fungal species belonging to 44 genera and 1 sterile mycelial form was isolated from *A. nepalensis* and *C. hystrix* decaying litters by employing 3 cultural methods (Table 2). Among the total, number of species recovered from *A. nepalensis* and *C. hystrix* leaves were 60 and 56 fungus, respectively of which 32 species were common to both litter types and 29 and 24 species were specifically isolated from alder and *C. hystrix* leaves, respectively. The most frequent species recorded from both litter substrates by the three isolation methods were: *Cladosporium cladosporioides, Cylindrocladium parvum, Fusarium oxysporum, Trichoderma koningii* and *T. viride*. *Penicilium* was the abundantly recovered genus with 21 species followed by *Aspergillus* and *Trichoderma* along with 5 species each. *Paecilomyces* (*P. farinosus, P. javanicum* and *P. variotii*) and *Gliocladium* (*Gliocladium* sp., *G. penicillioides* and *G. virens*) were represented by 3 species each, while the rest of the genera consisted of 1 or 2 species only. Different microfungi showed differential seasonal preferences during the course of litter decomposition (Table 2). Considering all 3 cultural methods, the microfungi isolated dominantly from alder leaves during summer were: *Chaetomium spirale, G. penicillioides, Nigrospora sphaerica, Penicillium lavitum, P. thomii, P. vermiculatum* and *Periconia minutissima,* whereas from *C. histrix* leaves such species were: *Monodictys* sp. and *Penicillium diversum*. *Mucor genevensis* occurred abundantly during rainy season from both trees litters. *Purpureocillium lilacinum* was recorded during rainy months on alder leaves but was found as ubiquitously on *C. hystrix* litter. Similarly, *Aureobasidium pullulans* was classified as winter species from *A. nepalensis* litter but was recorded as accidental fungus on *C. hystrix* leaves.

Number of fungal species recorded from decaying leaves of *A. nepalensis* and *C. hystrix* by dilution plating was 37 and 36, respectively (Appendix 1, 2). Out of these, 16 species were common to both litter types and 22 species occurred exclusively on alder leaves while other 20 species were specific to *C. hystrix* litter. Thus, total number of fungus recovered from the two litter substrates by suspension plating was 56. Throughout the study period, an irregular trend of increase or decrease in fungal species richness was observed. However, in both cases highest number of microfungi was recorded from September sampling. Fourteen species of *Penicillia* were isolated from two host litters. Fungi that were exclusively isolated from *A. nepalensis* litter in at least 8 months duration by this cultural method was: *Epicoccum purpurascens* and *Scytalidium thermophillum* (Appendix 1), while that of *C. hystrix* litter such species

were: *Mucor hiemalis, Pestalotiopsis* sp., *P. lilacinum, T. viride* and *Verticillium terrestre* (Appendix 2).

By employing washed disk method, a total of 29 and 27 fungal species were isolated from decomposing litters of *A. nepalensis* and *C. hystrix*, repectively (Appendix 3, 4). Of these, 15 species were commonly found on both types of litters, whereas 15 and 13 species were restricted to *A. nepalensis* and *C. hystrix* leaves, respectively. The fungal species richness was higher during rainy months. Microfungi isolated from alder leaves during 8 or more months were: *Alternaria alternata, Chrysosporium keratinophilum, E. purpurascens,* and *V. terrestre*, whereas from *C. hystrix* litter such fungus were: *Penicillium javanicum, P. rubrum, P. rugulosum, Pestalotiopsis* sp, *P. lilacinum, T. viride* and *V. terrestre*.

By surface sterilization method, total number of fungal species isolated from *A. nepalensis* and *C. hystrix* leaves were 27 and 26, respectively of which, 13 species were commonly recorded from both litters, whereas 15 and 13 species were restricted to *A. nepalensis* and *C. hystrix* leaves, respectively (Appendix 5, 6). Fungi isolated from alder decaying litter in 8 or more months were: *A. alternata, Colletotrichum gloeosporioides* and *Drechslera australiensis*, whereas that of *C. hystrix* litter, such dominant species were: *A. alternata, A. niger, C. gloeosporioides, Nodulisporium gregarium, P. variotii, Pestalotiopsis* sp., *Trichoderma longibrachiatum* and *V. terrestre*. The photographs of several frequently occurring microfungi are shown in Plate 1 and 2.

Sørenson's Similarity and Shannon's Diversity indices between the fungal species compositions of *A. nepalensis* and *C. hystrix* leaves varied during different seasons revealing the highest values in rainy and winter seasons, respectively (Figs. 4, 5). Species overlap (%) among the microfungi of two host substrates were recorded to be high showing 36.5% overlapping between the two litter types.

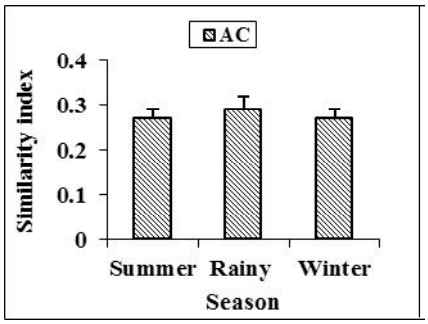


Fig. 4. Sorensen's similarity index of microfungi inhabiting the decaying leaves of *A. nepalensis* and *C. hystrix* (AC) during different seasons. Bars indicate SE.

PLATE 1

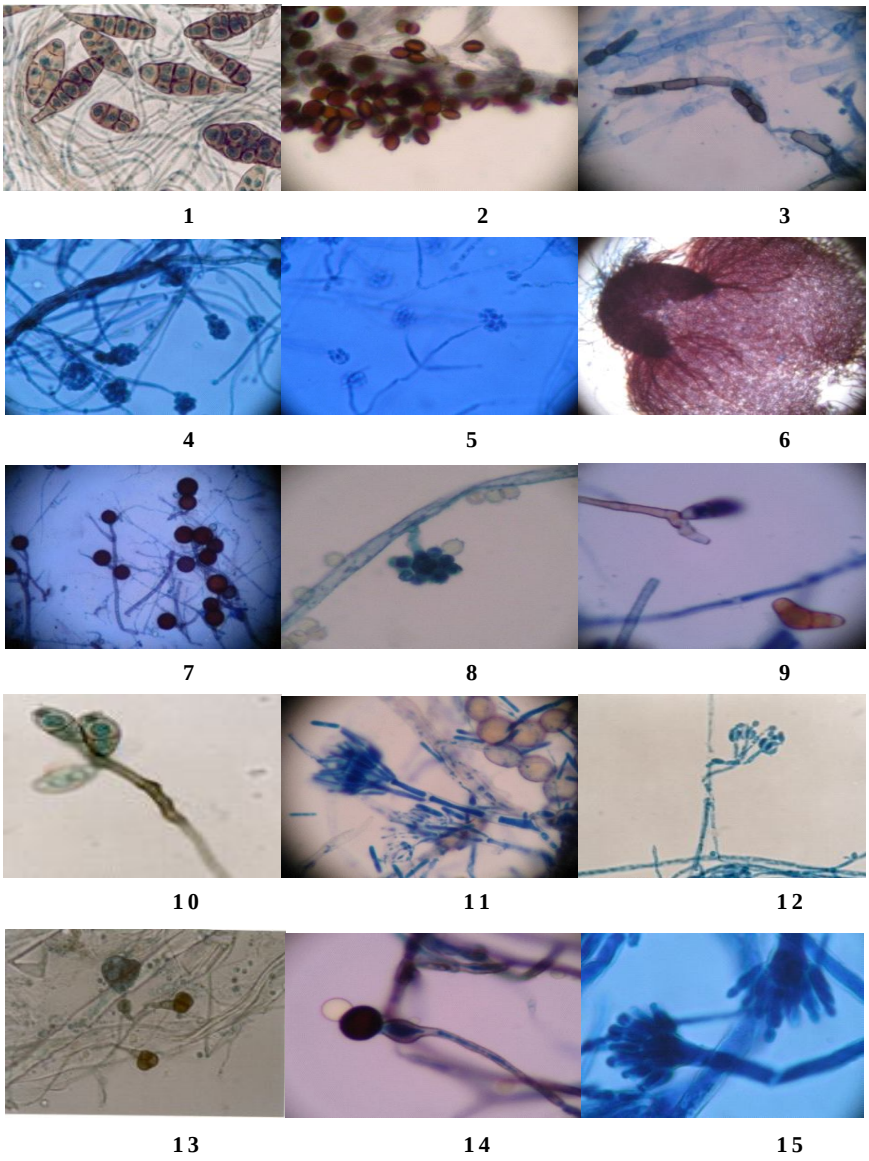
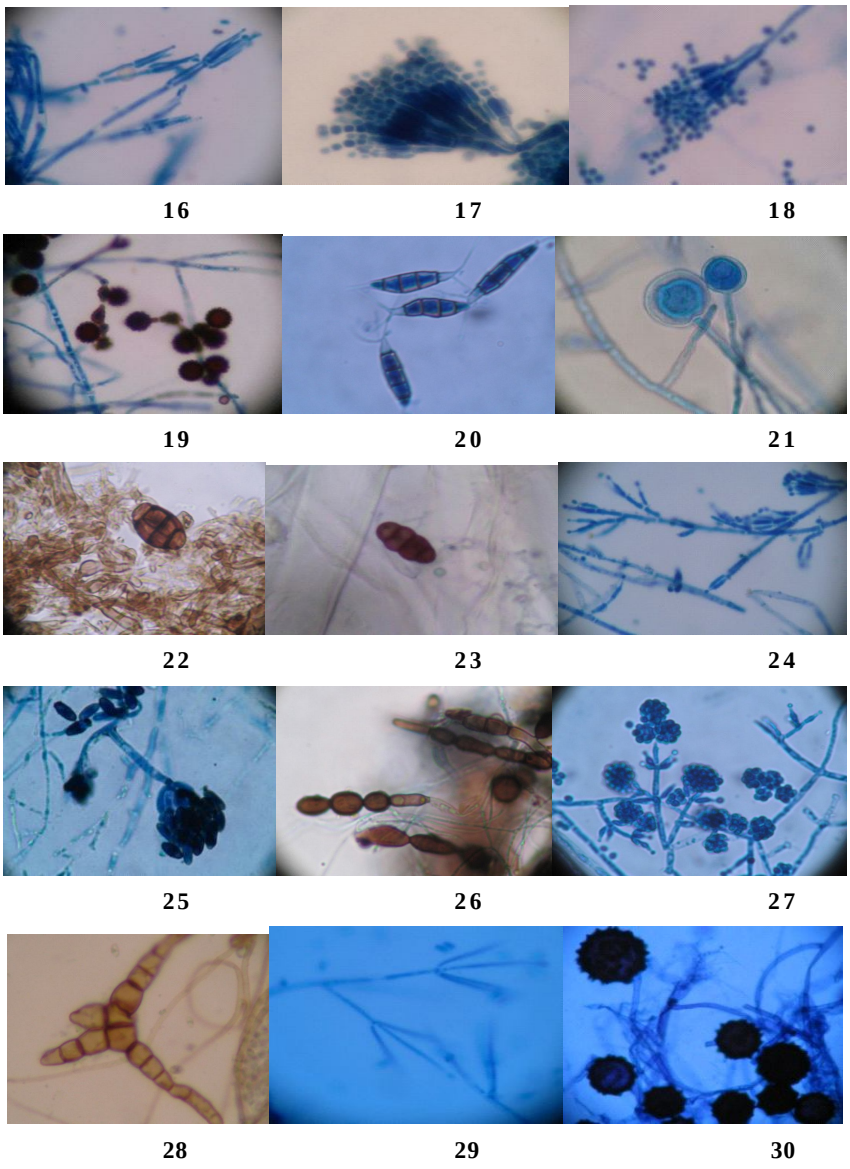


PLATE 1

1. *Alternaria alternata* **2.** *Arthrinium* sp. **3.** *Aureobasidium pullulans* **4.** *Cephalosporium coremioides* **5.** *Cephalosporium eichhorniae* **6.** *Chaetomium globossum* **7.** *Chrysosporium keratinophylum* **8.** *Cunninghamella echinulata* **9.** *Curvularia lunata* **10.** *Curvularia pallescens* **11.** *Cylindrocladium parvum* **12.** *Gliocladium virens* **13.** *Monodictys* sp. **14.** *Nigrospora sphaerica* **15.** *Oedocephalum lineatum*

PLATE 2



16 **17** **18**

19 **20** **21**

22 **23** **24**

25 **26** **27**

28 **29** **30**

PLATE 2

16. *Paecilomyces variotii* **17.** *Penicillium citrinum* **18.** *P. expansum* **19.** *Periconia minutissima* **20.** *Pestalotiopsis* sp. **21.** *Phoma minutispora* **22.** *Pithomyces chartarum* **23.** *P. maydicus* **24.** *Purpureocillium lilacinum* **25.** *Stachybotrys parvispora* **26.** *Scytalidium thermophilum* **27.** *T. koningii* **28.** *Tripospermum myrti* **29.** *Verticillium terrestre* **30.** *Zygorhynchus vuilleminii*

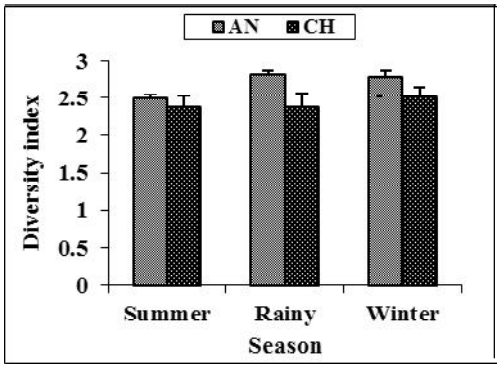


Fig. 5. Diversity (H′) indices of microfungi isolated from decomposing litter of *A. nepalensis* and *C. hystrix*. Bars indicate SE.

The numbers of ubiquitous, summer, rainy, winter, non-specific and accidental species in *A. nepalensis* decaying leaves were 22, 7, 12, 7, 6 and 7, respectively. Corresponding values in *C. hystrix* litter were 21, 2, 10, 5, 4, and 4, respectively (Table 2). Fungal community composition varied with litter type and their decomposition stages. Based on the 3 isolation methods, some species were recorded abundantly during early stage of litter decay period, while others were active colonizers in the mid- and/or late phase of decomposition of the two host substrates. Number of fungal species belonging to early, mid and late colonizers of alder decaying litter were 10, 10 and 11, respectively (Table 3), while that of *C. hystrix* leaves were 11, 9 and 10, respectively (Table 4).

Table 2. Species composition and seasonal occurrence of microfungi in decomposing leaf litters of *A. nepalensis* and *C. hystrix* isolated by different cultural methods.

Fungal species	**DPM (Mean %RA) occurrence**		**WDM (Mean %FO)**		**SSM (Mean % FO)**		**Seasonal**	
	AN	**CH**	**AN**	**CH**	**AN**	**CH**	**AN**	**CH**
Absidia repens Tiegh.	0.0	0.0	6.3	0.0	0.0	0.0	W	-
Alternaria alternata (Fr.) Keissl.	0.0	3.1	9.0	0.0	12.7	7.7	U	U
A. tenuissima (Nees) Wiltshire	0.0	1.7	0.0	0.0	0.0	0.0	-	R
Arthrinium sp.	0.0	1.1	0.0	0.0	0.0	0.0	-	R
Aspergillus candidus Link	2.4	2.8	0.0	3.2	0.0	5.6	R	SR

A. flavipes (Bainier and Sartory) Thom and Church	0.0	0.0	0.0	0.0	0.0	2.4	-	R
A. flavus Link	0.0	0.0	4.7	0.0	0.0	0.0	R	-
A. niger Tiegh.	3.9	5.5	9.0	0.0	9.3	11.7	U	U
A. wentii Wehmer	0.0	0.0	0.0	0.0	3.7	0.0	W	-
Aureobasidium pullulans (De Bary) G. Arnaud ex Cif., Ribaldi and Corte	1.8	0.9	3.7	0.0	0.0	0.0	W	AC
Cephalosporium coremioides Raillo	1.9	0.0	0.0	0.0	5.3	0.0	W	-
C. eichhorniae Padwick	2.5	0.0	0.0	0.0	0.0	0.0	NS	-
Chaetomium dolichotrichum L.M. Ames	0.0	1.1	0.0	0.0	3.3	3.5	R	SR
C. globosum Kunze ex Fr.	1.4	0.0	2.7	0.0	0.0	0.0	R	-
C. spirale Zopf	0.0	0.0	2.0	0.0	0.0	4.3	S	R
Chrysosporium keratinophilum D. Frey ex. J. W. Carmich.	0.0	0.0	18.0	0.0	0.0	0.0	U	-
Cladosporium cladosporoides (Fresen.) G. A. de Vries	9.2	8.5	12.7	16.5	0.0	0.0	U	U
C. herbarum (Pers.) Link	0.8	0.0	0.0	0.0	0.0	0.0	AC	-
Colletotrichum gloeosporioides (Penz.) Penz. and Sacc.	0.0	0.0	0.0	0.0	11.7	8.5	U	U
Cunninghamella echinulata (Thaxt.) Thaxt. ex Blakeslee	0.0	2.3	0.0	5.9	0.0	0.0	-	SR
C. elegans Lendn.	0.0	0.0	0.0	1.3	0.0	0.0	-	AC
Curvularia lunata (Wakker) Boedijin	0.0	1.2	0.0	0.0	0.0	5.9	-	R
C. pallescens Boedijin	0.0	1.5	0.0	0.0	0.0	0.0	-	R
Cylindrocladium parvum P.J. Anderson	5.7	5.1	16.0	9.9	15.3	13.6	U	U
Dematophora necatrix R. Hartig	0.0	2.6	0.0	0.0	0.0	0.0	-	NS
Drechslera australiensis (Bugnic.) Subram. B.L. Jain	0.0	0.0	0.0	0.0	7.3	0.0	U	-

Epicoccum. purpurascens Ehrenb.	4.1	0.0	15.7	0.0	0.0	0.0	U	-
Fusarium oxysporum Schltdl.	5.6	5.3	15.7	26.5	18.0	21.9	U	U
Gliocladium. penicillioides Corda	0.0	1.7	6.0	0.0	5.3	0.0	S	NS
G. virens Mill., Giddens and A.A. Foster	1.1	2.4	3.7	3.5	0.0	0.0	R	SR
Grallomyces portoricensis F. Stevens	0.0	1.7	0.0	0.0	0.0	0.0	-	NS
Hansfordia biophila (Cif.) M.B. Ellis	0.0	0.0	0.0	0.0	4.0	0.0	NS	-
Monodictys sp.	0.0	0.0	0.0	3.2	0.0	0.0	-	S
Mortierella renispora Dixon-Stew.	0.0	0.0	0.0	3.5	0.0	0.0	-	SR
Mucor genevensis Lendn.	0.0	0.0	2.3	3.7	0.0	4.5	R	R
M. hiemalis Wehmer	2.5	3.8	8.3	6.9	0.0	0.0	W	U
Nigrospora sphaerica (Sacc.) E.W. Mason	0.0	2.8	4.7	0.0	4.3	3.2	S	SR
Nodulisporium gregarium (Berk. and M.A. Curtis) J.A. Mey.	0.0	0.0	0.0	0.0	0.0	11.7	-	U
Oedocephalum lineatum B.K. Bakshi	0.0	0.0	0.0	0.0	7.0	0.0	R	-
Paecilomyces farinosus (Holmsk.) A.H.S. Br. and G. Sm.	0.0	1.8	0.0	0.0	0.0	0.0	-	W
P. javanicus (Friedrichs and Bally) A.H.S. Br. and G. Sm.	0.8	0.0	0.0	0.0	0.0	0.0	AC	-
P. variotii Bainier	1.7	3.1	2.3	3.5	4.3	6.9	U	U
Penicillium aurantiogriseum Dierckx	0.3	0.0	0.0	0.0	0.0	0.0	AC	-
P. citrinum Thom	0.0	2.3	2.7	2.7	0.0	0.0	NS	U
P. decumbens Thom	2.4	0.0	0.0	0.0	0.0	2.7	AC	-
P. diversum Raper and Fennell	1.5	0.0	0.0	2.7	0.0	0.0	R	W
P. duclauxii Delacr.	0.0	0.0	0.0	0.0	1.3	0.0	R	SR
P. ehrlichii Kleb.	0.0	0.7	0.0	0.0	0.0	0.0	-	AC
P. expansum Link	1.3	0.0	0.0	0.0	0.0	0.0	AC	-

P. fellutanum Biourge	1.8	0.0	0.0	0.0	0.0	0.0	W	-
P. herquei Bainier and Sartory	0.3	0.0	0.0	2.4	0.0	0.0	AC	W
P.italicum Wehmer	0.0	2.7	0.0	2.7	0.0	3.7	-	R
P. javanicum J.F.H. Beyma	0.0	0.0	0.0	2.9	0.0	0.0	-	U
P. levitum Raper and Fennell	0.0	0.0	0.0	0.0	2.3	3.2	S	NS
P. nalgiovense Laxa	3.6	0.0	0.0	0.0	0.0	0.0	U	-
P. purpurogenum Stoll	3.9	2.6	0.0	0.0	0.0	10.1	U	U
P. rubrum Stoll	0.0	0.0	0.0	4.0	0.0	0.0	-	U
P. rugulosum Thom	0.0	0.0	0.0	7.2	0.0	0.0	-	U
P. sclerotiorum J.F.H. Beyma	1.2	0.0	0.0	0.0	2.3	0.0	NS	-
P. simplicissimum (Oudem.) Thom	0.0	0.8	0.0	0.0	0.0	0.0	-	AC
P. spinulosum Thom	0.0	1.8	0.0	0.0	0.0	0.0	-	R
P. thomii Maire	0.0	0.0	0.0	0.0	3.0	0.0	S	-
P. vermiculatum P.A. Dang.	3.9	1.1	0.0	0.0	0.0	2.7	S	W
Periconia minutissima Corda	1.1	0.0	0.0	0.0	0.0	3.2	S	SR
Pestalotiopsis sp.	2.4	4.3	10.3	19.2	0.0	20.0	SR	U
Phoma minutispora P.N. Mathur	0.0	0.0	0.0	0.0	3.0	0.0	NS	-
Phomopsis sp.	0.0	0.0	0.0	0.0	0.0	2.7	-	R
Pithomyces chartarum (Berk. and M.A. Curtis) M.B. Ellis	0.0	0.0	3.0	0.0	0.0	0.0	R	-
P. maydicus (Sacc.) M.B. Ellis	1.4	0.0	4.0	0.0	0.0	0.0	R	-
Purpureocillium lilacinum (Thom) Luangsa-ard, Houbraken, Hywel-Jones and Samson	3.0	3.4	12.3	13.9	0.0	0.0	R	U
Pythium intermedium de Bary	0.0	0.0	0.0	0.0	6.0	0.0	U	-
P. rostratum E.J. Butler	0.7	0.0	0.0	0.0	0.0	0.0	AC-	-
Rhizopus sp.	0.0	1.7	0.0	0.0	0.0	0.0	-	W
Scytalidium thermophilum (Cooney and R. Emers.) Austwick	3.0	0.0	0.0	0.0	10.7	0.0	U	-
Stachybotrys parvispora S. Hughes	0.5	0.0	0.0	0.0	0.0	0.0	AC	-

Trichoderma harzianum Rifai	0.0	0.0	11.7	8.0	0.0	0.0	U	W
T. koningii Oudem.	7.1	4.6	15.7	13.9	0.0	17.6	U	U
T. longibrachiatum Rifai	4.3	0.0	0.0	0.0	13.0	15.2	U	U
T. viride Pers.	7.0	5.5	13.0	11.2	10.7	0.0	U	U
Trichothecium roseum (Pers.) Link	0.0	3.1	0.0	5.3	0.0	0.0	-	U
Tripospermum myrti (Lind) S. Hughes	0.0	0.0	0.0	0.0	4.7	0.0	U	-
Verticillium effusum G.H. Otth	0.0	0.0	0.0	0.0	4.0	0.0	NS	-
V. terrestre (Pers.) Sacc.	0.0	3.6	8.3	4.3	5.7	6.1	U	U
Zygorhynchus vuilleminii Namysl.	2.2	0.0	5.3	0.0	0.0	0.0	W	-
White sterile mycelia	3.4	3.1	9.0	5.3	5.0	5.1	U	SR
Total number of fungal species	**37**	**36**	**29**	**27**	**27**	**26**	**-**	**-**

DPM = Dilution plate method (% relative abundance), WDM = Washed disk method (mean % frequency of occurrence), SSM = Surface sterilization method (mean % frequency of occurrence), AN = *A. nepalensis* litter, CH = *C. hystrix* litter, U = Ubiquitous, S = Summer, R = Rainy, W = Winter, SR = Summer-rainy, NS = Non-specific, AC = Accidental, - = Absent.

Table 3. Categorization of microfungi colonizing the decomposing leaf litter of *A. nepalensis*.*

Early colonizers	Mid-stage colonizers	Late colonizers
Aspergillus candidus	*Absidia repens*	*Cephalosporium eichhorniae*
A. flavus	*Aspergillus wentii*	*Chaetomium spirale*
Chaetomium globosum	*Aureobasidium pullulans*	*Gliocladium penicillioides*
Mucor genevensis	*Cephalosporium coremioides*	*Hansfordia biophila*
Gliocladium virens	*Chaetomium dolichotrichum*	*Nigrospora sphaerica*
Paecilomyces variotii	*Mucor hiemalis*	*Penicillium citrinum*
Penicillium decumbens	*Oedocephalun lineatum*	*P. levitum*
Pestalotiopsis sp.	*P. scleroteorum*	*P. thomii*
Pithomyces chartarum	*Purpureocillium lilacinum*	*Periconia minutissima*
P. maydicus	*Zygorhynchus vuilleminii*	*Phoma minutispora*
		White sterile mycelia

Table 4. Categorization of fungal community colonizing the decaying leaf litter of *C. hystrix.**

Early colonizers	Mid-stage colonizers	Late colonizers
Alternaria tenuissima	*Dematophora necatrix*	*Aspergillus candidus*
Arthrinium sp.	*Gliocladium penicillioides*	*Chaetomium dolichotrichum*
Aspergillus flavipes	*Grallomyces portoricensis*	*Cunninghamella echinulata*
Chaetomium spirale	*Paecilomyces farinosus*	*Gliocladium virens*
Curvularia lunata	*Penicillium decumbens*	*Monodictys* sp.
C. pallescens	*P. herquei*	*Mortierella renispora*
Mucor genevensis	*P. vermiculatum*	*Nigrospora sphaerica*
Penicillium italicum	*Rhizopus* sp.	*Penicillium diversum*
P. levitum	*Trichoderma harzianum*	*Periconia minutisima*
P. spinulosum		White sterile mycelia
Phomopsis sp.		

***Based on the three isolation methods employed. Early colonizers = Occurring in at least 3 or more months in the first 4-5 months; Mid-stage colonizers = Occurring in at least 3 or more months in the mid sampling months; Late colonizers = Occurring in at least 3 or more months in the last sampling months.**

Discussion

This is the first report of a comparative study on microbial counts, fungal diversity, their seasonal occurrence and successional patterns on decaying leaf litters of two evergreen trees namely *Alnus nepalensis* and *Castanopsis hystrix* belonging to the order Fagales in North East India by employing three different isolation methods. Diverse fungal species, including anamorphic and teleomorphic Ascomycetes and Basidiomycetes, have been reported from decomposing litter of *Castanopsis* spp. (*C. fissa*, *C. diversifolia* and *C. sieboldii*) in recent years from China, Japan and Thailand (Tang et al. 2005, Osonoet al. 2008, Duong et al. 2008) but there is virtually no record of fungal community on *C. hystrix* litter in India. Our findings revealed that members of Deuteromycetes (77.3%) were represented with highest percentage followed by the members of Zygomycetes (11.3 %), Ascomycetes (7.2%), while members of Oomycetes and sterile mycelia equally represented by 2.1% each. This is in agreement with report that among the decomposers, mitosporic fungi mainly from Dematiaceous Hyphomycetes are by far the largest group of fungi involved in litter decay process, while Ascomycetous and Zygomycetous fungi are less in occurrence (Shanthi and Vittal 2010, Seephueak et al. 2010) . In

the present study, the species richness at generic level showed that Penicillia were the most diverse fungi represented by 24 species while rest of the recovered genera were represented by 1 to 5 species. Penicillia grow quickly and produce large number of conidia which are easily dispersed and exhibited wide ecological spectrum (Christensen 1981).

Seasonality is one factor which is believed to affect the microbial population, in general and fungal species composition, in particular (Seephueak et al. 2010, Sharma et al. 2011). The reports on microfungal diversity in decaying leaf litters suggest that the species composition vary according to the seasons. Nevertheless, it is still unclear how the seasons affect the fungal assemblages. As the presence or absence of aquatic Hyphomycetes is regulated primarily by season, one can assume that this effect operates via temperature (Nikolcheva and Bärlocher 2005). In this study, the microbial populations and fungal species richness were higher in rainy months than the samples collected during winter or summer seasons. Environmental differences can greatly influence the microbial community and fungal diversity in tropical leaf litters (Santana et al. 2005). Climatic variables such as temperature, moisture and humidity have also been found to affect the changes in population of microbial groups and fungal assemblages on decaying litters (Kshattriya et al. 1994, Pandey et al. 2007, Sharma et al. 2011). The observed seasonal preferences shown by the fungal community of both litter types may indicate their adaptability to the prevailing climatic conditions in a particular season and their role at different decomposition stages. Thus, many factors affect the variations observed in community structure i.e. the microclimate of the growing area, biological interaction within leaf litter, or the substrate microhabitat preferences (Lodge 1997).

Type of fungal species isolated from the two litter substrates was influenced by the method of isolation as the microfungi recorded by different cultural methods varied differentially. Some species could be isolated by a specific cultural technique while others were recovered by at least two or all three methods which emphasize the importance of using a combination of methods for isolating maximum fungal decomposer community. Different methodologies were adopted previously to study the fungal diversity of decaying leaf litters. The indirect isolation methods often results in appearance of more taxa including non-sporulating morphospecies (Bills and Polishook 1994). The direct method, in which the substratum is examined in the field or laboratory for fungal fruiting bodies, is regarded as the most common and better approach for taxonomic purposes (Polishook et al. 1996).

Generally different plant species have differing chemical compositions and this may affect the microbial communities and biomass (Prescott and Grayston 2013). Zhou and Hyde (2001) suggested that patterns of host- exclusivity and –recurrence might be explained by responses of fungal decomposers to the differences in physical structure and nutrient levels among host plants. But the reason why many microfungal species are recurrent (i.e. differentially abundant) on particular plant substrate and at specific stages of decomposition is unclear, and may involve the structure and chemistry of litter type or the fact that a few fungi present in decomposing leaves are endophytic in green and senescent leaves and persist as saprobes in the decaying organic matter at forest floor (Polishook et al. 1996). In the present study also, the physical (leaf area) and the organo-chemical compositions (cellulose and lignin contents) of the litters appears to have the influence on qualitative and quantitative nature of the microfungi. For instance, the recorded trend of fungal species richness at the substrate level in descending order was *A. nepalensis* > *C. hystrix*. Comparatively, the bigger leaf size, high nitrogen concentration and low ligno-cellulosic contents in *A. nepalensis* litter might have attributed to the maximum fungal species richness. Although *C. hystrix* bears smaller leaf sizes and its more recalcitrant materials (lignin and cellulose) might have contributed hindrance to the microfungal colonization. Several *Castanopsis* species has mechanisms that protect the leaves against fungal colonization such as hairs on both sides when young, smooth surface, leathery leaf tissues when mature and phenolic compounds (Duong et al. 2008). Differences in resource quality such as nitrogen and the presence of inhibitory tannin concentrations involved in decay are also important. The similarity index of the isolated species among both litter types was comparatively higher in rainy season, while the diversity index was higher in *C. hystrix* decaying leaves during winter season. The difference in similarity coefficients during different seasons indicates that some microfungi showed certain level of host specificity or recurrence in one or the other season. Fungal species overlap among the two plant substrates were recorded to be high showing 36.5% species overlapping between *A. nepalensis* - *C. hystrix*. The overall high overlap may be because the hosts studied were from the same order (Fagales). High Shannon index was recorded in both litter types in all the sampling months. The calculated values fall within the magnitude of H′ which is usually between 1.5 and 3.5 rarely greater than 4.5 as given by Margalef (1972).

Among different categories of litter fungi isolated from the two litter samples, ubiquitous colonizers represented the highest number of

species. The common ubiquitous fungi isolated from both samples included *A. alternata, A. niger, C. cladosporioides, C. gloeosporioides, C. parvum, F. oxysporum, P. variotii, T. koningii*, *T. viride* and *V. terrestre*. These fungi have been reported as primary saprophytes which can withstand adverse environmental conditions such as dessication, UV radiation and microbial lysis by producing thick walled pigmented multicellular spores and microsclerotia (Hudson 1968, Sharma et al. 2011). The occurrence of some of these fungi on the surfaces of green foliage of both the hosts has been reported previously (Kayini and Pandey 2010) and suggest that they may be carried over from the phylloplane being inhabitants of aerial plant surfaces (Osono 2006).

In the present study, changes in fungal species compositions were observed in the two litter types during three different phases of decomposition by all three employed methods, and were classified as early- (pioneer), mid- (mature) and late- (impoverished) stage fungi. Bill and Polishook (1994) suggested that colonization of leaf litter by various fungal species during decomposition is a sequential process with the replacement over time and is affected by the changes in nutrient and lignocellulosic concentrations of the litter besides competition between the inhabitant fungi. In the initial stages of litter breakdown, starch and amino acids are lost, leaving behind the recalcitrant molecules i.e. lignin, which allows greater fungal growth during this stage because these small, soluble carbon-based molecules are energy rich (Osono 2007, Herman et al. 2008). During later stages of decay, fungal assemblages may be dominated by secondary saprotrophs which are able to compete early colonized species when resources are less (Frankland 1998). White sterile mycelia was recorded as late colonizers of both litter types which can be regarded as representatives of those fungal species which do not sporulate naturally or under cultural conditions including monokaryotic Basidiomycetes (Sharma and Pandey 2012). These fungi can decompose lignin or lignin like humic substances vigorously in forest litters and soils, respectively. Osono (2007) also proposed that the members of Basiodiomycetes are considered as better decomposers of recalcitrant compounds than the Ascommycetes.

As suggested by Prescott and Grayston (2013) comparisons at multiple times during the year with periodical samplings and combination of isolation methods, would assist in developing a more complete image of the fungal communities and their successions associated with the different tree species litters. Since fungal community can in turn affect the decomposition rate, an understanding of these underlying mechanisms may improve our knowledge on anthropogenic influences on ecosystem functioning.

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Appendix 1. Relative abundance of microfungi isolated from decomposing leaf litter of *A. nepalensis* by dilution plate method.

Fungi	Months											
	Jun	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**
Aspergillus candidus Link	12.4	2.8	8.0	5.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
A. niger Tiegh.	16.0	6.1	10.8	4.7	0.0	9.4	0.0	0.0	0.0	0.0	0.0	0.0
Aureobasidium pullulans (De Bary) G. Arnaud ex Cif., Ribaldi and Corte	0.0	0.0	0.0	0.0	9.9	5.2	6.2	0.0	0.0	0.0	0.0	0.0
Cephalosporium coremioides Raillo	0.0	0.0	0.0	3.7	4.0	3.1	5.3	6.5	0.0	0.0	0.0	0.0
C. eichhorniae Padwick	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.6	9.0	5.8	6.1	0.0
Chaetomium globosum Kunze ex Fr.	6.3	0.0	5.9	4.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cladosporium cladosporioides (Fresen.) G. A. de Vries	0.0	12.9	6.3	9.1	7.9	9.3	11.3	13.0	16.1	10.6	0.0	13.9
C. herbarum (Pers.) Link	0.0	0.0	0.0	0.0	0.0	0.0	4.1	0.0	5.8	0.0	0.0	0.0
Cylindrocladium parvum P. J. Anderson	10.1	0.0	0.0	6.5	8.1	0.0	0.0	9.8	0.0	11.8	12.2	9.5
Epicoccum purpurascens Ehrenb.	10.1	7.0	0.0	2.1	0.0	9.3	4.1	0.0	9.0	5.8	0.0	3.5
Fusarium oxysporum Schltdl.	0.0	11.6	10.1	9.1	0.0	0.0	0.0	0.0	13.8	11.7	0.0	10.4
Gliocladium virens J.H. Mill., Giddens and A.A. Foster	0.0	0.0	3.2	4.0	5.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mucor hiemalis Wehmer	0.0	0.0	0.0	5.1	7.2	8.3	9.3	0.0	0.0	0.0	0.0	0.0
Paecilomyces javanicus (Friedrichs and Bally) A.H.S. Br. and G. Sm.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.7	2.2	0.0	0.0	0.0

P. variotii Bainier	10.1	0.0	0.0	4.4	6.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P. aurantiogriseum Dierckx	0.0	0.0	0.0	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P. decumbens Thom	5.2	15.1	4.1	0.0	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P. diversum Raper and Fennell	4.7	2.0	4.7	2.0	4.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P. expansum link	11.3	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P. fellutanum Biourge	0.0	0.0	0.0	3.6	4.1	4.1	4.3	5.4	0.0	0.0	0.0	0.0
P. herquei Bainier and Sartory	0.0	0.0	0.0	1.8	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P. nalgiovense Laxa	0.0	4.1	4.7	0.0	0.0	4.1	0.0	7.7	0.0	0.0	12.1	10.2
P. purpurogenum Stoll	6.4	0.0	6.9	7.0	0.0	0.0	9.3	0.0	8.0	0.0	9.6	0.0
P. scleroteorum J.F.H. Beyma	0.0	0.0	0.0	0.0	4.2	2.1	8.1	0.0	0.0	0.0	0.0	0.0
P. vermiculatum P.A. Dang.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.7	9.0	9.6	10.9	9.3
Periconia minutissima Corda	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.4	4.9	2.5
Pestalotiopsis sp.	0.0	6.2	10.1	7.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.2
Pithomyces maydicus (Sacc.) M.B Ellis	7.7	3.3	5.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Purpureocillium lilacinum (Thom) Luangsa-ard, Houbraken, Hywel- and Samson	0.0	0.0	0.0	5.4	6.1	7.2	8.2	8.6	0.0	0.0	0.0	0.0 Jones
Pythium rostratum E.J. Butler	0.0	0.0	0.0	0.0	0.0	0.0	8.3	0.0	0.0	0.0	0.0	0.0
Scytalidium thermophilum (Cooney and R. Emers.) Austwick	0.0	12.3	2.9	4.0	4.2	0.0	0.0	2.1	0.0	4.8	3.6	4.7

Stachybotrys parvispora S. Hughes	0.0	0.0	0.0	0.0	3.1	3.3	0.0	0.0	0.0	0.0	0.0	0.0
Trichoderma koningii Oudem.	4.9	0.0	7.7	0.0	11.8	13.8	11.3	0.0	13.7	8.1	9.6	4.0
T. longibrachiatum Rifai	0.0	6.4	4.9	8.5	0.0	0.0	0.0	0.0	0.0	9.4	10.7	11.8
T. viride Pers.	10.1	9.3	4.2	3.3	0.0	9.5	0.0	14.0	0.0	8.3	10.9	14.1
Zygorhynchus vuilleminii Namysl.	0.0	0.0	0.0	0.0	0.0	7.4	5.1	7.5	6.7	0.0	0.0	0.0
White sterile mycelia	0.0	0.0	0.0	0.0	0.0	4.1	0.0	0.0	8.9	10.5	7.3	9.6
Total number of fungal species	**12**	**14**	**16**	**21**	**17**	**15**	**13**	**12**	**11**	**12**	**11**	**12**

Appendix 2. Relative abundance of microfungi isolated by dilution plate method from decaying leaf litter of *C. hystrix*.

	Months														
Fungi	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**
Alternaria alternata (Fr.) Keissl.	0.0	0.0	0.0	8.4	3.7	5.9	6.9	0.0	0.0	0.0	0.0	0.0	11.6	0.0	10.0
A. tenuissima (Nees) Wiltshire	9.4	9.1	3.2	3.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Arthrinium sp.	0.0	0.0	6.1	4.6	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aspergillus candidus Link	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0	8.2	12.4	9.0
A. niger Tiegh.	16.4	10.9	12.7	0.0	0.0	0.0	0.0	9.4	0.0	0.0	10.7	12.0	10.1	0.0	0.0
Aureobasidium pullulans (De Bary) G. Arnaud ex Cif., Ribaldi and Corte	0.0	0.0	0.0	0.0	0.0	0.0	6.6	6.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chaetomium dolichotrichum L.M. Ames	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.4	2.2	4.2	3.0

Cladosporium cladosporioides (Fresen.) G.A. de Vries	8.1	13.9	19.4	6.0	15.3	0.0	15.4	12.9	13.5	13.0	9.7	0.0	0.0	0.0	0.0
Cunninghamella echinulata (Thaxt.) Thaxt. ex Blakeslee	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.8	0.0	7.7	9.1	6.5	5.8	-
Curvularia lunata (Wakker) Boedijin	8.2	3.5	4.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C. pallescens Boedijn	8.2	8.8	0.0	3.5	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cylindrocladium parvum P. J. Anderson	14.2	0.0	0.0	0.0	11.3	0.0	0.0	13.8	0.0	0.0	10.9	0.0	6.5	12.7	7.0
Dematophora necatrix R. Hartig	0.0	0.0	0.0	8.1	5.5	10.1	10.7	0.0	0.0	4.6	0.0	0.0	0.0	0.0	0.0
Fusarium oxysporum Schltdl.	0.0	0.0	11.9	7.7	9.3	13.1	0.0	10.9	10.1	0.0	0.0	0.0	12.7	0.0	4.0
Gliocladium penicillioides Corda	0.0	0.0	0.0	5.8	0.0	4.0	10.7	0.0	0.0	4.7	0.0	0.0	0.0	0.0	0.0
G. virens J.H. Mill., Giddens and A.A. Foster	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.1	10.0	11.4	6.0
Grallomyces portoricensis F. Stevens	0.0	0.0	0.0	0.0	0.0	0.0	7.5	0.0	5.8	7.1	5.2	0.0	0.0	0.0	0.0
Mucor hiemalis Wehmer	0.0	0.0	4.1	11.1	3.7	9.9	0.0	0.0	0.0	0.0	0.0	8.4	3.8	6.1	9.3
Nigrospora sphaerica (Sacc.) E.W. Mason	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.1	7.8	8.0	6.1	13.7
Paecilomyces farinosus (Holmsk.) A.H.S. Br. and G. Sm.	0.0	0.0	0.0	0.0	0.0	5.6	6.2	0.0	9.2	6.0	0.0	0.0	0.0	0.0	0.0
P. variotii Bainier	3.3	0.0	0.0	0.0	0.0	0.0	0.0	5.7	0.0	5.8	10.9	6.7	0.0	4.6	9.7
Penicillium citrinum Thom	5.1	4.5	2.1	0.0	0.0	0.0	8.6	7.7	0.0	6.0	0.0	0.0	0.0	0.0	0.0

P. ehrlichii Kleb.	0.0	0.0	0.0	6.8	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P. italicum Wehmer	3.7	4.6	0.0	5.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P. purpurogenum Stoll	0.0	0.0	0.0	5.1	3.8	6.2	0.0	6.7	8.0	9.3	0.0	0.0	0.0	0.0	0.0
P. simplicissimum (Oudem.) Thom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.9	0.0	6.5	0.0	0.0
P. spinulosum Thom	1.2	6.4	7.1	4.1	0.0	7.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P. vermiculatum P.A. Dang.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9	5.7	7.5	0.0	0.0	0.0	0.0
Pestalotiopsis sp.	0.0	15.0	5.0	0.0	5.5	13.8	0.0	6.7	0.0	8.1	0.0	6.4	0.0	0.0	4.0
Purpureocillium lilacinum (Thom) Luangsa-ard Houbraken, Hywel-Jones and Samson	0.0	4.0	6.1	3.5	5.8	0.0	0.0	0.0	10.6	9.6	3.5	0.0	0.0	0.0	8.0
Rhizopus sp.	0.0	0.0	0.0	0.0	0.0	3.7	6.9	7.7	7.1	0.0	0.0	0.0	0.0	0.0	0.0
Trichoderma koningii Oudem.	0.0	0.0	0.0	0.0	0.0	9.9	0.0	0.0	0.0	9.6	9.9	9.9	10.0	12.1	7.7
T. viride Pers	15.1	4.7	10.2	0.0	7.5	0.0	15.9	6.2	12.0	0.0	0.0	0.0	0.0	10.2	0.0
Trichothecium roseum (Pers.) Link	6.9	9.1	4.1	0.0	5.5	0.0	4.5	5.2	0.0	10.6	0.0	0.0	0.0	0.0	0.0
Verticillium terrestre (Pers.) Sacc.	0.0	4.2	4.1	13.2	3.8	9.8	0.0	0.0	7.6	0.0	5.8	5.7	0.0	0.0	0.0
White sterile mycelia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	8.3	0.0	10.4	16.4	7.7
Total number of fungal species	**12**	**13**	**14**	**17**	**15**	**13**	**11**	**12**	**12**	**13**	**13**	**11**	**12**	**11**	**13**

Appendix 3. Per cent frequency (%) of microfungi isolated from decaying leaves of *A. nepalensis* by washed disk method.

	Months											
Fungi	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**
Absidia repens Tiegh.	0.0	0.0	0.0	0.0	0.0	16.0	16.0	28.0	16.0	0.0	0.0	0.0
Alternaria alternata (Fr.) Keissl.	0.0	16.0	16.0	12.0	8.0	0.0	16.0	20.0	8.0	12.0	0.0	0.0
Aspergillus flavus Link	20.0	12.0	16.0	8.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
A. niger Tiegh.	24.0	0.0	12.0	12.0	16.0	24.0	20.0	0.0	0.0	0.0	0.0	0.0
Aureobasidium pullulans (De Bary) G. Arnaud ex Cif., Ribaldi and Corte	0.0	0.0	0.0	0.0	0.0	8.0	16.0	8.0	12.0	0.0	0.0	0.0
Chaetomium globosum Kunze ex Fr.	8.0	4.0	8.0	12.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C. spirale Zopf	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	12.0	8.0
Chrysosporium keratinophilum D. . Frey ex. J.W. Carmich	0.0	0.0	20.0	12.0	0.0	8.0	12.0	44.0	24.0	16.0	16.0	0.0
Cladosporium cladosporioides (Fresen.) G.A. de Vries	0.0	0.0	32.0	36.0	0.0	36.0	24.0	8.0	40.0	0.0	0.0	40.0
Cylindrocladium parvum P.J. Anderson	28.0	12.0	20.0	24.0	0.0	0.0	0.0	0.0	0.0	20.0	44.0	44.0
Epicoccum purpurascens Ehrenb.	0.0	28.0	0.0	0.0	24.0	16.0	28.0	0.0	28.0	20.0	20.0	24.0
Fusarium oxysporum Schltdl.	0.0	12.0	0.0	16.0	0.0	12.0	32.0	0.0	0.0	32.0	44.0	40.0
Gliocladium penicillioides Corda	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.0	20.0	24.0	8.0
G. virens J.H. Mill., Giddens and	0.0	16.0	16.0	4.0	8.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

A.A. Foster)												
M. genevensis Lendn.	8.0	4.0	0.0	8.0	8.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mucor hiemalis Wehmer	0.0	0.0	0.0	0.0	8.0	24.0	16.0	24.0	0.0	0.0	0.0	0.0
Nigrospora sphaerica (Sacc.) E. W. Mason	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.0	8.0	8.0	12.0	12.0
Paecilomyces variotii Bainier	0.0	8.0	12.0	0.0	8.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Penicillium citrinum Thom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.0	8.0	0.0	4.0	4.0
Pestalotiopsis sp.	16.0	-	20.0	20.0	36.0	32.0	0.0	0.0	0.0	0.0	0.0	0.0
Pithomyces chartarum (Berk and M.A. Curtis) M.B. Ellis	12.0	4.0	12.0	8.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P. maydicus (Sacc.) M.B. Ellis	4.0	16.0	8.0	0.0	12.0	8.0	0.0	0.0	0.0	0.0	0.0	0.0
Purpureocillium lilacinum (Thom) Luangsa-ard, Houbraken, Hywel-Jones and Samson	0.0	0.0	0.0	32.0	60.0	24.0	32.0	0.0	0.0	0.0	0.0	0.0
T. harzianum Rifai	16.0	0.0	16.0	0.0	12.0	12.0	28.0	0.0	0.0	28.0	28.0	0.0
Trichoderma koningii Oudem.	12.0	0.0	0.0	24.0	12.0	0.0	0.0	28.0	36.0	24.0	44.0	8.0
T. viride Pers.	12.0	12.0	0.0	24.0	24.0	28.0	32.0	24.0	0.0	0.0	0.0	0.0
Verticillium terrestre (Pers.) Sacc.	0.0	0.0	4.0	8.0	8.0	12.0	0.0	0.0	8.0	24.0	20.0	16.0
Zygorhynchus vuilleminii Namysl.	0.0	0.0	0.0	0.0	16.0	0.0	16.0	12.0	20.0	0.0	0.0	0.0
White sterile mycelia	0.0	0.0	0.0	8.0	0.0	0.0	0.0	16.0	16.0	12.0	20.0	36.0
Total number of fungal species	**11**	**12**	**14**	**18**	**15**	**14**	**13**	**12**	**13**	**12**	**12**	**12**

Appendix 4. Frequency (%) of fungal species isolated from decaying leaf litter of *C. hystrix* by washed disk method.

Fungi	Months														
	Jun	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**
Aspergillus candidus Link	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	28.0	12.0	8.0	0.0
Cladosporium cladosporioides (Fresen.) G.A. de Vries	28.0	24.0	0.0	28.0	40.0	20.0	24.0	20.0	24.0	0.0	0.0	0.0	0.0	16.0	24.0
Cunninghamella echinulata (Thaxt.) Thaxt. ex Blakeslee	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24.0	32.0	12.0	8.0	12.0
C. elegans Lendn.	0.0	0.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cylindrocladium parvum P.J. Anderson	0.0	4.0	0.0	16.0	0.0	28.0	0.0	20.0	0.0	0.0	0.0	0.0	32.0	28.0	20.0
Fusarium oxysporum Schltdl.	0.0	0.0	16.0	32.0	0.0	0.0	24.0	0.0	28.0	32.0	48.0	44.0	24.0	0.0	0.0
Gliocladium virens J.H. Mill., Giddens and A.A. Foster	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.0	8.0	12.0	0.0	16.0	8.0
Monodictys sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0	8.0	12.0	16.0	0.0	0.0
Morteirella renispora Dixon-Stew.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.0	8.0	8.0	0.0	8.0	12.0
Mucor genevensis Lendn.	4.0	0.0	0.0	20.0	12.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M hiemalis Wehmer	0.0	0.0	0.0	0.0	0.0	0.0	8.0	12.0	20.0	0.0	16.0	20.0	12.0	16.0	0.0
Paecilomyces variotii Bainier	0.0	0.0	8.0	8.0	4.0	0.0	8.0	8.0	4.0	12.0	0.0	0.0	0.0	0.0	0.0
Penicillium citrinum Thom	8.0	4.0	4.0	8.0	8.0	8.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P. diversum Raper and Fennell	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.0	4.0	12.0	8.0	0.0	8.0

P. herquei Bainier and Santory	0.0	0.0	0.0	0.0	4.0	12.0	4.0	0.0	8.0	4.0	0.0	0.0	0.0	0.0	0.0
P. italicum Wehmer	4.0	0.0	16.0	8.0	12.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P. javanicum J.F.H. Beyma	4.0	4.0	0.0	4.0	0.0	8.0	4.0	4.0	4.0	0.0	0.0	0.0	0.0	4.0	8.0
P. rubrum Stoll	4.0	0.0	0.0	8	0.0	12.0	4.0	4.0	0.0	8.0	8.0	0.0	12.0	0.0	0.0
P. rugulosum Thom	8.0	4.0	0.0	16.0	8.0	0.0	0.0	8.0	16.0	0.0	0.0	0.0	24.0	12.0	12.0
Pestalotiopsis sp	36.0	40.0	16.0	0.0	48.0	28.0	20.0	0.0	32.0	36.0	32.0	0.0	0.0	0.0	0.0
Purpureocillium lilacinum (Thom) Luangsa-ard, Houbraken, Hywel- and Samsom	8.0	20.0	36.0	24.0	16.0	0.0	8.0	0.0	0.0	24.0	20.0	32.0	0.0	0.0	20.0 Jones
Trichoderma harzianum Rifai	0.0	0.0	0.0	36.0	16.0	32.0	24.0	0.0	0.0	12.0	0.0	0.0	0.0	0.0	0.0
T. koningii Oedem.	12.0	0.0	0.0	4.0	0.0	28.0	32.0	32.0	20.0	0.0	16.0	20.0	0.0	32.0	16.0
T. viride Pers.	0.0	12.0	52.0	16.0	24.0	0.0	24.0	20.0	0.0	0.0	8.0	0.0	0.0	0.0	12.0
Trichothecium roseum (Pers.) Link	0.0	8.0	16.0	8.0	16.0	16.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.0	8.0
Verticillium terrestre (Pers.) Sacc.	0.0	4.0	12.0	8.0	4.0	4.0	8.0	0.0	12.0	8.0	0.0	4.0	0.0	0.0	0.0
White sterile mycelia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24.0	0.0	24.0	8.0	24.0
Total number of species	**10**	**10**	**12**	**16**	**13**	**12**	**12**	**11**	**11**	**13**	**13**	**11**	**12**	**13**	**14**

Appendix 5. Frequency (%) of fungal species isolated from decomposing alder leaf litter by surface sterilization method.

Fungi	Months											
	Jun	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**
Alternaria alternata (Fr.) Keissl.	0.0	20.0	12.0	20.0	16.0	20.0	20.0	12.0	0.0	20.0	0.0	12.0
Aspergillus niger Tiegh.	32.0	0.0	20.0	28.0	32.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
A. wentii Wehmer	0.0	0.0	0.0	8.0	8.0	12.0	16.0	0.0	0.0	0.0	0.0	0.0
Cephalosporium coremioides Raillo	0.0	0.0	0.0	0.0	16.0	20.0	0.0	0.0	28.0	0.0	0.0	0.0
Chaetomium dolichotrichum L.M. Ames	0.0	0.0	4.0	12.0	8.0	12.0	4.0	0.0	0.0	0.0	0.0	0.0
Colletotrichum gloeosporioides (Penz.) Penz. and Sacc.	0.0	16.0	16.0	16.0	0.0	0.0	0.0	16.0	12.0	28.0	20.0	16.0
Cylindrocladium parvum P.J. Anderson	0.0	0.0	0.0	0.0	0.0	0.0	28.0	40.0	32.0	36.0	24.0	24.0
Drechslera australiensis (Bugnic.) Subram. B.L. Jain	16.0	8.0	4.0	8.0	0.0	8.0	0.0	12.0	0.0	8.0	16.0	8.0
Fusarium oxysporum Schltdl.	20.0	8.0	0.0	8.0	0.0	0.0	28.0	36.0	28.0	24.0	44.0	20.0
Gliocladium penicillioides Corda	0.0	0.0	0.0	0.0	0.0	0.0	12.0	-	16.0	16.0	12.0	8.0
Hansfordia biophila (Cif.) M. B. Ellis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.0	16.0	0.0	8.0	8.0
Nigrospora sphaerica (Sacc.) E.W. Mason	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.0	20.0	0.0	16.0	8.0
Oedocephalum lineatum B.K. Bakshi	0.0	0.0	16.0	20.0	16.0	24.0	8.0	0.0	0.0	0.0	0.0	0.0

Paecilomyces variotii Bainier	8.0	8.0	4.0	8.0	16.0	8.0	0.0	0.0	0.0	0.0	0.0	0.0
Penicillium duclauxi Delacroix	0.0	0.0	0.0	8.0	0.0	8.0	0.0	0.0	0.0	0.0	0.0	0.0
P. levitum Raper and Fennell	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.0	8.0	4.0	8.0
P. scleroteorum J.F.H. Beyma	0.0	0.0	0.0	4.0	12.0	8.0	4.0	0.0	0.0	0.0	0.0	0.0
P. thomii Maire	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.0	8.0	4.0	8.0
Phoma minutispora P.N. Mathur	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0	12.0	8.0	4.0	0.0
Pythium intermedium de Bary	4.0	0.0	8.0	12.0	16.0	12.0	0.0	0.0	0.0	0.0	8.0	12.0
Scytalidium thermophilum (Cooney and R. Emers.) Austwick	0.0	24.0	24.0	24.0	36.0	0.0	20.0	0.0	0.0	0.0	0.0	0.0
T. longibrachiatum Rifai	0.0	24.0	12.0	24.0	24.0	28.0	20.0	24.0	0.0	0.0	0.0	0.0
Trichoderma viride Pers.	24.0	24.0	20.0	20.0	28.0	0.0	0.0	0.0	0.0	12.0	0.0	0.0
Tripospermum myrti (Lind) S. Hughes	8.0	0.0	4.0	8.0	16.0	8.0	0.0	8.0	0.0	4.0	0.0	0.0
Verticillium effusum G.H. Otth	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0	16.0	12.0	8.0	0.0
V. terrestre (Pers.) Sacc.	8.0	12.0	0.0	12.0	12.0	16.0	8.0	0.0	0.0	0.0	0.0	0.0
White sterile mycelia	0.0	0.0	0.0	0.0	4.0	0.0	8.0	4.0	12.0	24.0	0.0	8.0
Total number of fungal species	**9**	**9**	**12**	**17**	**15**	**13**	**11**	**12**	**12**	**13**	**13**	**13**

Appendix 6. Frequency (%) of microfungi isolated from decomposing leaves of *C. hystrix* by surface sterilization method.

Fungi	Months														
	Jun	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**
Alternaria alternata (Fr.) Keissl.	8.0	20.0	12.0	0.0	0.0	8.0	0.0	0.0	0.0	0.0	12.0	16.0	20.0	8.0	12.0
Aspergillus candidus Link	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.0	20.0	0.0	12.0	20.0	12.0	0.0
A. flavipes (Bainier and Sartory) Thom and Church	0.0	16.0	12.0	8.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aspergillus niger Tiegh.	24.0	0.0	0.0	20.0	16.0	28.0	16.0	0.0	0.0	0.0	16.0	24.0	8.0	12.0	12.0
Chaetomium dolichotrichum L.M. Ames	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.0	12.0	12.0	4.0	0.0	8.0
C. spirale Zopf	0.0	0.0	24.0	16.0	24.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Colletotrichum gloeosporioides (Penz.) Penz. and Sacc.	12.0	16.0	0.0	0.0	0.0	12.0	12.0	12.0	0.0	0.0	8.0	0.0	16.0	16.0	24.0
Curvularia lunata (Wakker) Boedijin	0.0	0.0	24.0	20.0	16.0	28.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cylindrocladium parvum P.J. Anderson	0.0	28.0	24.0	0.0	0.0	0.0	0.0	20.0	32.0	0.0	20.0	16.0	16.0	28.0	20.0
Fusarium oxysporum Schltdl.	24.0	40.0	0.0	24.0	0.0	44.0	0.0	0.0	32.0	32.0	40.0	24.0	24.0	28.0	16.0
Mucor genevensis Lendn.	4.0	16.0	12.0	20.0	16.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nigrospora sphaerica (Saccardo) E.W. Mason	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0	12.0	0.0	4.0	12.0	8.0
Nodulisporium gregarium (Berk and	8.0	0.0	24.0	20.0	0.0	0.0	0.0	20.0	12.0	20.0	20.0	20.0	16.0	16.0	0.0

M.A. Curtis.) J.A. Mey.															
Paecilomyces variotii Bainier	8.0	8.0	16.0	8.0	8.0	8.0	12.0	12.0	0.0	0.0	12.0	12.0	0.0	0.0	0.0
Penicillium decumbens Thom	0.0	0.0	0.0	0.0	0.0	4.0	4.0	12.0	8.0	12.0	0.0	0.0	0.0	0.0	0.0
P. italicum Wehmer	8.0	16.0	20.0	12.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P. levitum Raper and Fennell	0.0	0.0	8.0	8.0	12.0	12.0	0.0	8.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P. purpurogenum Stoll	0.0	0.0	0.0	0.0	32.0	0.0	20.0	20.0	16.0	20.0	0.0	0.0	24.0	0.0	20.0
P. vermiculatum P.A. Dang.	0.0	0.0	0.0	4.0	8.0	12.0	0.0	8.0	8.0	0.0	0.0	0.0	0.0	0.0	0.0
Periconia minutissima Corda	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0	0.0	16.0	8.0	8.0	4.0
Pestalotiopsis sp.	24.0	0.0	36.0	32.0	36.0	48.0	40.0	36.0	24.0	0.0	0.0	0.0	0.0	16.0	8.0
Phomopsis sp.	0.0	8.0	12.0	12.0	8.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Trichoderma koningii Oudem.	0.0	24.0	20.0	28.0	28.0	0.0	44.0	0.0	20.0	28.0	20	0.0	16.0	24.0	12.0
T. longibrachiatum Rifai	12.0	0.0	0.0	20.0	24.0	32.0	36.0	32.0	20.0	20.0	0.0	32.0	0.0	0.0	0.0
Verticillium terrestre (Pers.) Sacc.	8.0	8.0	0.0	16.0	8.0	0.0	0.0	12.0	0.0	8.0	12.0	12.0	0.0	0.0	8.0
White sterile mycelia	0.0	0.0	0.0	0.0	0.0	0.0	8.0	0.0	0.0	20.0	0.0	16.0	12.0	0.0	20.0
Total number of fungal species	**11**	**12**	**14**	**16**	**13**	**11**	**10**	**11**	**11**	**12**	**11**	**12**	**12**	**11**	**13**

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Variations in soil physico-chemical properties of different traditional homegardens of Mizoram, Northeast India

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Abstract

Physico-chemical properties of soil was studied at two depths (0-15 and 15-30 cm) across three differently sized homegardens (large (> 0.5 ha), medium (0.2 – 0.5 ha) and small (<0.2 ha) located in Mizoram, North-East India. Seventy five homegardens was sampled for the purpose. Soil moisture content and water holding capacity showed higher values in the large homegarden compared to the small and medium ones while soil pH was lower in the former than the latter. The results were presumably related to dense floor litter layer, greater accumulation of organic matter at the top soil (0-15 cm) and greater species richness/ density in large garden than the small and medium ones. Total organic carbon, total keldahl nitrogen and ammonium-N, nitrate-N and available-P varied significantly within the homegardens (P>0.01) and registered lower values in the small garden and they increased with the increase in garden size. A clear relationship was notice between the soil nutrients and garden size in most cases.

Keywords Water holding capacity, total organic carbon, total nitrogen, garden size

Introduction

Homegardens are one of the oldest forms of landuse activities, most predominantly exists in the humid tropics. These homegardens are considered to be ecologically sustainable (Torquebiau 1992**,** Jose and Shanmugaratnam 1993, Kehlenbeck and Maass 2004) probably because

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of their near-nature characteristics – higher species diversity, multi-strata canopy and a closed nutrient cycling. Variation in size, species composition and management objectives have been frequently reported (Fernandes and Nair 1986, Christanty 1990, Das and Das 2010)

In Mizoram, North-East India homegarden is the major land use system next to shifting agriculture. Apart from supplementing food production through shifting cultivation, homegardens supply additional daily needs of the farmers such as fibres, spices and condiments, timber for agricultural tools, medicines, fodder, fuelwood etc. Also traditional homegardens are equally important for their potential role in soil protection and water conservation in the highly fragile hill ecosystems of the region. These homegardens in the state vary in their sizes influencing the species density and composition **(**Sahoo 2009). It is expected that with different sizes, density and compositional pattern the edaphic characteristics in the homegardens also vary and may demand different management interventions for improving the overall sustainability of these important land use systems. However these traditional gardens in the state have received little scientific attention. In this paper we report our preliminary findings about the status of soil physico-chemical properties along a size gradient in the homegardens of five district of Mizoram, India.

Materials and Methods

Study site

The study was conducted in five districts viz., Aizawl, Kolasib, Serchip, Champhai and Mamit, previously under undivided Aizawl district of Mizoram, Northeast India. From each district, three villages were selected randomly where homegardens prevailing in each village were divided into three categories based on their size (area of coverage) – large (> 0.5 ha), medium (0.2 – 0.5 ha) and small (<0.2 ha). Again from each selected village 5 homegardens belonging to each size category were selected as the ultimate unit of the study. Homogeneity in slope and aspect were given due consideration while selection of the homegardens in order to minimize the variability due to these local factors on soil properties. Details of the physiographic and climatic features of the study sites have been represented in Table 1.

Collection of soil samples and analyses

Five cores (6.5 cm inner dia) from 0-15 cm and 15-30 cm depth were collected from each selected homegarden in the month of March. All the soils collected were pooled garden-wise and depth-wise and sieved

Table 1. Physiographic and climatic features of study sites

Parameters	Aizawl	Kolasib	Serchip	Champhai	Mamit
Latitude (Range)	23º41´33.5"- 23º48´44.2"N	24º07´45.9"- 24º30´03.4" N	23 º 13´43.3"- 23º 23´12.5"N	23º26´18.9" - 23º30´00.0" N	23º48´59.4" 23º54´37.8" N
Longitude (Range)	92º39´06.0"- 92º52´22.6"E	92º34´35.2"- 92º45´44.5" E	92º 50´39.1"- 92º54´44.7"E	93º19´19.7"- 93º21´38.8" E	92º24´52.5- 92º29´37.2" E
Altitude (m; asl) (Range)	115 – 1163	307 - 710	695 - 1013	1481 - 1638	60-940
Mean Annual temp. (ºC)	27.21	25.73	22.83	18.62	32.5
Average annual rainfall (mm)	3103	2618	2502	2028	2913
Relative humidity(%)	69.81	76.15	71.17	66.75	58.88

through 2mm mesh screen. The soil moisture content (SMC), pH, ammonium-N and nitrate-N were determined within 36 hours of sampling following standard procedures **(**Anderson and Ingram 1993). Rest of the soil samples were air-dried and analyzed for total kjeldahl nitrogen (TKN) using Kel Plus (Pelican model), while available phosphorous and soil organic carbon (SOC) was estimated by molybdenum blue method and rapid titration method respectively **(**Allen et al. 1974). Water holding capacity (WHC) was determined using Keen's box and the SOC values were multiplied by a constant (1.724) to obtain the soil organic matter (SOM) values **(**Allen et al. 1974). Soil texture was determined by Boucous hydrometer method **(**Anderson and Ingram 1993).

Results and discussion

The physical properties of soil such as water holding capacity and moisture content differed significantly (P>0.001) between the gardens (Table 2). Greater soil moisture content (SMC) and water holding capacity (WHC) was recorded in the larger homegarden as compared to the smaller and medium one, this might be due to dense litter layer on the floor of the larger homegarden and also greater accumulation of organic matter, obviously related to the greater species richness/ density in the same garden. WHC of soil as influenced by organic matter accumulation is considered one of the important indicators of sustainability. The relation between species diversity in homegardens and their ecological sustainability have also been discussed by various workers (Soemarwoto 1987, Torquebiau 1992, Kumar and Nair 2004). WHC in the sites declined with increasing depth registering greater value in the surface (0-15 cm) soil layer in all the homegardens. SMC was also greater in the upper soil layer in all the home gardens. Abebe et al. (2006) opined that animal wastes along with the other contributors also play an important ecological role by providing manure for the improvement of soil fertility and crop productivity in the homegarden system. Higher values of the major soil physical properties in the top (0-15 cm) layer in the present study sites might also be ascribed to the greater accumulation of litter and other domestic waste on the floor of the traditional home gardens as use of animal wastes such as pig dung and poultry excreta is also a common practice. Soil texture in the sites was relatively consistent throughout the profile, which was typified by sandy loam to loamy sand. However, there was a variation in the sand, silt and clay content across the profile increasing from surface soil layer to subsurface soil layer (Table 2). These differences among the homegardens are likely due to combination of factors like microclimate, topography and plant species composition as observed by various authors (Zinke 1962**,**

Table 2 Soil physico-chemical properties of the homegardens of different districts. Values are ± 1SE.

	HOME GARDENS					
	Large		**Medium**		**Small**	
Soil depth (cm)	0-15	15-30	0-15	15-30	0-15	15-30
Parameters	***AIZAWL DISTRICT***					
Moisture						
content (%)	29.60±.61	27.37±.0.23	27.83±.0.29	26.03±.0.08	23.03±.0.37	22.77±.0.20
WHC (%)	54.75±3.67	51.21±4.03	51.23±0.63	47.90±1.71	50.4±2.21	47.67±1.78
Soil texture						
Sand (%)	54.39±2.18	50.89±4.07	57.55±1.89	53.37±1.59	68.18±1.46	63.08±1.86
Silt (%)	31.71±1.07	30.75±1.59	27.85±1.13	31.66±0.99	20.25±0.75	19.16±1.13
Clay (%)	13.89±1.81	18.36±1.635	14.60±3.22	14.95±0.60	11.56±1.06	17.75±0.84
Textural class	Sandy loam	Loamy sand	Sandy loam	Loamy sand	Sandy loam	Sandy loam
pH	5.72±0.14	5.14±0.07	5.54±0.26	5.26±0.14	5.27±0.07	5.33±0.12
SOC (%)	2.44±0.09	1.82±0.07	2.97±0.06	2.61±0.09	2.66±0.12	2.57±0.08
SOM (%)	4.19±0.15	3.14±0.13	5.12±0.09	4.49±0.15	4.59±0.21	4.44±0.14
TKN (%)	0.63±0.04	0.51±0.02	0.54±0.05	0.48±0.003	0.49±0.04	0.47±0.05
C/N ratio	3.88±0.16	3.55±0.01	5.03±0.48	5.32±0.17	6.15±0.56	5.66±0.35

NO_3-N (µg g^{-1})	8.42±0.06	6.78±0.24	7.65±0.24	6.52±0.34	6.32±0.32	5.06±0.13
NH_4-N (µg g^{-1})	7.21±0.32	5.90±0.31	6.85±0.12	5.33±0.24	4.51±0.52	3.92±0.11
PO_4-P (µg g^{-1})	12.09±0.81	9.28±0.66	8.23±0.3	7.36±0.44	4.55±0.29	3.44±0.3
			KOLASIB DISTRICT			
Moisture						
content (%)	27.9±0.15	23.17±0.78	25.93±0.91	23.86±2.94	21.96±1.93	18.93±0.53
WHC (%)	64.48±2.03	57.03±2.29	61.44±2.95	57.63±1.1	56.97±1.42	55.86±3.67
Soil texture						
Sand (%)	55.24±3.12	53.84±3.01	58.32±2.54	58.13±4.19	64.43±3.98	63.19±3.77
Silt (%)	33.84±2.87	34.09±2.84	28.86±1.29	28.17±1.48	27.69±3.07	28.37±2.65
Clay (%)	10.92±0.91	11.97±1.281	12.82±1.48	13.69±2.45	7.90±0.94	8.43±1.15
Textural class	Loamy sand	Loamy sand	Sandy loam	Sandy loam	Sandy loam	Sandy loam
pH	5.03±0.05	4.78±0.008	5.15±0.02	5.12±0.02	4.77±0.02	4.95±0.02
SOC (%)	2.09±0.15	1.07±0.11	1.81±0.08	1.25±0.02	1.26±0.1	1.01±0.04
SOM (%)	3.6±0.27	1.84±0.19	3.12±0.14	2.15±0.04	2.18±0.18	1.74±0.08
TKN (%)	0.58±0.06	0.43±0.03	0.40±0.02	0.33±0.02	0.23±0.02	0.16±0.01
C/N ratio	3.68±0.56	2.60±0.54	4.24±0.44	3.72±0.30	6.84±0.43	6.30±1.04
NO_3-N (µg g^{-1})	8.64±0.26	6.17±0.88	6.22±0.49	5.60±0.05	3.36±0.23	2.76±0.10
NH_4-N (µg g^{-1})	5.74±0.23	5.18±0.41	3.39±0.30	2.58±0.12	3.31±0.12	2.45±0.09
PO_{-4}-P (µg g^{-1})	7.05±1.53	4.95±0.08	5.71±0.33	5.11±0.22	3.61±0.58	2.23±0.69

			SERCHIP DISTRICT			
Moisture						
content (%)	30.21±0.61	28.36±0.21	29.5±1.41	28.3±0.68	27.78±0.38	26.57±0.57
WHC (%)	57.52±1.24	52.87±2.29	51.63±2.05	49.15±0.78	49.06±0.88	45.11±1.87
Soil texture						
Sand (%)	51.58±0.85	60.24±3.56	55.65±3.43	56.58±3.31	67.09±2.87	59.05±1.41
Silt (%) 37.79±0.23	26.25±2.35	31.68±2.06	34.48±2.19	25.86±2.22	30.97±1.35	
Clay (%)	10.62±1.06	13.5±1.91	12.67±1.38	8.94±1.11	7.04±0.67	9.98±0.41
Textural class	Loamy sand	Sandy loam	Sandy loam	Loamy sand	Sandy loam	Loamy sand
pH 5.55±0.16	5.70±0.02	5.48±0.09	5.25±0.12	5.88±0.05	5.94±0.04	
SOC (%)	2.17±0.09	2.01±0.09	2.11±0.07	1.93±0.06	1.36±0.15	1.12±0.03
SOM (%)	3.74±0.16	3.46±0.16	3.67±0.12	3.33±0.11	2.35±0.25	1.93±0.05
TKN (%)	0.39±0.04	0.26±0.03	0.29±0.03	0.21±0.02	0.21±0.01	0.18±0.01
C/N ratio	7.59±0.51	7.48±0.62	7.20±0.67	9.09±0.81	6.42±0.67	6.13±0.13
NO_{-3}-N (µg g^{-1})	9.58±0.59	8.99±0.17	7.49±0.62	7.23±0.41	5.93±0.37	5.31±0.36
NH_{+4}-N (µg g^{-1})	7.44±0.34	5.96±0.06	6.71±0.61	5.54±0.46	4.74±0.30	3.85±0.31
PO_4-P (µg g^{-1})	10.72±0.62	9.39±0.31	7.49±0.66	6.49±0.17	4.79±0.61	3.97±0.43

CHAMPHAI DISTRICT						
Moisture						
content (%)	26.52±1.06	24.16±1.22	22.19±0.89	20.53±0.55	21.31±1.7	18.81±0.65
WHC (%)	57.39±2.65	55.54±5.7	50.18±0.67	47.29±2.06	44.15±3.23	41.32±1.70
Soil texture						
Sand (%)	57.98±2.57	56.71±1.87	60.85±3.64	60.84±2.45	63.92±3.33	63.43±1.16
Silt (%)	26.06±1.56	31.28±1.49	26.84±2.79	27.49±2.20	26.65±2.00	24.01±1.98
Clay (%)	15.95±2.08	12.01±0.55	12.29±1.56	11.66±0.28	9.42±1.33	12.57±1.53
Textural class	Sandy loam	Loamy sand	Sandy loam	Sandy loam	Sandy loam	Sandy loam
pH	5.96±0.06	5.81±0.09	5.85±0.06	5.53±0.17	5.65±0.17	5.35±0.22
SOC (%)	1.86±0.14	1.50±0.27	1.23±0.06	1.14±0.04	1.22±0.09	1.07±0.04
SOM (%)	3.20±0.24	2.59±0.46	2.11±0.10	1.96±0.08	2.11±0.06	1.85±0.06
TKN (%)	0.27±0.03	0.24±0.02	0.21±0.02	0.18±0.01	0.16±0.01	0.14±0.008
C/N ratio	7.09±0.77	6.18±0.55	5.94±0.48	6.34±0.25	7.81±1.14	7.94±0.78
NO_3-N (µg g^{-1})	7.36±0.97	6.05±0.41	5.95±0.20	5.18±0.03	4.16±0.29	3.01±0.36
NH_4-N (µg g^{-1})	5.81±0.31	4.68±0.34	4.92±0.07	3.81±0.15	3.24±0.21	2.58±0.33
PO_4-P (µg g^{-1})	10.21±0.69	8.87±0.24	8.21±1.23	7.41±0.51	6.17±0.26	5.61±0.47

MAMIT DISTRICT						
Moisture						
content (%)	33.41±0.51	29.54±0.41	30.32±0.89	27.8±0.55	26.82±0.38	23.37±0.71
WHC (%)	61.22±1.76	48.57±1.59	55.32±2.55	43.56±1.21	51.06±0.95	45.21±1.27
Soil texture						
Sand (%)	53.55±0.76	65.24±1.22	52.35±2.33	49.58±1.18	62.29±3.56	59.51±2.41
Silt (%)32.59±0.23	28.15±2.44	35.58±3.16	37.58±2.34	29.57±2.52	32.77±1.65	
Clay (%)	13.86±1.06	6.61±1.91	12.07±1.38	12.84±1.11	8.14±0.67	7.72±0.41
Textural class	Sandy loam	Loamy sand	Sandy loam	Loamy sand	Sandy loam	Loamy sand
pH	5.45±0.16	5.81±0.02	5.68±0.09	5.37±0.12	5.68±0.05	6.04±0.04
SOC (%)	2.37±0.09	2.13±0.09	2.23±0.07	1.79±0.06	1.26±0.15	1.05±0.03
SOM (%)	4.09±0.16	3.67±0.16	3.84±0.12	3.09±0.11	2.17±0.25	1.81±0.05
TKN (%)	0.41±0.04	0.28±0.04	0.37±0.06	0.24±0.03	0.22±0.02	0.20±0.03
C/N ratio	5.78±0.48	7.61±0.57	6.03±0.55	7.46±0.67	5.73±0.27	5.25±0.43
NO_3-N (µg g^{-1})	9.98±0.32	10.25±0.54	8.73±0.35	7.76±0.61	6.24±0.45	5.76±0.22
NH_4-N (µg g^{-1})	8.14±0.24	6.26±0.27	7.41±0.25	6.33±0.22	5.14±0.14	4.78±0.15
PO_4-P (µg g^{-1})	10.81±0.52	8.39±0.31	8.57±0.42	7.51±0.31	6.19±0.61	5.17±0.32

WHC-Water holding capacity, SOC-Soil organic carbon; SOM- Soil organic matter; TKN- Total Kjeldahl nitrogen.

Rhoades 1997, Pinho et al. 2010) who suggested that the choice of tree species that are planted or otherwise managed in the homegarden may have a significant effect on soil, as even individual trees can alter or improve soils in different ways.

Soil pH was acidic (4.77- 5.72) in all the stands with little variation. Slightly low soil pH in the larger homegarden as compared to the other ones could be the result of lower rate of leaching leading to greater accumulation of reaction products in the soil. However, decreasing pH with depth may be because of the fact that organic matter content and nutrient availability also decrease with depth. Organic matter produced in the homegardens may have a buffering effect on soil pH due to several processes, which include the increase in cation exchange capacity (CEC) and the size of the exchange complex from humification of organic matter additions, the formation of complexes with Aluminum ion, and the release of calcium and magnesium in the soil solution, thus reducing the activity of hydrogen ion. Soil organic carbon (SOC), TKN and ammonium-N, nitrate-N and available-P varied significantly within the homegardens ($P>0.01$) and registered lower values in the smaller garden and they increased with the increase in size of the garden. TKN varied appreciably among sites and depth (Table 2). The concentration was higher at surface soil (0-15 cm) layer and declined with increasing depth. TKN was maximum in the large home gardens in all the districts and intermediate in the medium size home gardens with lower values in the small size home gardens. SOC reduced with increasing depth where minimum was recorded in the smaller size home gardens. Soil organic matter is of great importance because of its influence on soil physical, chemical and biological properties and on creating a favorable medium for biological reactions and life support in the soil environment and once the levels decreased; they are generally slow to recover. Organic matter differs across the study sites which might be due to difference in plant species composition and organic matter in the soil surface. For instance, large size garden have more plant species and therefore more litter resulting in higher organic matter pool in the site. Further, accumulation of more human and other wastes and incorporation of the plant debris might also have caused high organic matter in case of larger gardens and *vice-versa* (Tchatat et al. 2004, Abebe et al. , 2006, Pinho et al. 2010).

The available forms of nutrients (NH_4-N, NO_3-N and PO_4-P) varied significantly ($P>0.001$) within the home gardens with greater values in the upper soil depth as compared to the subsurface soil layer. Greater values of NH_4-N, NO_3-N and PO_4-P were recorded the in the large size home

garden and minimum values in the small size home gardens (Table 2). The difference in the available nutrients among homegarden categories may be related to the variation in SOM which might have resulted in varied level of soil micro fauna in the homegardens as soil microorganisms affect the availability of soil nutrients, especially, available N for plant uptake or loss mainly through concurrent processes of mineralization and immobilization (Shi et al. 2006, Pandey and Srivastava 2009). Also low soil pH level affects the availability of phosphorous (Shah et al. 1998) as the smaller homegardens in the present study revealed lower level available-P. However, further investigations are needed to support these hypotheses for the homegarden system in the region. Overall, the soil physical properties like WHC, soil moisture content, were significantly positively correlated with soil chemical properties, which indicate that the nutrient concentration in soil depends on the soil structure.

There is a strong correlation between different home garden categories *viz*. large, medium and small. Nutrient status is better in the large homegarden soils compared to medium and small home gardens (Figure 1 to 5). Soil organic matter, total N, ammonium, nitrate and phosphate were higher in the large home gardens followed by medium and small home gardens irrespective of their location. Linear regression suggests that the trend of nutrient were higher in the homegardens at lower altitude and the home gardens at higher altitude have low soil nutrient status particularly in case of soil organic matter and total N content of soil **(**Figure 1 and 2). However, the three available forms of nutrients viz. ammonium, nitrate and phosphate did not show any clear trends (Figure 3, 4 and 5). Further, almost all the soil nutrients were significantly correlated among

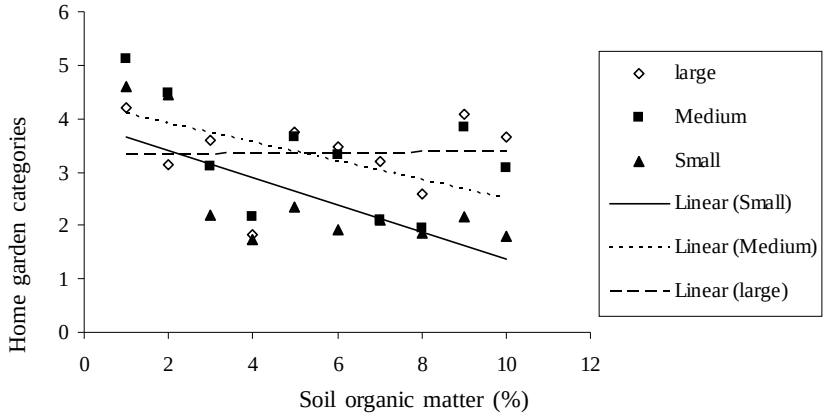

Figure 1 Soil organic matter (SOM %) in different categories (Large, Medium and small) of home gardens

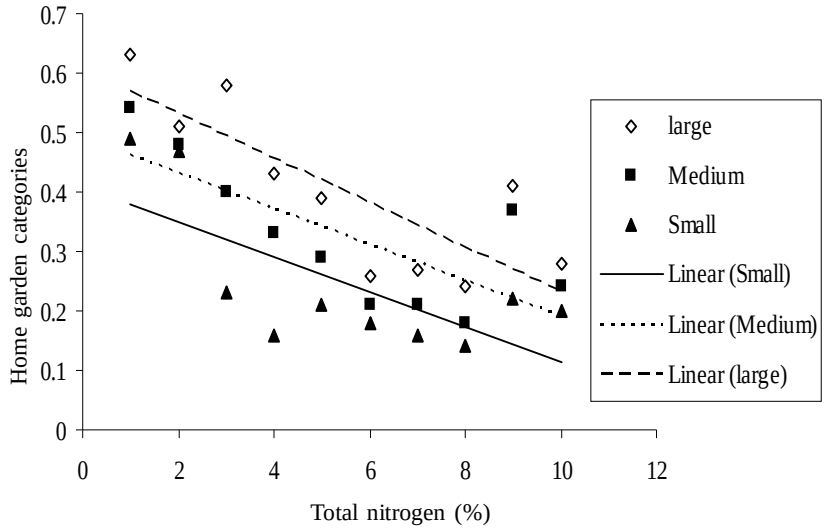

Figure 2 Total nitrogen (TKN %) in the soils of different categories (Large, Medium and small) of home gardens

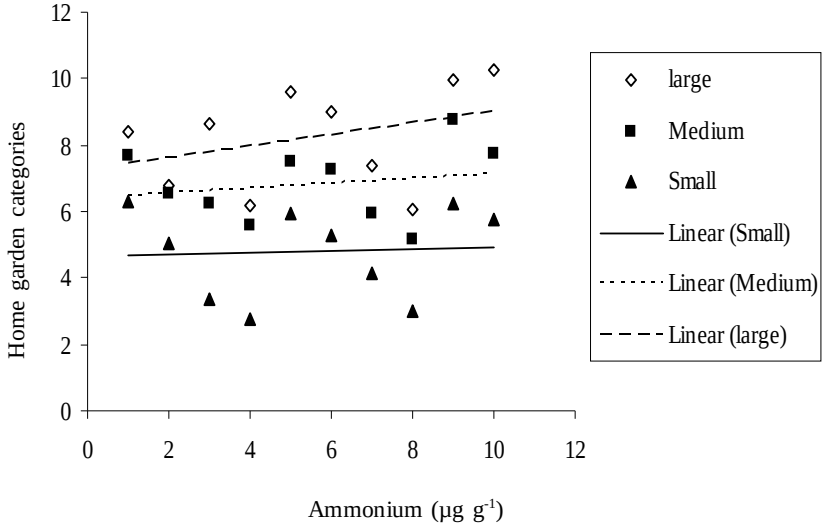

Figure 3 Ammonium (NO_3-N (µg g^{-1})) in the soils of different categories (Large, Medium and small) of home gardens

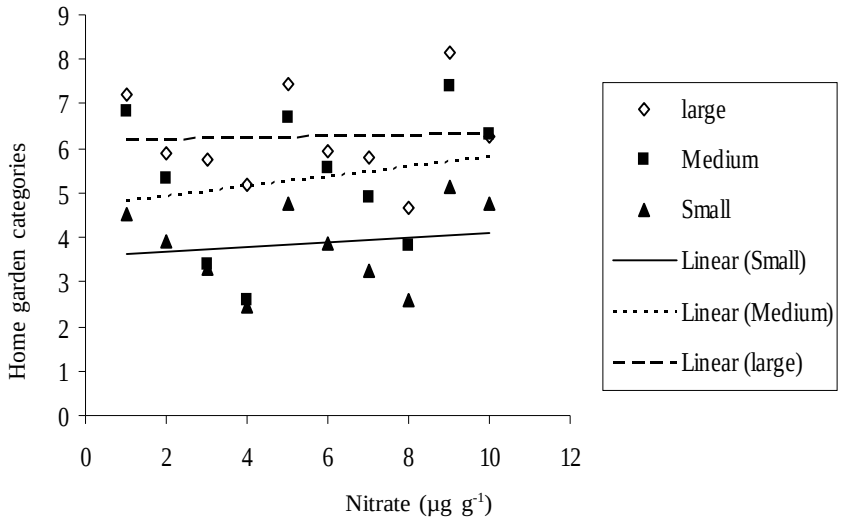

Figure 4 Nitrate (NH_4-N (µg g^{-1})) in different categories (Large, Medium and small) of home gardens

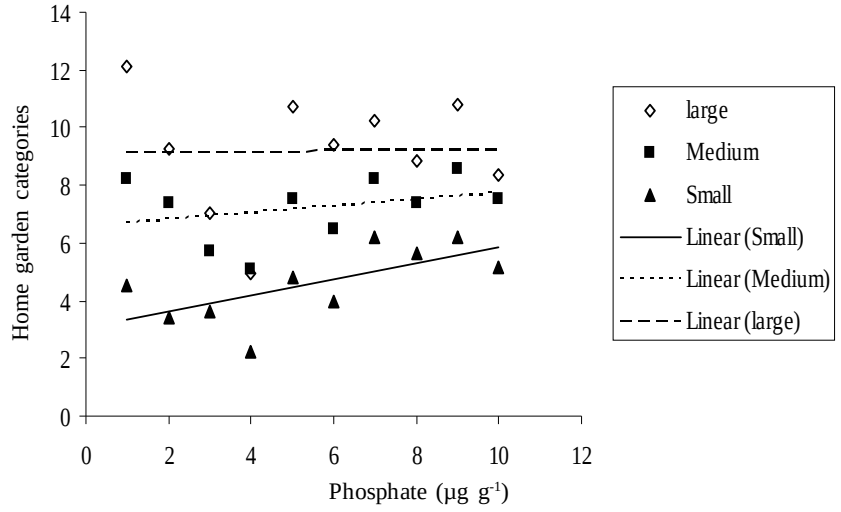

Figure 5 Phosphate (PO_4-P (µg g^{-1})) in different categories (Large, Medium and small) of home gardens

Table 3. Correlation matrix ('r' values) of soil nutrients in large, medium and small categories of home gardens

		large	Medium	Small
Soil organic matter	**Large**	1	0.700*	0.349
	Medium		1	0.824*
	Small			1
Total N	**Large**	1	0.950**	0.744*
	Medium		1	0.880**
	Small			1
NO_3-N	**Large**	1	0.876**	0.754*
	Medium		1	0.922**
	Small			1
NH_4-N	**large**	1	0.874**	0.904**
	Medium		1	0.945**
	Small			1
PO_4-P	**large**	1	0.885**	0.657*
	Medium		1	0.842*
	Small			1

* Significant at 0.05 and ** Significant at 0.01

the different categories of home gardens which suggest the clear relationship of soil nutrients with the homegarden categories (Table 3).

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The nature and function of traditional home gardens in Assam, Northeast India: A review

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Abstract

Homegardens are worldwide recognised as sustainable agroforestry systems which are considered to be a repository of species and genetic diversity. However studies on the traditional homegardens in Assam, northeast India and their role in the conservation of diversity are limited. The objective of the present paper is to review the status of the studies on homegardens in Assam, northeast India. Description and inventory of the system were found to be the main research efforts on the traditional homegardens of Assam. The homegardens exhibit complex structure, diverse floristic composition and multiple functions which contribute to their ecological and socio-economic sustainability. The characteristics and functions of traditional homegardens are closely related to many factors, such as their geographic location and the cultural backgrounds and socioeconomic conditions of the owners. Biodiversity conservation in the homegardens was found to be linked to the multiple values of the different plant species to the homegardeners and reflected a complex human-plant interaction. Further research on dynamics of the traditional homegardens, economic valuation of tangible and intangible products and services, resource partitioning and utilization among the different plant functional groups, and realistic valuation of unrecognized benefits such as carbon sequestration will provide a sound basis for better realization and exploitation of the benefits of the homegardens.

Keywords Homegardens, multipurpose trees, plant use, plant biodiversity, conservation

Introduction

Traditional resource management options such as agroforestry systems have the potential to provide options for improvement in livelihoods through simultaneous production of food, fodder and firewood as well as mitigation of the impact of climate change. Homegardens are a complex agroforestry system and one of the oldest forms of managed land use system. It evolved through generations of gradual intensification of cropping in response to increasing human pressure and the corresponding shortage of arable lands (Kumar and Nair 2004, Peyre et al. 2006). The term homegardens can be defined as "land use system involving deliberate management of multipurpose trees and shrubs in intimate association with annual and perennial agricultural crops and invariably livestock within the compounds of individual houses, the whole tree-crop–animal unit being intensively managed by family labour" (Fernandes and Nair 1986). These systems have also been described as a small-scale 'supplementary' food production system, using 'marginal land and marginal labour' (Hoogerbrugge and Fresco 1993). Homegardens exemplify many agroforestry characteristics i.e., the intimate mix of diversified agricultural crops and multipurpose trees that fulfil most of the basic needs of the local people while the multistoried configuration and high species diversity of the homegardens help reduce the environmental deterioration commonly associated with monoculture production systems (Nair 1993). The basic objectives for maintaining this agroforestry system is to ensure availability of multiple products such as food, fuel, vegetables, fruits, fodder, medicines besides generating income and employment (Kumar and Nair 2004). The crop combinations found in the homegardens of a region, however, are strongly influenced by the biophysical and socio-cultural factors besides the specific needs of the household and nutritional complementarity with other major food sources (Kumar and Nair 2004). The maintenance of multispecies and multistrata agroforests is deemed worthwhile because of the growing interest in developing multifunctional land-use systems which contribute not only to production objectives, but also to the objectives of biodiversity and environmental conservation (Wiersum 2004). When defined in terms of spatial structure, growing cycle and species diversity, homegardens come close to natural ecosystems (Wojtkowski 1993).

Traditional agroforestry systems such as homegardens, are considered to maintain valued biological interactions and biodiversity at higher levels than the more recently discovered-simplified, input driven and disturbed, modern agroforestry systems (Leakey 1998). Home gardens

are living gene banks and a reservoir of plant genetic resources that preserve landraces, cultivars, rare species and endangered species and species neglected in larger ecosystems (Eyzaguirre and Linares 2001). The adoption of the Convention on Biological Diversity in June 1992 and the succeeding importance given to the conservation of plant genetic resources have resulted in increasing attention on traditional agroforestry systems such as homegardens. Homegardens have been highlighted in the past few decades as an important site for *in situ* conservation (Perera and Rajapakse 1991, Gajaseni and Gajaseni 1999) while some have considered the possibility of their potential to maintain species *ex situ* (Kabir and Webb 2009). The home gardens can be an option for *on-farm* conservation and contribute to *on-farm* conservation strategies of genetic resources at ecosystem, species, and within species level (Gajaseni and Gajaseni 1999). The rural homegardens provide a good example of the concept of 'trees outside forests'. At the Kotka meeting in 1993 (FAO 2000), experts recognized the uniqueness and importance of different resource types and defined a new concept of 'trees outside forests' (TOF), which considers trees at all levels and in all aspects, emphasizing their social consideration at the policy level and in the assessment of the world's forest resources, and economic role and promoting their consideration at the policy level and in the assessment of the world's forest resources. "Trees outside forests" according to Bellefontaine et al. (2002) refer to trees grown outside of "forests" or other wooded land, and which are located on other land such as agricultural land, gardens, around homes etc. A large body of research has demonstrated that the conservation of tropical biodiversity in degraded tropical landscapes can be assisted through the management of diverse agroforestry systems (Bhagwat et al. 2008). In tropical countries with rapid population growth and declining forest cover, home gardens may become increasingly important to both livelihoods and to conservation—particularly in regions with high population densities, expansive agriculture, or traditional farming practices that include mixed gardens. In such situations, home gardening may be a possible option to maintain species *ex situ* while replacing goods and services previously found in forests.

Homegardens have been receiving research attention from scientists around the world (Gajaseni and Gajaseni 1999, Blanckaert et al. 2004, Kabir and Webb 2009). In India most of the research on homegardens has been concentrated in Kerala (Kumar et al. 1994, Peyre et al. 2006), Karnataka (Shastri et al. 2002), Andaman and Nicobar (Pandey et al. 2007) with limited information available on the homegardens of northeast India (Das and Das 2005, Shrivastava and Heinen 2005). The northeast India is

one of the biodiversity rich regions of India represented by an array of environmental situations and are considered to be the genetic treasure house of biodiversity. In rural northeast India, homegardens are ubiquitous landscape components. In addition to the cultivation of vegetables for consumption and sale, homegardens are often sites where certain selected and valued plants collected from nearby forests are grown (Shrivastava and Heinen 2005). However the traditional homegardens in rural northeast India including Assam are the least investigated systems and the present work is a review of the traditional homegardening systems studied in different regions of Assam and will attempt to highlight the structural and functional attributes of the traditional homegardens of Assam including their potential for *in situ* biodiversity conservation.

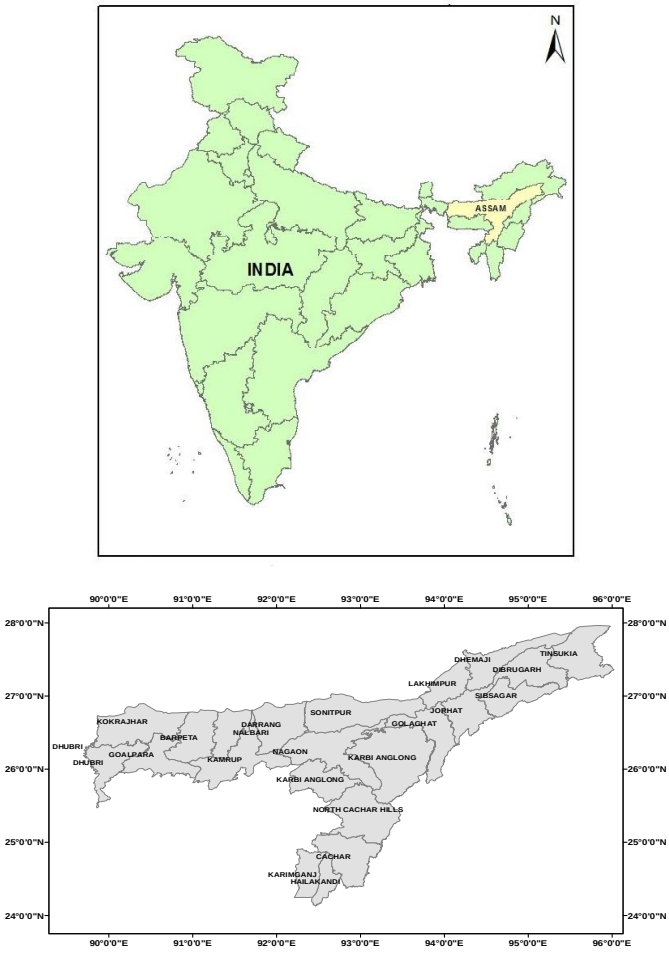

Fig 1 Location map of the state of Assam

Traditional homegardens in Assam

Assam, situated at the foothills of the eastern Himalayas, is the largest State in northeast India and lies in the middle reach of the river Brahmaputra and Barak (**Fig 1**). The land has uneven topography, full of hills, plains and rivers. Situated between 89°42'-96°02' E Longitude and 24°12'-27°58' N Latitude, Assam is bordered in the North and East by the Kingdom of Bhutan and Arunachal Pradesh. Along the South lie Nagaland, Manipur and Mizoram. Meghalaya lies to her South-West, Bengal and Bangladesh to her West. The mighty Himalaya covers three sides of the province. It can be divided into three principal geographical regions: the Brahmaputra Valley in the north; the Barak Plain in the south; and the Mikir (Karbi Anglong) and Cachar Hills that divide the two regions. The northern part of Assam is wholly occupied by the elongated valley of the mighty river Brahmaputra. Most of Assam's population lives in this valley. The Brahmaputra River flows through Assam from east to west over a length of approximately 650 kilometers. Its main branch originates in the Tibetan plateau, flowing from west to east as the Tsangpo River, and then turns south through the eastern Himalaya as the Dihang River to enter Assam, where it is joined by other branches to form the Brahmaputra. The Brahmaputra valley is bounded by the foothills of the Himalayas to the north and another lower range of hills and mountains to the south. In the center part of Assam, to the south of the hills is the Barak Valley which is contiguous with the densely populated country of Bangladesh. In the south, the Barak, flows through the Cachar district and enters Bangladesh with the name Surma. The Barak River rises in the Indian state of Nagaland at an elevation of approximately 2,300 meters and passes through the Manipur Hills of Manipur state over a river length of nearly 400 kilometers. It then flows generally westward from Lakhipur through the Cachar Plains region of Assam over a river length of approximately 130 kilometers to enter Bangladesh. Barak Valley is situated in the south Assam. In the north there is North Cachar Hills, in the east there is Manipur Hills and in the south there is Mizoram hills. The area is 6962 sq. km.

The geographical area of Assam is 78,438 km^2 of which land cover is approximately 35.28% forest cover and tree cover 1.99% (FSI 2011). The tree cover is a subset of the concept of trees outside forests and include all trees outside the recorded the forest area less than 1.0 ha in extent. This land cover type also includes trees in the rural and urban homegardens of Assam which occur as blocks or are scattered around the individual houses. Homegardens in Assam may provide the majority of the tree dominated

habitat outside forests but data on the approximate extent of the homegarden habitats in relation to the geographical area are lacking for adequate comparisons and scientific assessments. A study in Southern Assam, Barak Valley, reported that the rural homegardens constitute 10.63 to 13.75% of the geographical area and cover land area of upto 405.52 km^2 (Das and Das 2014). Such spatial extent of the rural homegardens, when compared to studies from other parts of the world such as the homegarden coverage of approximately 12% of the geographical area reported from Bangladesh (Kabir and Web 2008), indicates that the homegardens form an important component of the rural ecosystem and is the dominant TOF class in the region (Das and Das 2014). Such data on the coverage of the rural homegardens can provide an initial basis for information on the extent to which rural inhabitants depend on natural resource systems, such as homegardening, to supplement farming systems. Also such information on the extent of the tree dominated habitat outside forests can provide real opportunities for biodiversity conservation and sustainable development outside the protected area system. Traditional homegardens are an important component of the farming systems in the rural regions of Assam state but reports documenting the presence of such an important agroforestry system has been limited to inventory of the systems from Golaghat, Lakhimpur, and Jorhat districts of Upper Assam, Brahmaputra Valley (Barooah and Pathak 2009, Tanjang and Arunachalam 2009, Zimik et al. 2012, Saikia et al. 2012) and Cachar district of Southern Assam, Barak Valley (Ramakrishnan et al. 1996, Godbole 1998, Sinha and Das 2000, Das and Das 2005, Devi and Das 2013). System description has been the most dominant aspect of the homegarden research in Assam so far. Some work has been done on the ethnobotanical aspect of the homegardens in Upper Assam (Borthakur et al. 1999, Borkataki et al. 2008) and the homegarden productivity and economic returns (Shrivastava and Heinen 2005). The Assamese people are rich in cultural activities and maintain traditional homegardens of different sizes (Saikia et al. 2012). The homegarden owners in Assam are mostly smallholders with homegardens mostly within the sizes of <1 ha. Homegarden size is by and large a function of the population density and differs with the geographical area studied. The size of the homegardens is related to the status of the household and influences cropping intensity, plant density and labour used (Hoogerbrugge and Fresco 1993). Saikia et al.(2012) in their study of homegardens from the villages of Golaghat and Jorhat districts in Upper Assam reported the homegarden size to range from 0.05-0.33 ha with an average of 0.16 ha while Shrivastava and Heinen (2005) in their study in Naogaon and Golaghat districts of

Upper Assam, Brahmaputra Valley, reported an average homegarden size of 0.19 ha. In another study by Zimik et al. (2012) reported the homegardens from Lakhimpur district in Upper Assam to range from 0.06 to 0.27 ha. Similarly in Southern Assam, Barak Valley reports indicate homegardens size to range from 0.07 to 0.78 ha and 0.13 to 0.28 ha with an average of 0.20 and 0.18 ha among the homegardens of Meitei Manipuri community (Devi and Das 2010, 2013) and range from 0.02 to 1.20 ha with an average of 0.33 ha from the homegardens of tea garden labors in Cachar district, Southern Assam (Das and Das 2010). In another study on the homegardens in different traditional communities in Barak Valley reported the homegarden size to range from a minimum of 0.017 ha in Karimganj district to a maximum of 2.41 ha in Cachar district with an average of 0.26 ha in the homegardens of the three districts of Barak Valley, Southern Assam (Das and Das 2014). The homegarden size reported from the various studies in Assam falls within the range of global inventory of other tropical homegardens by Fernandes and Nair (1986).The homegarden size and diversity may be related to the socio-economic conditions of the families that maintain them but limited reports on the socio-economic characteristics of the homegarden owners could be detected for the homegardens of Barak Valley, Assam (Das and Das 2005, Das and Das 2007, Devi and Das 2010) and the socio-economic factors such as total cultivable area and land fragmentation affecting homegarden dynamics in Brahmaputra Valley, Assam (Shrivastava and Heinen 2005).

Structure and composition of traditional homegardens in Assam

Presence of a large number of species on the same land management unit, often seemingly not following any specific geometry, makes it difficult to define the temporal/spatial architecture of homegardens (Kumar and Nair 2004). The structural entities of homegardens are, however, arranged in a complex micro-zonal pattern having well-defined vertical/horizontal stratification with each structural ensemble occupying a specific niche, such that they cannot be easily dissociated from one another (Nair and Sreedharan 1986). Understanding these interrelations will be one step forward in utilizing the advantages of homegarden agroforestry (Kumar and Nair 2004). Traditional homegardens often have complicated vertical structures (**Fig 2**). They vary in their vertical structure according to their location (e.g. more complex in the tropics), floristic composition, age and size (Kehlenbeck and Maass 2004). The layered canopy configurations and combination of compatible species are the most conspicuous characteristics of all homegardens (Nair 1993). Das and Das (2005) reported four to five vertical layers from the homegardens of tea garden labors in

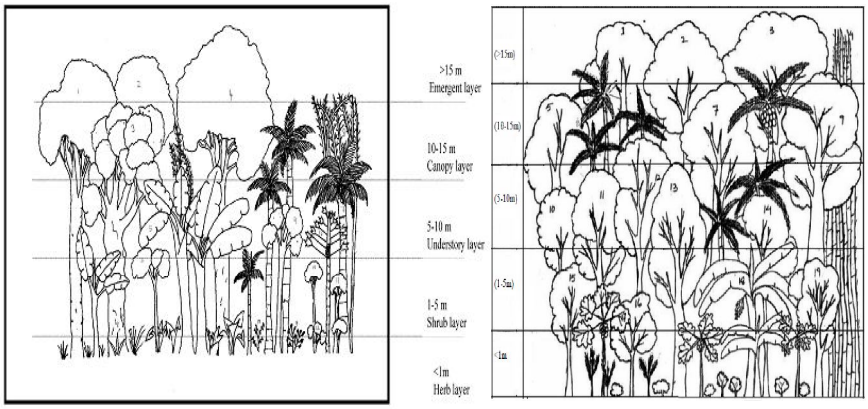

Fig 2 Vertical stratification in a typical homegarden of the a) tea garden labors and b) Meitei Manipuri community in Barak Valley, Assam
(Source: Das and Das 2005; Devi and Das 2013)

Cachar district Barak Valley, Southern Assam, similarly Devi and Das (2010, 2013) reported on Meitei Manipuri homegardens with five distinct vertical strata. In Upper Assam, there are reports indicating the presence of five vertical strata in homegardens of different districts; e.g. Lakhimpur (Zimik et al. 2012), Golaghat and Jorhat (Saikia et al. 2012). Other reports indicate the vertical stratification of homegardens (Barooah and Pathak 2009, Tanjang and Arunachalam 2009) but do not give details of the number of layers observed and the species occupying the different layers. Such information on the vertical stratification of homegarden studies is necessary as the wide range of species of different heights and life forms found in the different vertical layers of the traditional homegardens add to their ecological efficiency in terms of use of physical and chemical resources such as water, sunlight, and nutrients (Wiersum 1982, Blanckaert et al. 2004). It has been observed from the studies on the homegardens in Upper Assam and Southern Assam that all the four or five vertical strata recorded were not found in all the homegardens and the most common layers occurring in all the homegardens include the canopy, shrub and herb layers (Das and Das 2005, Zimik et al. 2012, Devi and Das 2013). The complex vertical structure of the homegardens in Assam was found to mimic the surrounding natural forests (Das and Das 2005, Saikia et al. 2012, Zimik et al. 2012) and support the assumption by authors around the world (Jensen 1993, Kumar and Nair 2004) that the structural characteristics of homegardens are comparable to those of the natural mixed forest vegetation systems. Tropical and sub-tropical homegardens have been described as multilayered, species-rich agroforestry systems (Rico-Gray et al. 1990), which are generally accepted

to be economically efficient, ecologically sound and sustainable (Torquebiau 1992). Besides the vertical structure homegardens also have distinct horizontal structure (Das and Das 2005, Devi and Das 2013) which together help in the efficient utilization of water, light and space and support diverse wildlife species besides meeting various social and basic needs of the families. The homegardens appear to be a haphazard mixture of trees, shrubs and herbs. But the locations of most plants were found to be deliberate, which could be distinguished into several management/ horizontal zones (Das and Das 2005). Farmers choose specific zones based on practical considerations, plant requirements and soil conditions (Devi and Das 2013). Das and Das (2005) in their study of the homegarden labors in Barak Valley, Assam identified five management/ horizontal zones while Devi and Das (2010) in their study of Meitei homegardens in Barak Valley, Assam identified a total of ten horizontal zones. Such zonation of species indicates knowledge of the ecological requirement of the plant species and the role of traditional knowledge in the management of homegardens.

While most advances in agriculture and forestry entail single-species stands, characterized as 'biological deserts' of low species diversity, tropical homegardens are glorious examples of species diversity in cultivated and managed plant communities (Kumar and Nair 2004). Several landraces and cultivars, and rare and endangered species have been preserved in the homegardens (Watson and Eyzaguirre 2002). The diversity and species composition in the homegardens is often a reflection of the owners' socioeconomic status (Soemarwoto and Conway 1991), his cultural requirements and management techniques. The high species diversity are strategies to ensure higher availability of multiple products on the farm itself (Kumar et al. 1994). The inventory of the species diversity in the homegardens made from Barak Valley report a total of 122 trees and shrubs from 46 families (Das and Das 2005) and 92 species (including trees, shrubs and herbs) from 43 families (Devi and Das 2010). Studies from the homegardens in Upper Assam indicate higher species richness with reports of 294 plant species from 92 families (Saikia et al. 2012) and 268 plant species from 82 families (Zimik et al. 2012). The number of species per homegarden also varies greatly among the different regions in Assam with reports of a range of 17 to 69 species with a mean of 44 species per homegarden (Saikia et al. 2012) and a range of 28 to 87 species with a mean of 51 species per homegardens (Zimik et al. 2012) from studies in Upper Assam, Brahmaputra Valley. In Southern Assam, Barak Valley, studies on the homegardens diversity report a range of 9 to 54 species with a mean of 26 species per homegarden (Das and Das 2007) and a range of 9

to 28 species per homegardens (Devi and Das 2013). Ecological and socioeconomic factors influence the species richness of traditional homegardens, including the utilization of the products of homegardens (Gajaseni and Gajaseni 1999, Wezel and Ohl 2005). They include geographic location, climate, water availability, garden size and history, agricultural policy, market needs, food culture and household preferences (Huai and Hamilton 2009). Species richness has been reported to have strong relationship with homegarden size from some homegardens in Assam (Das and Das 2005, Zimik et al. 2012) while some of the studies report a poor relationship of species richness with homegarden size (Saikia et al. 2012) indicating the greater influence of cultural, socio-economic and personal preference of the homegarden owners on homgarden species richness (Das and Das 2005, 2007). However most studies on floristic richness of homegardens lack information on the degree of heterogeneity in the study area (e.g. extent and socioeconomic nature of sampling units) (Kumar and Nair 2004) which makes comparisons between homegardens from different regions difficult. Biophysical factors, altitude and slope of the farms also affect the diversity of plant species (Zimik et al. 2012) but studies on their influence on homegarden floristic richness has till date not been focussed for the homegardens of Assam. Some authors have advocated an ecological approach to computing diversity indexes which is a relatively new area of research in homegardens. Most studies indicate a high diversity with values ranging from 2.86 to 3.5 and low concentration of dominance in the homegardens of different regions in Assam (Saikia et al. 2012, Das and Das 2007, Devi and Das 2013), which might be related to the socio-economic factors and personal preference of the homegarden owners. A high diversity in homegarden system is the result of selection of species with tangible benefits by the owners. Reduced risk of yield of losses due to pests and weeds is an added advantage of a high level of diversification (Gajaseni and Gajaseni 1999).

Plant utilization in traditional homegardens of Assam

Villagers plant trees mainly for household consumption and income. Plant species inventoried in the homegardens include those supplying food, cash, fuelwood, timber, shade, fencing and medicine, among which majority are indigenous (Das and Das 2005). Species in traditional homegardens are used for many purposes (Huai and Hamilton 2009). Das and Das (2005) in their study of the homegardens in Barak Valley, Assam noted that the plants managed in the homegardens are used for eight main purposes with the highest number of species being in the fruit and timber use category. In the Meitei Manipuri homegardens of Barak Valley, Assam nine to ten main

use categories including fuel, fruit, timber, vegetable, medicinal, cash, religious, ornamental, spice and miscellaneous use categories have been reported (Devi and Das 2010; 2013). Studies on the plant utilization pattern in the homegardens of Upper Assam report seven to eight major use categories with the dominance of fruit bearing tree species (Saikia et al. 2012, Zimik et al. 2012). Fruit tree species commonly occurring in the homegardens of lower and upper Assam include *Artocarpus heterophyllus*, *Cocos nucifera, Litchi chinensis,Mangifera indica, Musa sp.* and *Psidium guajava* (Das and Das 2007, Saikia et al. 2012, Zimik et al. 2012) while dominant timber species include *Toona ciliata* and *Syzygium cuminii* from Barak Valley (Das and Das 2007), *Tectona grandis*, *Shorea robusta*, *Michelia champaca* and *Gmelina arborea* from Upper Assam (Saikia et al. 2012, Zimik et al. 2012). Most of the tree species noted in the homegardens are multipurpose and are often preferred by the homegarden owners for their multiple value (Das and Das 2005, 2007). An important characteristic of the homegardens is the predominance of indigenous fruit trees. The fruit trees make an important contribution to the nutrition of households (Nair 1993). Fruit trees not only provide food during their life span but also the final harvest of timber generates a cash income (Das and Das 2005). Several studies on the homegardens of Assam have recorded the presence and dominance of fruit trees but have not highlighted the presence of indigenous fruits trees species which are important as they are an important source of nutrition for women and children especially for the poorer families with small land holdings. Das and Das (2005) reported the presence of indigenous fruit trees in the homegardens and noted that different varieties of indigenous fruit trees such as *Artocarpus heterophyllus* and *Musa sp.* are cultivated in the homegardens of Barak Valley, Assam. They also noted the presence of several wild/ lesser known fruit trees such as *Artocarpus chama*, *Artocarpus lakoocha*, *Garcinia* sp., *Licuala peltata* etc. in the homegardens which are managed because of their value for food, timber and cash, many of these can be labelled as 'Cinderella' tree species, as they have been overlooked by science and the products of such species have been collected, gathered and utilized by man and are still of enormous importance to the rural people (Leakey and Newton 1994). The presence of underutilized/ wild tree species like *Dysoxylum binectariferum* and *Palaquium polyanthum* have also been reported from other homegardens in Barak Valley which are domesticated due to their value as timber but the species also has some unexploited economic and medicinal value, which if the homegarden owners are made aware of, can benefit them commercially (Devi and Das 2013). Borthakur et al. (1999) in their ethnobotanical exploration of the homegardens of Upper Assam also noted the presence

of species in the homegardens which have representatives in the adjoining forest areas. Many species in the homegardens have been reported to have value as fuelwood (Das and Das 2005, Devi and Das 2013, Saikia et al. 2012, Zimik et al. 2012) and the presence of such species in the homegardens can lessen the pressure on nearby forests. Vegetables form an important use category in some homegardens (Shrivastava and Heinen 2005, Zimik et al. 2012, Devi and Das 2010) due to associated cultural preferences which are followed by religious and medicinal plants. Homegardens are an important reservoir of many medicinal plants used for the basic treatment of various ailments and diseases of both human beings and their livestocks (Zimik et al. 2012). Most reports on the homegardens list the common plant species with medicinal value such as *Aegle marmelos*, *Azadirachta indica*, *Terminalia arjuna* and *Terminalia chebula* (Das and Das 2005, Saikia et al. 2012, Barooah and Pathak 2009, Tanjang and Arunachalam 2009), while some studies have been made on the detailed assessment of the medicinal plants in the homegardens in Assam (Saikia and Khan 2011). Another important aspect of the homegardens in Assam is the presence of plants which are used for live fencing including species such as *Erythrina variegata*, *Jathropha curcas*, *Moringa oleifera* and *Spondias pinnata* (Das and Das 2005, Borkataki et al. 2008). Plants grown as live fences have strong soil binding capacity and are efficient enough to strengthen the mud boundaries of crop fields and houses (Eyzaguirre and Linares 2001,Ramakrishnan et al. 1996). It is to be noted that many of the species used for live fencing were reported to have medicinal properties, which are retained in the traditional knowledge of the people (Das and Das 2005, Borkataki et al. 2008). The homegardens of Assam are found to be basically subsistence based small holder farming systems with plant diversity which often serve as a source of additional cash income for the homegarden owner during emergency (Das and Das 2005). The preference of growing more fruit trees in the homegardens for generating additional cash has been noted by several authors (Das and Das 2007, Devi and Das 2013). *Areca catechu* is used as a masticator (fruit) and is a common occurrence in the homegardens of Assam often in separate zones known as betel groves (Das and Das 2005, Devi and Das 2013, Tanjang and Arunachalam 2009) due to their commercial importance. It has been noted by several authors in Assam that due to the commercial importance of *Areca catechu* and other similar cash crops there has been a growing shift from traditional homegarden plants to dominance of cash crops (Saikia et al. 2012) and such a shift has especially been noted for the larger homegardens (Das and Das 2005, Tanjang and Arunachalam 2009), which could ultimately in the future negatively impact the overall diversity of the traditional homegardens. This

shift is likely to threaten the characteristics of traditional homegardens, such as biodiversity, a multi-purpose nature, and ecological and socioeconomic sustainability (Peyre et al. 2006). Proximity of the homegardens to urban areas and market areas can be additional factors which influence the dominance of commercially important plant species. Often it is mentioned that urban-market pressure results in decreased total species diversity in the homegardens, whereas subsistence farmers in remote areas are compelled to produce diverse products and, therefore, species diversity increases in remote areas (Wezel and Ohl 2005). Bamboo forms an important component of the homegardens in Assam and is often managed in a separate zone or land known as bamboo groves (Das and Das 2005, Shrivastava and Heinen 2005, Nath and Das 2008, Barooah and Pathak 2009, Saikia et al. 2012). The different species of bamboo encountered from the homegardens have multiple uses and is often used for making a vast array of household items and agricultural implements. Many of the products from bamboo are sold in the local markets and are a source of cash for the homegarden owners (Das and Das 2005, Devi and Das 2010). Villagers show a higher preference of some bamboo species because of their utilization value and their commercial value as raw material for paper industry (Das and Das 2005).

Biodiversity conservation in traditional homegardens of Assam

Homegardens are important sites for *in situ* conservation of plant diversity (Perera and Rajapakse 1991, Gajaseni and Gajaseni 1999) and can also serve as gene pools for the eroding indigenous tree species. Many wild, rare tree species like *Aquilaria malaccensis* and *Vatica lanceaefolia* are also conserved in homegardens because of their high commercial value (Das and Das 2005). Several authors have noted the presence of *Aquilaria malaccensis* in high frequency in the homegardens of Upper Assam (Zimik et al. 2012, Saikia and Khan 2012, Saikia and Khan 2013) and their value as a economic plant have been highlighted in great detail and have stressed the urgent need, in addition to protection and conservation of this species in the homegardens to create awareness among the local people about the importance of such rare wild species. It is important to point out that wild, rare tree species like *Aquilaria malaccensis* and *Vatica lanceaefolia* have almost disappeared from the natural forests of Assam but their conservation in the homegardens highlight the concept of 'Conservation through use' (Eyzaguirre and Linares 2001) which is an element of a complementary conservation strategy. Homegarden plant diversity (especially native species diversity) may be positively influenced by the ease with which farmers may collect seeds or seedlings from the forest, frequency of natural seed-

dispersal events into the home gardens, end use of the products, and many socioeconomic variables (Kabir and Webb 2009). The homegardens serve as treasure house and gene pool of many rare wild species such as *Caryota urens, Garcinia* sp., *Licuala peltata* etc. which are eroding from the nearby forests (Das and Das 2007) but their importance has rarely been assessed in the studies of the homegardens of Assam.

Ecological function of traditional homegardens in Assam

An increasing number of studies are focusing on the structure and composition of the traditional homegardens in Assam. However studies on many areas of homegarden research are still lacking for Assam including the studies on the functional dynamics of homegardens, details on the nutritional security provided by the homegarden species and the biophysical aspects of the sustainability of the traditional homegardens. Homegardens comprising diverse multipurpose trees are represented by different plant functional types with differing phenological behaviour. The multipurpose trees in the homegardens with differing phenological behaviour provide a temporal complementary of resource and provide opportunities for ecological adaptation of the species to the changing climatic conditions. Also the diverse phenological behavior plays an important role in regulating the food supply for the herbivore population and the year-round availability of products, and such information can be useful in the selection of species for integration into other agroforestry systems which can be sustainable in the long run (Das and Das 2013). However studies on this functional aspect of the traditional homegardens in Assam are lacking and only a few studies have been conducted on the phenological behaviour of multipurpose trees and bamboo in the homegardens of Barak Valley (Nath et al. 2008, Das and Das 2013). It is generally regarded that the homegardens possess a closed nutrient cycling, much similar to the tropical forests (Nair et al. 1999, Soemarwoto and Conway 1991). The dynamics of litter production and decomposition and subsequent bioelement release, which endow sustainability to these forests (Heal et al. 1997, Lavelle et al. 1993), are, therefore, relevant to homegardens yet little quantitative information exists in this respect. Among the available reports on homegaden litterfall, Das and Das (2010) in their study of the litter production and decomposition in the homegardens of Barak Valley reported that the annual litter production in the homegardens was 6.27 Mg ha^{-1} with a bimodal distribution pattern and the nitrogen input through litterfall accounted for 48.17 kg ha^{-1} $year^{-1}$. In order for the homegarden systems to continue to provide social, economic and environmental benefits for successive generations, a clear understanding of the various aspects of nutrient cycling including the effects

of litter/green manure addition on soil organic matter and nutrient dynamics is essential (Kumar and Nair 2004). Understanding the nutrient, energy and water balance in the homegardens is crucial to providing a scientific foundation for better design and management of the system to permit efficient use of resources, to avoid loss of energy and to increase production (Benjamin et al. 2001). With the increasing emphasis the world over on carbon sequestration in terrestrial ecosystems, homegardens that are mostly steady-state systems could be of crucial importance in the carbon-credit discussion (Montagnini and Nair 2004) but studies on this important function has not yet focused on the homegardens of Assam. With solid quantitative foundations and research back-up for assessing carbon sequestration potential of homegardens and with enabling policies put in place for rewarding landowners for carbon credits, the homegardens of future are bound to have a much better value and prestige than today (Kumar and Nair 2004).

Conclusions and suggestions

Traditional homegardens are an important component of the farming systems of the rural people in Assam which have evolved through several generations and are reflective of their cultural background. The high structural and floristic diversity of the homegardens in the different regions in Assam are influenced by the unique biophysical environment and socio-cultural factors under which they persist. The assemblage of the large diversity of trees, shrubs and herbs in the homegardens and the complex structure they exhibit serve a range of social, cultural and economic needs of the owners besides providing options for *in situ* conservation of wild biodiversity. The large extent of the distribution of the homegardens in the rural landscape evident from existing studies highlight the importance of such an essential component of the trees outside forests in the face of the increasing degradation of the natural forests in the region. With their structural attributes similar to that of forests, the homegardens function similar to that of natural forest in many ways including providing goods and services to the owners and thereby reducing the pressure in nearby forests. The shift of the traditional homegardens from traditional subsistence based system to more commercial oriented system, reported for some regions in Assam, is an issue of concern and needs to be addressed before the sustainability and biodiversity conservation potential of such systems are damaged.

Although studies on the structure and function of homegardens in Assam are slowly gaining focus, there are relatively few studies on the

economic, cultural and ecological significance of the homegardens. More research needs to be taken up on the traditional ecological knowledge and traditional resource management of the homegardens in Assam before such a sustainable resource management system fades in the face of the increasing urbanization and modernization. There is an urgent need to strengthen and document such traditional systems of natural resource management for economic viability, ecological sustainability and social acceptability. In this context, it is pertinent to mention the initiative of preparing a 'Peoples Biodiversity Register' (Gadgil and Rao 1998), with the objective of documenting and preserving biodiversity and related knowledge of the people. There is a need to focus more research on the ecological function of the traditional homegardens in Assam including their nutrient dynamics and carbon sequestration potential to better understand the value of such an important system so that these systems are recognized deservedly in policy discussions at the regional and national level.

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Advances in PCR based molecular markers and its application in biodiversity conservation

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Abstract

Polymerase chain reaction (PCR) was invented by Kary B Mullis in 1986. It has now become one of the most trend-setting techniques that have transformed the depth and precision of analysis in molecular biology. Due to considerable advancement in the basic technique of the PCR it has become indispensable tools in a phenomenally wide range of research and application in biodiversity studies. The PCR technique involves repeated enzymatic synthesis of segments of DNA using a specific DNA polymerase and two oligonucleotide primer that match to the two extremities (one for the 5' end of the sense strand and other for 5' end of the antisense strand) of the DNA segment to be amplified. The method consists of repeated thermal cycles, each cycle consisting of three steps, denaturation, annealing and extension.

Keywords Polymerase chain reaction, molecular markers, biodiversity conservation

Background and principle of PCR

In 1986, Kary B Mullis has invented the technique of polymerase chain reaction (PCR) in molecular biology, which works on the principle of enzymatic *in vitro* amplification of DNA. The main principle of PCR is

to use the enzyme called DNA polymerase which is responsible for making a copy of the DNA strand. It is used to amplify a single copy or few copies of a piece of DNA (template DNA) and produces millions of copies of one or more particular target DNA fragments which can be electrophoresed and visualized by staining. PCR technique is characterized by its high speed, selectivity and sensitivity. PCR with tandem repeat and arbitrary primers, is special variants of the PCR technique, useful for DNA fingerprinting (McClelland et al. 1994). In a typical PCR, three temperature controlled steps can be discerned with each consisting three steps (denaturation, annealing and extension), which are repeated in a series of 25 to 40 cycles. A basic PCR setup and reaction usually require components, for example, 1) A buffer, usually containing Tris-HCl, KCl and $MgCl_2$, 2) A thermostable DNA polymerase which adds nucleotide to the 3' end of a primer annealed to single stranded DNA, 3) Two oligonucleotide primers, 4) Deoxyribonucleotides, 5) Template DNA.

Since DNA mainly exists as double strand and the enzyme can work only in single strand, and so it is necessary to separate the strand of DNA. Therefore, the first step is to make the template DNA to be single stranded by raising the temperature to 94° C (denaturation step). Since the enzyme works on single strand DNA but it needs a small region of double strand DNA to get started, so in a second step, a short piece single strands DNA, called primer, is added that binds to a particular place of the DNA molecule. This process is completed by lowering the temperature to about 45 to 65°C (depending upon primer sequence and experimental strategy) and is called annealing. Now the DNA polymerase enzyme is ready to copy the single strand molecule starting from the bound primer region. This process is called 'extension' as it extends DNA from DNA. This step is completed by choosing a temperature where the activity of the thermostable polymerase is optimal, i.e. usually 72 °C (elongation step). The polymerase now extends the 3' ends of the primer. Since this happens at both primers binding sites on both DNA strand, the target fragment is completely replicated.

In the next cycle, the two resulting double stranded DNAs are again denatured, and both the original strand as well as the product strand now acts as a template. Repeating these three cycles to 25-40 times results in the exponential amplification of the target (amplicon) between the 5' end of the two primer binding sites. Other, longer products are also generated, however, since these fragments are only linearly amplified, their relative amount in the final product is negligible. To allow for exponential

amplification, the primer must anneal in opposite directions, so that their 3' ends face target. Amplification is most efficient when two primer binding sites are not further apart than about 4 kb. However, amplification of up to 10 kb can be obtained under optimal conditions.

Polymerase

DNA polymerase catalyzes the synthesis of long polynucleotide chains from monomer deoxyribonucleotide triphosphate, using one of the original parental strands as a template for synthesis of new strand. DNA synthesis proceeds in the 5' to 3' direction since the polymerization is from the 5' α- phosphate of the deoxyribonucleotide triphosphate to the 3' terminal hydroxyl group of the growing DNA strand. The DNA polymerase requires a short segment of DNA or primer to anneal to a complimentary sequence to prime synthesis. dNTP's are covalently joined to the free hydroxyl group of the primer and form a newly synthesized strand complimentary to the template.

In the initial stages of PCR development, the Klenow fragment of the DNA polymerase I of *Escherichia coli* was used for DNA amplification. However, this enzyme denatures irreversibly at the melting temperature 94 °C, new enzyme has to add after each cycle. In 1988, the DNA polymerase was introduced from an organism that habitually lives in very hot environment. The organism tapped for such an enzyme is the thermophilic eubacteria species, *Thermus aquaticus,* and the enzyme is Taq polymerase. Taq polymerase, withstands the high temperature to a certain extent. Primer may be specific primers, the sequence of which was designed based on sequence information. On the other hand extreme anonymous DNA sequence can be amplified by arbitrary primers (Micheli and Bova 1997). Taq enzyme allow the amplification of a much longer DNA segment (as much as 10 kb in length) than the klenow fragment, which can cope up with a maximum of about 400 bp. One disadvantage of Taq polymerase is pre-potentiality of induction of base substitution mutations in the copies of target DNA. This enzyme unlike T4 polymerase, does not possess an appreciable amount of 3'-5' exonuclease activity, and is therefore, incapable of proof reading in the synthesized strands. Taq polymerase incorporate one incorrect nucleotide for about every 2×10^{24} nucleotide incorporated. The Taq polymerase can extend sequence upto 100 bases in length in less than one minute. In general, this group of enzymes adds a non-template specific nucleotide to the 3' termini of the both strand of an amplicon. This addition is predominantly an Adenine (A) residue. In case polymerase enzyme having 5' to 3' exonuclease activity, there is a degradation of bases from 3' end.

For this reason either the enzyme or primers should be added last when setting up the reaction. This problem can be overcome by hot start PCR technique or alternatively by incorporating 3' phosphorylate linkage in the primer during synthesis, using standard oligonucleotide synthesis chemistry.

Polymerization

The extension rate of thermostable polymerase is between 2 and 4 kb per minute. Hence complete strand synthesis of 200 bp to 5 kb amplicon should be accomplished in less than 3 minutes. For longer targets, extension step may be anywhere upto 20 min long. Moreover, adding polymerization time extensions of 15 to 20 sec per cycle can improve specificity, yield and length of such product.

Primers

The aim of good primer design is to maximize both the specificity and efficiency of the amplification reaction. The important parameters to be considered when designing a primer is the ability to form a stable duplex with the specific site on the target DNA and no binding with other primer molecule or any other target site. The primer stability can be measured in the length (base pairs) of a DNA duplex, the GC/AT ratio, Kcal/mol (duplex formation free energy), or in °C (melting temperature).

1. Dimer formation % PCR primers should be free of significant complementarity at their 3' termini as this promotes motion of primer dimer artifacts that reduce the product yield.
2. Self-complimentary primer should be avoided.
3. Melting temperature (TM) stability % PCR product should have a GC/AT ratio similar to or higher than that of the amplification template. A more important factor is the Tm difference between the template and the less stable primer. PCR is efficient if this difference is minimized. If the expected product is 500 bp, select short (16-18 nucleotide) primers. For synthesis of a 5 kb fragment choose about 24 mer.

   TM value of oligonucleotide can be calculated by three formulas given below:

   1. Tm = [2°C (A+T)+4°C(G+C)]

   Accurate for primer upto 20 nucleotides. Use annealing temperature of 3-5°C below the Tm calculated.

2. $Tm = 81.5 + 16.6 [\log_{10} (J^+) + 0.41 (\% G+C) – 6000/L) -0.63 (\% FA)$

Where, (J^+) = Conc. of monovalent cations

L = Oligonucleotide length

FA = Formamide

This is suitable for oligonucleotide of 14-70 residues.

3. $Tp = 22 +1.46 (ln)$

Where, Tp = Optimum annealing temperature within ±2 – 5 °C variation.

ln = Effective length of primers = (Number of G or C) + (Number of A or T).

This formula is suitable for oligonucleotides of 20–35 residues.

Primers that are stable at their 5' termini but somewhat unstable at their 3' ends, perform best in sequencing as well as in PCR. This primer structure effectively eliminates false priming. Therefore, the 5' end and central part of the primer must be also form a duplex with the target DNA site in order to prime efficiently.

PCR based molecular markers

PCR-based molecular markers were identified as having potential utility in corn breeding in the 1980s (Helentjaris et al. 1985, Paterson et al. 1988, Caeteno et al. 1997). There are common molecular markers used today. These are: Random amplified polymorphic DNA (RAPD), Amplified Fragment Length Polymorphism (AFLP), Inter simple sequence repeats (ISSRs) and Simple sequence repeats (SSRs). Various PCR modifications and their functions have been listed in appendix 1.

Random amplified polymorphic DNAs (RAPDs)

RAPDs are 'anonymous' DNA fragments amplified using single short primers, generally 10 bases long, of 'arbitrary' (also termed 'random' or non-specific) sequence. Individual primers operate in both forward and reverse directions, thus amplifying between inverted repeats of the binding sequence, if repeats are close to each other. A single primer is usually able to amplify simultaneously fragments from around 5 to 20 sites in the genome. Amplified fragments are generally separated by agarose gel electrophoresis.

Polymorphism is detected as the presence or absence of products following the application of ethidium bromide or other DNA stains to gels. Polymorphisms arise primarily due to base variation at putative primer annealing sites (primer can, or cannot, bind), although length differences are also possible. When it comes to data analysis, RAPDs are generally assumed to have their origin in nuclear DNA. However, they may more rarely originate from organellar DNA.

RAPDs

Key advantages

As with AFLPs, no sequence data are needed for the organism being tested. Each arbitrary primer can reveal several polymorphic loci. Furthermore, as there are a very large number of different arbitrary primers available, the technique can reveal a very large number of markers. As with AFLPs, loci are distributed through the genome. The RAPD technique and the visualization of products on agarose gels are both very simple methods to perform.

Main disadvantages

RAPDs tend to demonstrate low reproducibility and hence there is a need for tight experimental control of conditions. Low reproducibility makes comparison difficult with other studies and the studies conducted in the same laboratory.

Due to reproducibility concerns, several reputed journals no longer consider for publication any manuscripts that are based primarily on RAPD analysis. When RAPDs are being used, it is important to repeat a subset of reactions in order to check reproducibility: only consistently revealed polymorphisms should be scored. Like AFLPs, RAPD markers are (generally) dominant in nature, limiting the information they can reveal on heterozygosity and requiring assumptions to be made during statistical analysis. In addition, since RAPD amplification depends on non-specific primers, similar sized products revealed in different individuals may not be homologous, especially when making comparisons between species. RAPD analysis is essentially a ‘quantitative’ procedure and the quality of DNA used needs to be good. If DNA is degraded, amplification results will look different from those on intact DNA of the same individual, with a ‘bias’ toward smaller products in the first case. Finally, because RAPD primers are ‘arbitrary’, they may, like AFLPs, amplify contaminating DNA in samples. Clean plant material and good extraction and PCR practice are therefore essential.

Amplified fragment length polymorphisms (AFLPs)

AFLPs are DNA fragments, normally between 80 and 500 base pairs (bp) in length, that are obtained by digesting DNA using restriction enzymes (enzymes that cut DNA at particular sequences), then ligating oligonucleotide adapters to digested products and finally amplifying these sequences by PCR. The PCR primers used are 'semi-specific', consisting of a 'core' adaptor sequence, a restriction enzyme specific sequence, and a 'tail' of one to five other nucleotides. The higher the number of other nucleotides in the 'tail', the lower the number of bands obtained in PCR. Two rounds of amplification ('pre-selective' and 'selective') are normally carried out, the second round using more specific primers (more other nucleotides added to the 'tail') than the first. AFLP banding profiles are the result of variation in restriction sites and in intervening regions. The AFLP technique generates products from many sites in the genome, perhaps revealing 50 to 100 fragments in an individual reaction. Generally, products are separated on polyacrylamide gels. They are then visualized using radioactive, fluorescent, silver staining or other methods. Bands are scored as presence or absence in individuals. When it comes to data analysis, AFLPs are generally assumed to have their origin in nuclear DNA. However, they may more rarely originate from organelles DNA.

AFLPs

Key advantages

The primers for AFLP analysis are commercially available and no sequence data for the organism being tested are needed. This is useful when dealing with less-researched species. Each AFLP reaction can reveal a very large number of polymorphic loci, making the approach excellent for fingerprinting. Loci are reasonably randomly distributed through the genome. The technique is fairly reproducible, which makes comparison between different studies and different laboratories. Polymorphisms can be analyzed using automated methods (on sequencing machines).

Main disadvantages

The technique is quite technically demanding and therefore relatively expensive. Since AFLPs are (generally) scored as dominant markers, certain assumptions on heterozygosity have to be made during statistical analysis. This is a problem when dealing with highly heterozygous organisms such as trees. AFLP analysis relies on enzyme digestion of DNA and so the quality of DNA used for testing needs to be reasonably high, otherwise some samples may not digest properly. In addition, more starting DNA is required

than for other PCR-based techniques. As AFLP primers are only 'semi-specific', they may amplify contaminating DNA in samples, and so clean plant material, good extraction and PCR practice are especially required.

Main differences, RAPDs compared to AFLPs

RAPDs are less reproducible than AFLPs, and the quality of the information they provide is therefore lower. However, the laboratory procedures for RAPDs are simpler, less technically demanding, and therefore less costly, than those for AFLPs. This is the reason why RAPD analysis continues to be used in population genetic studies.

Inter simple sequence repeats (ISSRs)

ISSRs are DNA fragments located between adjacent, oppositely oriented, simple sequence repeats (or SSRs, see more on these below). ISSRs are amplified using 'semi-specific' primers. These consist of simple sequence repeat sequences with a few other nucleotides as anchors into non-repeat adjacent regions. The composition of anchoring bases can be changed in order to reveal different products. The technique exploits the abundance of SSRs in genomes, and about 10 to 60 fragments are generated simultaneously. Products are separated by gel electrophoresis and generally scored as the presence or absence of bands. ISSRs are generally assumed to have their origin in nuclear DNA. However, they may more rarely originate from organellar DNA.

ISSRs

Key advantages

As with RAPDs and AFLPs, no prior sequence data is needed for the organism under study. Each ISSR primer can reveal quite high numbers of polymorphic loci. As with AFLPs and RAPDs, loci are distributed through the genome. The ISSR technique is less technically demanding than AFLPs and more reproducible than RAPDs.

Main disadvantages

Although considered more reproducible than RAPDs, the ISSR technique still suffers from consistency problems. Like AFLPs and RAPDs, ISSR markers are (generally) dominant in nature, limiting the information they can reveal on heterozygosity. Like RAPDs, ISSR analysis is essentially a 'quantitative' procedure, and the quality of DNA used for testing therefore needs to be good. Since ISSR primers are only 'semi-specific', they may, like AFLPs and RAPDs, amplify contaminating DNA in samples.

Main similarities and differences, ISSRs compared to AFLPs and RAPDs

ISSRs, AFLPs and RAPDs all provide dominant markers through the genome. Although ISSRs have some advantages compared to AFLPs (being less technically demanding) and RAPDs (being more reproducible), they have not been applied as widely as either of the other methods. Of the three techniques, AFLP analysis is, if resources allow, considered to be the method of choice.

Simple sequence repeats (SSRs)

SSR polymorphism is based on variation in the number of co-occurring (tandem) short repeats, generally of mono-, di-, tri- or tetra-nucleotides (e.g., [A]n, [CA]n, [AGC]n, [GACA]n), at a site. These repeat regions (otherwise known as microsatellites) have been found to be hypervariable, possibly due to DNA polymerase slippage or mispairing at repeats during the normal replication process. Normally, the more repetitions of a repeat, the more likely it is to be polymorphic. For example, a [CA]10 repeat is more likely to be polymorphic than a [CA]4 repeat. Generally, variation at a single locus only is assessed in a single PCR reaction, although samples are sometimes 'multiplexed' for detection purposes.

Hypervariability means that SSRs are excellent targets when looking for genetic variation. Generally, polymorphism is studied in nuclear DNA, although variation in organellar DNA is sometimes also assessed. Length polymorphisms are generally visualized by running products on polyacrylamide gels. Radioactive, fluorescent, silver staining or other techniques are used for detection. The initial detection of SSRs and their flanking regions, to which pairs of primers can then be designed, relies on DNA sequence information being available. Normally, this means sequencing the species in question, although 'cross-transfer' of primers between species is sometimes possible. In order to obtain species-specific sequence information, enriched libraries (for certain types of repeat) can be constructed from an organism, screened for SSRs, and DNA then sequenced to reveal repeats and flanking regions. Alternatively, database searches (e.g., NCBI) may reveal SSRs and flanking sequences in an organism, although this is unlikely for less-researched species.

For organellar DNA, 'universal' primers are sometimes used to detect SSR variation. Universal primers are those designed to highly conserved sequences of DNA that remain the same across a wide range of genera and even plant families. These conserved sequences flank more

variable regions where polymorphism can be detected.

SSRs

Key advantages

Unlike the techniques above, nuclear SSRs are co-dominant markers that reveal full genotypic information. This is a great strength in detailed population studies, especially for highly heterozygous organisms such as trees. In addition, nuclear SSRs can show extremely high levels of allelic variation at individual loci. It is not unusual for 20 alleles to be observed at one locus in a single population. High allelic variation makes SSRs the method of choice for studying gene flow, paternity and genetic bottlenecks in populations. The technique can give highly reproducible results, and polymorphisms can be analyzed using automated methods (on sequencing machines).

Since the technique relies on specific primers, it can be used on lower quality DNA than dominant marker procedures. SSR analysis is the basis of modern forensic practice using very small quantities of, often, poor quality DNA. As the technique relies on specific sequences, analysis can be targeted to different genomes: nuclear, chloroplast or mitochondrial.

Main disadvantages

Species-specific primer development is relatively expensive and the construction of enriched libraries for the initial detection of SSRs requires technical skill. Sometimes, SSRs are too variable to be useful in comparisons, as there are insufficient common reference points among tested individuals (all differences, no similarities). This has frequently led to misapplication of the approach in cross-population comparisons. In a single reaction, the SSR technique (generally) only assesses variation at a single locus. This is unlike with dominant markers, which can sometimes reveal diversity at very many loci simultaneously. Whether resources are available to carry out sufficient reactions to study sufficient SSR loci to address the question at hand is therefore an important consideration. Although in theory revealing easily interpretable co-dominant markers, assessment of SSRs is not always straightforward. First, ‘stuttering’ often occurs during amplification. This leads to product artifacts and difficulties in accurate sizing. Generally, the smaller the basic repeat, the more problematic is scoring. Second, ‘null’ alleles – in which no amplification of the intended target occurs due to a change in sequence in one of the primer binding sites – are relatively common. This means that what first appears to be a homozygote, with two copies of a particular allele, may in fact be a

heterozygote, with one allele amplifying and the other not. 'Null' alleles result in biased estimates of allelic and genotypic frequencies in populations, and the underestimation of heterozygosity. 'Null' alleles are more likely if using primers originally designed for another species.

Applications of PCR

Evolutionary biology

A DNA sequence amplified with highly evolutionary conserved or universal primer provides a consistent metric for comparison over the range from population to phyla. By judicious selection of primers, DNA's can be selectively amplified from symbiotic organism that cannot be grown in pure culture. DNA isolated from specimens in museum collections will permit studies of genetic variation in population through time.

Forensic analysis

The analysis of individual identity in forensic sample has been greatly facilitated by the amplification of highly polymorphic DNA regions. The capacity of PCR to amplify DNA from sample containing minute amounts of DNA including individual hair or from sample containing partially degraded DNA has allowed genetic type of material that previously could not be characterized.

Developmental biology

The presence of specific mRNA has been examined in mouse embryos by following reverse transcription with DNA amplification. This level of sensitivity will promote our understanding of gene expression during early embryogenesis. One of the first example of an RNA processing event that result in a change in the nucleotide sequence of a messenger RNA was facilitated by the use of PCR (White *et al.*, 1989).

DNA fingerprinting

PCR has been used to study DNA polymorphism in the genome using known sequence can be used as random primers to amplified polymorphic DNA having sequence specific to primers used. Such an application of PCR generates random amplified polymorphic DNA (RAPD). They can be used to detect to constructs RAPD maps similar to RFLP maps (Caetano et al. 1991).

DNA sequencing

Polymorphism at the DNA level can be studied by several means.

The most direct strategy is to be determination of the nucleotide sequence of a defined region and the alignment or this sequence to an orthologous region in the genome of another, more or less related organism. DNA sequencing is mainly applied for evaluating medium and long – distance relatedness in phylogeny, but sometimes it is also used for population studies. DNA sequencing comparatively difficult as well as expensive.

Site directed mutagenesis

The primer must match their template sequence well enough to prime, but they do not have match exactly, especially towards the 5' end. Any mismatch will be incorporated into the product, and will represent changes in the original sequences. This idea, originally called "miss pairing" by Mullis et al. (1987).

RNA finger printing

RNA finger printing is a pattern of amplified cDNA fragment, which is displayed as a finger print on a polyacrylamide gel. Comparison between patterns generated from different RNA population allows differentially expressed species to be detected as difference between the patterns. Differentially amplified cDNAs can then be isolated, sequence and used as a probe to confirm differential expression and to screen cDNA libraries.

Screening of phage libraries

Isolating clone from a cDNA or genomic library often involves the screening the library by several rounds of plating and filter hybridization. This is both laborious and time consuming. These problems can be decreased by use of PCR for the early rounds of screening (prior to conventional filter hybridization screening of multiple genes) using appropriate primers for these genes in the same PCR.

Rapid (Ligase - free) sub cloning of the PCR products

The first step in ligase – free sub cloning is to linearize the plasmid vector at the desired site with appropriate restriction enzyme. The second step is to perform PCR on genomic DNA or cDNA of interest. Like conventional PCR, the primers (primer A and B) must contain sequences at their 3' end (approximately 20- 25 nucleotides) that are complimentary to opposite strand of the target sequence at a predetermined distance from each other. For ligase free sub cloning, primers A and B must also contain sequences at their 5' end, approximately 24 nucleotide in length (designated as the 5' addition sequences), that are identified to each of the 3' ends of the linearized plasmid. Since the two 3' end of the linearized plasmid are

different from each other. The PCR fragment may be sub cloned directionally simply by choosing the appropriate 5' addition sequence for each primer.

PCR amplification using primers A and B will result in PCR product containing 5' addition sequence at each end. Next the PCR product is freed from excess primer and divided into two tubes containing linearized plasmid, tube 1 contain primer A and primer C (cis complementary to the plasmid vector) and tube 2 contain b and d (d is complimentary to the plasmid). After second PCR reaction, the reaction mixture tube 1 and 2 are combined, and denature and allowed for annealing resulting in cyclization. Although cyclized product contains two nicks (non- covalently linked end) it, may be used directly to transform competent *E coli*. Once enter inside the bacterial cell, the two nicks are joined and the recombinant plasmid is replicated.

Cloning PCR fragments

Cloning of PCR products can be done by incorporation of restriction sites into deoxyoligonucleotides primers.

T/A cloning

T/A cloning relies on the terminal deoxynucleotide transferase activity of some polymerases used in PCR. Terminal deoxynucleotidyl transferase (TdT) activity results in addition of one or more nucleotides at the 3' ends of blunt ended DNA molecule (Hu 1993). Example: Taq DNA polymerase extends a single dG nucleotide if the 3' terminal nucleotide on a fragment is a dG but adds dA if the 3' terminal nucleotide is a dC. A 3' terminal dT nucleotide result in the non – addition of a dT and the additional of a dA.

The vector into which dA tailed PCR fragment are to be cloned must contain a 3' T overhanging sequences. This can be obtained either by incubating a blunt ended vector with taq DNA polymerase and an excess of dTTP, or incubating a blunt ended vector with dideoxythymidine triphosphate (ddTTP) and terminal transferase. T4 or *Pfu* polymerase generates blunt ended (e.g) by cutting with *EcoR* V or *Sma I*.

PCR and sequencing from single pollen grain

In order to eliminate the laborious step of DNA extraction preceding all studies within the field of plant molecular biology, attempts were made by Petersen et al. (1996) to do amplification directly on pollen grains. Successful PCR amplification was obtained in reactions including single pollen grains from *hordeum vulgare*. Pollen grains were transferred using

an eyelash attached to a toothpick into microtubes containing 14 µl H_20 and 5 µl standard TQ- buffer for PCR (0.6 M Tris HCl pH 8.5, 20mM $MgCl_2$ 166 mM $(NH_4)_2SO_3$, 0.1 M 2 - mercaptoethanol). Immediately after the transfer, the tubes were heated to 95 ^oC for 10 min to destroy all enzymatic activity. The PCR amplification was performed in 50 µl reaction volume running 30 cycles using the procedure outlined by Saki et al. (1988). The remaining reagents were added after heat treatment of the tubes and amplification was performed. (Petersen et al. 1996).

Identification of plants based on barcoding technology

The search for a plant DNA barcode has focused on genes of the chloroplast genome and several candidates, such as accD, atpF–atpH, matK, nhdJ, psbK–psbI, rbcL, rpoB, rpoC1, and trnH–psbA have been proposed (Chase et al. 2005, Kress et al. 2005, Newmaster et al. 2006, Yoo et al. 2006). Among the candidate barcode genes, matK is one of the most promising candidates for a plant barcode. The matK gene is approximately 1570 bp in length and codes for a maturase protein. The coding region of matK is generally located within an intron of the chloroplast trnK gene, except in some ferns, in which it encodes tRNALys(UUU) (Neuhaus and Link 1987) which is usually amplified (990 bp) by PCR technique. Being a coding region, the very high evolutionary rate of matK has made it usable in phylogenetic reconstructions at high taxonomic levels, such as Order or Family, and sometimes also at low taxonomic levels, such as Genus or Species (Wolfe 1991, Hilu et al. 2003, M¨uller et al. 2006, Chase et al. 2007, Lahaye et al. 2008).

***In situ* PCR on plant tissues**

This technique can be used to understand the complexities of gene expression in plants. The key of successful insitu PCR is the complete removal of the chitin through enzymatic digestion releasing protoplasts that can be spread on to a glass slide for assay. The various signals produced at different developmental stages can be studied with insitu PCR (Benito et al. 1996). Insitu PCR is an emerging tool in virology, cancer research and developmental biology. It has been applied in the study of arbuscular mycorrhiza (AM) fungi to confirm the presence of different alleles in AM fungal genes and also to identify different nuclear population with single spore.

Genome mapping and sequencing

Use of PCR for the rapid construction of synthetic gene

This method is based on early observation of Mullis et al. (1968) in which multiple overlapping oligonucleotides could be used to generate synthetic DNA through several sequential rounds of klenow based PCR amplification. In this method, two sequential PCR reactions are used. The first PCR reaction generates templates DNA corresponding to the synthetic genes, which is then amplified in the second PCR reaction. In general and even number of oligonucleotides should be synthesized and should contain overlap between 15 and 30 nucleotide in length. Outermost oligonucleotide corresponds to opposite strands and be positioned so that they will extent inward towards each other overlap gene. Typically, oligonucleotides should be between 60 and 125 nucleotides in length. Mix overlapping oligonucleotides in a standard PCR reaction and generate a double stranded PCR product then span full length of the synthetic gene. From this take small aliquot of the first a PCR reaction and amplify the synthetic gene in the second strand PCR reaction that contains the flanking primer (A, B). The sequence of the flanking primers should contain restriction sites to facilitate cloning (Modan et al. 1997).

Application of synthetic gene

1. One can design a synthetic gene that contains codon that are preferentially utilized in the organism to be used for protein expression.
2. Synthetic gene can be designed to introduce/ exclude convenient restriction sites for cloning experiments.
3. To study large- scale alterations/ mutational analysis of motifs present in either proteins / transcriptional elements (promoter, termination and so forth).
4. Selection of unique or novel promoter/ protein sequence.
5. Saturation of mutagenesis of gene thought the used of random nucleotide incorporation.

PCR amplification used for monitoring cancer therapy

PCR techniques are capable of detecting as few as 1 cancer cell in 10^6 normal cells, providing a much more sensitive detector for the oncologist. The two PCR primers chosen from the sequence adjacent to the brake point on each chromosome. It is only in cells with translocation

that the primers are brought together so that sequence between them is amplified.

PCR amplification is used to detect bacterial and viral infections

To detect HIV (Human immuno deficiency virus) PCR primers made for sequence in the virus, and PCR is carried out using DNA extracted from peripheral blood cells. This approach detects integrated HIV DNA in infected cells. Detections of *Mycobacterium tuberculosis* by PCR amplification has been performed using primer for a sequence within a gene that are highly conserved in all mycobacterial species.

Bacterial detection

Late blood caused by oomycite pathogen *Phytophthora infestans* is a devestating disease of potato and tomato worldwide. A rapid and accurate detection of *P. infestans* is necessary. Region specific to *P. infestans* was use to contract the PCR primers. It result in 600 bp amplify product with only isolates of *P. infestans* from potato and tomato (Trout et al. 1997).

Plant virus detection

Development of group- , or virus -, or strain specific primers requires nucleotide sequence information for atleast several members of virus group and the more viruses for which sequence information in available, the more likely primers with desired specificity can be designed (Martin 1996).

PCR and transgenic research

PCR can be used to detect the presence of a gene transferred into an organism (transgene) by using the end sequence of the transgene amplification of DNA from the transgenic organism. A small amount of saliva, obtained from mice by oral wash using a plastic pipette tip, contains enough oral epithelial cells and lymphocyte to yield sufficient DNA for nested PCR analysis for both transgene determination and genetic monitoring procedures (Irwin et al. 1996).

Micro-dissected sequence of chromosomes, e.g., of salivary glands chromosomes of drosophila, can be used for amplification to determine the physical location of genes in chromosomes.

PCR amplifications and sex determinations

Male carry unique sequence on Y chromosomes e.g., DYZ1 (3.5

kb) sequence is present on the Y chromosomes in as many as 5000 copies. PCR technique can be used to amplify a 149 bp fragment from DYZ1 sequence which is specific to males.

CONCLUSION

PCR with its capacity for synthesizing millions copies of a specific target DNA fragment from a complex template has a new insights to the problems on molecular genetics, evolutionary biology and development. This rapid, sensitive and automated amplification reaction can be combined with simple non-radioactive methods for detecting the amplified target sequence and therefore, promises to play a crucial role in all DNA based diagnostic procedures.

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Appendix 1. PCR MODIFICATIONS

PCR	MODE OF FUNCTION	REFERENCES
IN SITU PCR	This technique is used to amplify target DNA or RNA within intact cells permitting the co-relation of PCR result with cellular localization and morphology. Fixed cells and tissue are permiabilised and contains and PCR reagents are added to this. Thermal cycling through suitable parameter is followed by detection of PCR products using appropriate methods. E.g. Fluorescence microscopy	Omar B and John H (1997)
Hot Start PCR	Assembling all components of PCR increase the potential of miss-priming before thermal cycling has been initiated. In the Hot Start technique, initial denaturation is performed in the absence of polymerase or primers. Thus enzyme and primer never co-exist below the annealing temperature. Nonspecific priming is minimized and specificity and yield increases.	Aquila et al. (1991)
Nested PCR	When the target is present in low copy number of absolute specificity is essential, nested PCR is often the most essential method of optimization. Nested primer increases the specificity of a PCR. The chance that undesired sequence is amplified would be increased with the increasing number of amplification cycles. Two rounds of PCR consecutively, using two different pairs of primers, One pair (internal primer) within the region amplified by the first pair. Only fragment that has sequence complementary to the second set of primer will be amplified.	Albert and Fenyo (1990)
Long PCR	Routine PCR usually involves the generation of products less than 5 kb in length. This poses no great problem using conventional PCR	Barnes (1994)

	protocols. For amplification of longer genomic fragments, template DNA should be pure. Certain thermostable polymerase is more efficient than others when amplifying long amplicons. Taq Tth, Tli (exo-) and Tbr are capable of producing PCR fragments of at least 12 kb and using optimized buffer and cycling conditions can generate product excess of 20 kb.	
Inverse PCR / Inside Out PCR / IPCR	Inverse PCR is useful in amplifications of DNA flanking region of known sequence. This method is based upon cutting DNA with restriction enzyme and ligating the fragment intra-molecularly to form circular sequence can then be used to amplify a linear fragment which comprises sequence from as specific circular molecule. The amplified sequence is those that flank the core sequence in the genome, their length depending upon the positions of the restriction side on each side.	Ochman et al. (1988)
Alu PCR	This method uses primer for repetitive sequences that are inserted at many places in genomes. One of these elements, the Alu repeat, is present in as many as 9, 00,000 copies in the human genome. This 300 bp Alu repeat is variable, but it contains a sequence that is human specific. Two oligonucleotide primers were made, one in each direction, using the most conserved section of the sequence. The technique is widely used for "rescuing" human DNA sequence from other DNA.	Nisson et al. (1991)
Asymmetric PCR	Asymmetric PCR for producing single stranded DNA for sequencing. One of the two primers for the PCR is present in limiting concentrations. A	Gyllensten and Erlich (1988)

	small number of cycle take places producing double stranded DNA copies of the target sequence until the limiting primer is depleted. The other primer continues to initiate DNA synthesis using as templates the previously synthesized DNA. At end excess of strand remain single stranded. They accumulate at a linear rather than an exponential rate. It is useful in sequencing or for use as a hybridizing probe.	
AP PCR	Arbitrary Primed polymerase chain reaction. Initial cycle of the reaction are performed under low stringency condition (usually achieved with relatively low temperature during the annealing step and/ high $MgCl_2$ concentration in the reaction buffer) competitive between these annealing events results in reproducible and quantitative amplification of many discrete bands. Further amplifications of this sequence under high stringency conditions.	McClelland and Welsh (1994)
Allele – Specific PCR	Alternative forms of a gene (alleles) that differ by a single substitution can exist in population and that alone can be amplified.	Sarkar et al. (1990)
Whole Genome PCR	Amplifications of linker strategy allow application of every DNA sequence present in a complex mixture. It is useful when starting out with a very small amount of a complex DNA and larger amount are desired for some purpose. DNA is digested with as restriction enzyme and the fragment is ligated to as plasmid. Plasmid sequences flanking the insertion site are used for PCR primers. Whole genomes PCR can also applied to the analysis of protein – DNA interaction.	Norman Arnheim and Henry Elrich (1992)
IS - PCR	Insertion Sequence – based polymerase chain reactions (IS - PCR). Primers	Adhikari (1999)

	whose sequences are based on two high – copy insertion elements. ISS112 and ISS1113, Isolated previously from *Xanthamonous Oryzae pv oryzae*, because the element are in high copy and dispersed differently in the genome.	
Rep - PCR	PCR method based on repetitive element sequence such as BOX, ERIC and REP are collectively called as rep-PCR, useful in identifying many phyto-pathogenic bacteria. These sequence are common to most gram- negative bacteria.	Adhikari (1999)
RT - PCR Reverse transcription PCR	PCR can be applied to RNA if the later is reverse transcribed in cDNA prior to amplification. This can be achieved using a separate purified reverse transcriptase, although some DNA polymerase also exhibit reverse transcriptase, activity which allows the whole procedure to be carried out in one reaction vessel. RT- PCR is being increasingly used to plants to study aspects of gene expression and to detect the presence of pathogenic RNA viruses.	Liang and Pardee (1992) Darell (1998)
RADES - PCR	Randomly amplified differentially expressed sequence PCR differ from other differential display method in that the template for the PCR fingerprinting step is amplified double stranded cDNA which can be generated from very small quantities of starting material. Fingerprints visualized by Agarose gel electrophoresis.	Murphy and Pelle (1994)
DDRT- PCR	Differential display. The technique analysis difference in the gene expressions at the mRNA level and both qualitative and quantitative differences can be detected. This method is based on the assumption that virtually all mRNAs can be reversed transcribed and amplified by the polymerase chain reaction. If a sufficiently large set of arbitrary primers	Liang and Pardee (1992)

	is used. cDNA synthesis is initiated by an oligo dT based primer.	
RAP - PCR	RNA arbitrarily primed PCR. First strand cDNA synthesized is primed to an oligonucleotides of arbitrary sequence.	Welsh et al. (1992)
Targeted RNA finger printing	This allows differentially expressed member of specific gene families to be detected and cloned. This involved arbitrarily primed reversed transcription step, cDNA amplification perform using a degenerate primer corresponding to a coding region conserved among the members of specific gene family of interest. It offers the possibility of estimating the proportion of transcripts differentially expressed in different cell types or different physiological, pathological or external conditions.	Stone and Wharton (1994)
LM- PCR	Ligation mediated PCR (LM- PCR) method is used to amplify all fragment of the genome sequence ladder. The unique aspect of LM- PCR is the ligation of an oligonucleotide linker on the 5' each and each DNA molecule. This provide a common sequence obtain the 5' end in the conjugation with a gene specific primer, allows conventional, exponential PCR is to be used for signal amplification.	Muller and Wold (1989)
RS - PCR	RNA template specific PCR (RS - PCR). Total RNA is reverse transcribe using an oligonucleotide primer 47 bp in length whose sequence contain 17 bases at it 3' end (segment d 17) that is complimentary to a region of the target mRNA and 30 based tag at its 5' end. The second strand of the DNA is synthesized the first cycle of PCR with primer U30 and t30. Upstream (sense) primer U30 is a 30 mer whose sequence corresponds to the target RNA a predetermined distanced (optimally 200- 500 base) up streamed from	Shuldiner et al. (1993)

	reversed transcription primer d 17 t 30. Whereas downstream antisense primer t30 is as 30 mer whose sequence is identical to segment t 30 of reverse transcription primer d17 t30. With these primers, sequence derived from RNA that had been tagged with unique sequence t30n during reverse transcription are amplified preferentially, whereas contaminating DNA that lacks the unique tags are not amplified.	
RC - PCR	Recombination circle PCR - amplification to generate products such that when these products are combined, denature and reannealed, they form double stranded DNA with single stranded end that are designed to anneal to each other to yield circle, an application termed recombinant circle PCR.	Jones and Winistorfer (1991)
RP - PCR	RECOMBINATION PCR - used to add homogenous ends to DNA, and in this respect, RP- PCR is similar to RC- PCR. These homologous ends mediated recombination *invivo* following transfection of *E. coli* with linear PCR products, resulting in the formation of DNA joints *invivo*. If these recombinant circles contain plasmid sequence that permit replication and a selectable marker such as an antibiotic resistant gene. *E. coli* can be transformed by the recombinant of interest. RP- PCR provides a rapid method for the recombination and / or site directed mutagenesis of DNA with very few steps.	Jones and Winistorfer (1991)
SSP- PCR	Single specific primer – PCR (SSP-PCR). This method permits amplification of genes to which only as partial sequence information is available, and allow a uni-directional genome walking from known into unknown region of the chromosomes. The chromosomal DNA is digested with one or two restriction enzymes;	Shyamala and Ames (1992)

	the unknown end of the restricted chromosomal DNA is ligated to suitable oligomer of known sequence, sufficiently long to serve as a PCR primer or the unknown end can be ligated to a vector, in which the vector sequence can be used as the primer. The ligation mixture is than amplified.	
Ramp PCR	The annealing temperature is lower from cycle to cycle, usually by 2°C during the first few amplification step. This can be useful if the annealing temperature of a given primer cannot be exactly determined, for e.g. Because of high degree of degeneracy. It can also be applied when primers of widely different TM or Tm are used.	Gilliland et al. (1990)
Competitive RT - PCR	Competitive RT- PCR is a technique that is a commonly used for quantification of specific mRNA species (Gilliland *et al.,* 1990). This procedure involves co amplifications of a competing template that used the same primer as those for the target cDNA, but the amplified products can be distinguished from each other.	Gilliland et al. (1990)
COLD-PCR Co-amplification at lower denaturation temperature-PCR	COLD-PCR is a novel form of PCR that preferentially amplifies mutant alleles in a mutant/wild type mixture when the wild-type allele is in vast excess. Fast COLD-PCR, a variant form of the method, is applied to point mutations or insertion/deletions that lower the melting temperature (Tm) in comparison to the wild-type allele. In Fast COLD-PCR, preferential amplification of a mutant allele is achieved by setting the PCR denaturation temperature during each cycle at the critical temperature (Tc) at which mutant DNA duplexes but not wild type duplexes, are denatured. COLD-	Wang et al. (2008)

	PCR is normally carried out in a thermocycler with independent temperature control of each well, ensuring that Tc is precisely achieved. Well-to-well temperature variation of standard bench thermocyclers is often not within the narrow range required to achieve efficient COLD-PCR mutation enrichment.	
RAPD-PCR	Single Oligonucleotide of arbitary sequence, which primer amplification of several discrete DNA products. Now primer binding sites located with ampliflable distance of each other	Williams et al. (1990)

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Diversity of medicinal plants and their conservation in Darjeeling Hills of Eastern Himalayas, India

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Absttract

Darjeeling hills had long been reported to have abundant plant richness and high endemism. Majority of the species of the region is characterized by great medicinal importance and thus the species are facing high degree of threat. A case study was carried out in four distinguishable forest subtypes (Sites 1, 2, 3 and 4) of Singalila range located between 1800 m and 3100 m altitudinal gradient. A total of 6, 8 and 41 medicinally important tree, shrub and herb species were recorded. Site 1 (1800 m) had the best richness, density and diversity of species amongst all - though the over all values in other Sites were also good. The evenness and diversity values were relatively high. However, status of some plants like, *Aconitum, Swertia, Astilbe, Ophiopogon, Litsea, Zanthoxylum* were unsatisfactory. Ethno-medicinal uses of the recorded plants together with *in situ* and *ex situ* conservation were discussed. Finally domestication of commercially viable species was recommended.

Keywords Darjeeling, Singalila range, Diversity, Medicinal Plant, Ethno medicine, Conservation

Introduction

Biodiversity is not only essential for the very survival of mankind and their economic well-being but also for the general ecosystem stability and functioning. No amount of technological advancement can replace the dependence of man on plants, animals and microbes for food, fuel, fibre,

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fodder and medicine. Despite the rapid strides in the production of synthetic drug, about 80% of the world's population still depends upon traditional plant medicine for primary health care needs.

India is fortunate enough to harbour around 6.8% of the world's flowering plants in the vast land mass (2.46% of world's land area) (Balakrishnan 1996) and was thus identified as one of the top twelve mega-diversity centres of the world. Then, amongst the first order land-forms of India, the mighty Himalayas – lying in between the Indus river in the west and Bramhaputra river in the east for about 2400 Km – was the most influential. It had not only shaped the social, cultural and political spectrum of the country but also was rich in biodiversity due to its varied geographical, topographical, climatic, physiological and ecological zones (Khoshoo 1991). It was estimated that ecological stages in the Himalayas did correspond to latitudinal displacement of over 5000 Km (Anonymous 1977). 'The Himalaya' was thus assigned as one of the 'Biodiversity Hotspots' of the world (Conservation International 2005) and there were an estimated 8000 species of angiosperms (Sharma 2000) of which 3471 species being endemic (Nayar 1996).

It was the eastern part of the Himalayas that had been considered to be floristically the richest due to comparative higher moisture-temperature (Singh and Singh 1985) and was also designated as a Mega-centre of endemic plants for harbouring 1808 endemic species (Nayar 1996). It must be mentioned here that the effects of Pleistocene glaciation were limited in the region so the environment was relatively more stable in the geological past. Consequently, speciation was more developed resulting in higher proportion of endemics (Chatterjee 1939). The richness and diversity of plants in this region was due to the heavy precipitation received from the monsoon winds blowing inland from the Bay of Bengal as it passed the alluvial gap between the Rajmahal hills and the Shillong plateau. Besides, the abruptly rising hills from the plains together with the special horse-shoe shaped arrangement of the fold Mountains rendered maximum rainfall. The region was also in direct contact with many other floristic zones, so there has been free migration of flora from the subtropical, temperate and subalpine regions – rendering the place as one of the richest botanical diversity centres of the subcontinent (Rao 1994). Thus, over a century ago, Clarke (1898), Hooker (1907) and later Chatterjee (1939) had considered a distinct phytogeographic 'Eastern Himalayas' – presently comprising of Arunachal Pradesh, Sikkim and Darjeeling. The present piece deals with Darjeeling hills only.

Physiography of Darjeeling

The Darjeeling is a district of West Bengal state of India, with a geographical area of 3149 Km^2 ($26^0 31' – 27^0 13'$N Lat. and $87^0 59' – 88^0 53'$E Long.) (Fig.1). It shared its boundaries with Sikkim in the north, Nepal and Bhutan to the west and north-east, respectively while Bengal plains were in the south. It was a predominantly mountainous district where hilly tracts occupied 77% (2417 Km^2) of the area and the elevations ranged between 130 m (Sukana) and 3636 m a.m.s.l. (Sandakphu). River Tista flowing southwards from Sikkim bisected the district, while the rivers Ramam, Rangit (between northern ridges) and rivers Mahananda and Balason (on the southern sides) were the other important ones. Besides, the tract was intersected with numerous seasonal, perennial streams and hill torrents cutting deep valleys and ravines. There were heavily wooded ridges, terraced slopes, sprawling tea-gardens, occasional bare grassy patches and congested human settlements.

The climate was primarily determined by altitude, though aspect, slope angle and precipitation had strong influence on the local weather which varied across the gradient. Three main climate zones could be identified – Himalayan Subtropical (foothills - 1500 m), Himalayan Temperate (1500m – 3000m) and Himalayan Subalpine (>3000m). The monsoon and winter seasons were well demarcated and so was spring/ summer. Total annual precipitations reached up to 350 cm, especially in the southern slopes, of which nearly 80% occurred in the rainy season (mid-May – September). While it was hot-humid in the lower altitude with summer temperature reaching 34^0C, but on the whole Darjeeling was identified by cool-moist climate (mean maximum and minimum temperatures were 15^0C and 9^0C, respectively), deficient sunshine (plenty of cloud, rain, fog) and low evapo-transpiration. At higher elevations, frost-snow were common in winter months and temperature dipped to $– 8^0$C.

The soils in Darjeeling were derived out of Darjeeling Gneiss and Daling rocks in the north and south, respectively. Soil properties varied with the nature of underlying bed-rock, aspect, elevation, slope angle and standing vegetation. Generally, the soils were acidic, deep, dark (yellowish-brown, brown, reddish-brown, black) sandy-loam, loam, clay-loam. They were well drained, friable with clear wavy boundary rich in silica but deficient in lime. At higher altitudes, percent organic C was very high (3-6%) because of slow rate of humification. Rock out-crops or exposure of bed-rock was rare. There were distinct litter layer and plentiful roots.

Floristic composition and diversity

Darjeeling though occupied a relatively small area of the Eastern Himalayas but has no less been important floristically. Ever since Hooker (1849) reported collecting 3500 species from these hills, there have been contributions from several authors depicting the richness of flora (Gamble 1875, 1896, Clarke 1876, 1885, Cowan and Cowan 1929b, Biswas 1966, Hara 1966, 1971, Ohashi 1975, Das 1995). More recently, Das et al. (2008) reported an estimate of 2912 vascular species – 2650 species of angiosperms in them – from Darjeeling hills alone. Therefore, this region though occupying only 0.01% of India, harboured about one seventh of the country's flowering plants. Takhtajan (1969) had treated Eastern Himalayas as a 'Cradle of Flowering Plants' from where angiosperms had migrated. Therefore, several very primitive species were recorded from Darjeeling hills – *Alnus nepalensis, Betula alnoides, Holboelia latifolia, Kadsura heteroclita, Cinnamomum sp., Litsea sp., Magnolia sp, Michelia sp.*

The sharp altitudinal gradient and abundant rainfall ensured five distinct forest types (Anonymous 2011). From the foothills to upwards, these were -

1. Northern Subtropical Semi-evergreen; 2. Northern Sub-Tropical Broadleaved Wet Hill; 3. Northern Montane Wet Temperate; 4. East Himalayan Moist Temperate; 5. Sub Alpine

These hills being equidistant from the warm-wet South Asia and cold-dry Central Asia had a matrix of species from far and wide regions. Das (1995) had documented floristic elements from eleven phytogeographical regions. Majority of the representatives were from South-East Asia and Malaya and Sino-Himalayas (37%). There were African, American, Australian and Eurasian species also. Around 14% (151 species) of the species were endemic to Eastern Himalayas, while the proportions of recent exotics were over 10% (112 species). Land connections had ensured migration of Sino-Japano-Malayan elements (Kanai, 1963) and Pleistocene glaciation ensured movement of species from the Himalayas to south India and Africa (Meher-Homji 1972, 1974). It has been argued that some European, American elements and many others were either ignorantly (e.g. *Bidens pilosa, Stellaria media,Galinsoga parviflora*) or wilfully introduced (Tea, Potato, Pineapple, Mandarine orange, *Cinchona*, Strawberry, *Araucaria*, *Cryptomeria*) as cash crop, food crop, garden plants or forest trees (Mukherjee 1994).

The importance of biodiversity is incalculable. Apart from providing

aesthetic and ethical values, biodiversity controls ecosystem function and stability (Singh 1996), ecosystem services (Costanza et al. 1997) possesses precious genetic library (Hinegardner 1976) and provides enormous economic benefits (Costanza et al.1997, Mannion 1995) for human health (Dobson 1995). It is now demanding attention not only for its above significance but also for rapid rate of depletion.

The Himalayas in general and Eastern Himalayas in particular have a rich repository of medicinal and aromatic plants. In Darjeeling hills, number of workers have highlighted enumerative works on the same (Biswas 1956, Yonzone 1981, 1984, Rai and Sharma 1994, Rai et al. 1998, Das and Mandal 2003, Chhetri et al. 2005a, Yonzone et al. 2012b). Howerver, disturbances were common in most of the forests across the Himalaya (Singh and Singh 1992) and the loss of plant diversity was not only due to decline in forest cover but also for species specific habitat loss (Rao 1994). In Darjeeling hills, anthropogenic forces have led to the loss of forest cover (e.g. per capita forest cover has decreased from 0.48 ha in 1901 to 0.23 ha in 1951 and 0.07 ha at present) and decline in species diversity. Bhujel (1996) had estimated 6.5% (123 species) of the total species to be threatened. Later, Chhetri et al. (2005b) categorized 14% of the recorded plants to be threatened, while recent publications have indicated new species (Yonzone et al. 2012a, Rai et al. 2013). Earlier, Nayar (1996) had listed 51 species out of 569 endemics in Sikkim-Darjeeling region to be medicinal. Thus, having sizable proportion of endemic medicinal species, where plants were confined to a narrow and restricted zone with specific habitat requirements, they were more prone to extinction because of the potential threats.

Major drivers affecting the diversity of the region

i. Habitat modification and degradation

Degradation and loss of habitat have been identified as a major factor threatening 91% of plants globally. In Darjeeling, during the past one and a half century majority of the virgin forest tracts had been converted to tea-gardens (ca. 100 odd gardens spread over 37000 ha of land) and agricultural fields (rice, maize, potato, ginger, large cardamom, Mandarin orange etc.) covering 43% (1415 Km^2) of the land area (Anonymous 1 2013). Practically every forest type below 2000m elevation has been affected. Clearings for human settlements, terraced slopes, fertilizer-

pesticide runoff have all contributed to the disruptions of original species composition (Plates 1, 2).

ii. Old forest practices and policies

Darjeeling Forest Division was established in 1878 and since then it had been managed through twelve successive Working Plans. Kurseong and Kalimpong Forest Divisions have been managed through six and nine Working Plans, respectively. Until recently, their primary goal was exploitative, i.e. yield and silvicultural requirements of few important species. Presently, total forest cover of Darjeeling is 38% (1240 Km^2) and there are over 50% tree cover including tea-gardens and other plantations. However, because of century old practices of clear felling, long time gap between felling and re-plantation, mono-specific plantation, introduction of exotic species (like *Cryptomeria japonica*, *Pinus patula*, *Cupressus sp*. *Eucalyptus alba*) have led to subsequent invasion by alien species. Allelopathic effects of these on natural vegetation have gel to the loss of diversity and impoverishment of soil.

Further, Darjeeling had 95% (2996 Km^2) of its land in the rural areas supporting huge livestock population (~6, 20, 000) of grazing animals (cattle, buffalo, sheep, goat, pig) (Anonymous 1 2009). Though grazing in Reserve Forests were banned but the mountainous terrain made it difficult to enforce the law – leading to loss of phytomass and making the slopes prone to landslides (Plate 3).

iii. Collection of plants for Rural and Ethnic Purposes

The rural population of Darjeeling mainly depends upon forests for medicine, fodder, fuel wood and other ethnic uses. With rapid increase in rural population (ca. 11, 18, 860 in 2011 cf. 3, 50, 779 in 1951) demand for forest products by rural people for local use have increased significantly. Official figures are available for the amount of firewood and fodder collected but no authentic record exists for edible-medicinal plants harvested from the wilderness.

It has been reported that ~120 ha of forest land was encroached upon but that is too small in comparison to the ground reality. Population density (585 people Km^{-2}) of Darjeeling was very high compared to other part of Himalaya (Jammu and Kashmir – 124 people Km^{-2}; Himachal Pradesh – 123 people Km^{-2}; Uttarakhand – 189 people Km^{-2}; Sikkim – 86 people Km^{-2}). Encroachment was therefore widespread as the hilly terrain was hardly equipped to handle such a huge population.

PLATE 1 : A deforested hill slope showing human settlement at a distance

PLATE 2 : The sprawling tea garden of Darjeeling (pix. R. Maiti)

PLATE 3 : A *jau* (local cattle breed) grazing in Singalila range

iv. Unplanned Urbanization and Tourism

The urban area of Darjeeling was only 5% (~153.5 Km^{-2}) of its total land area but that held nearly 40% (7, 27, 963 people) of the total people. This was because of very high population growth in the urban areas (decadal growth rate of ~40%) leading to expansion of settlements, roads and other associated paraphernalia. Darjeeling town had a population of 1, 18, 805 in an area of 10.6 Km^2, while Kalimpong and Kurseong towns with areas of 8.68 Km^2 and 5.05 Km^2, respectively had populations of 49,403 and 42,446, respectively (census, 2011). This had resulted in accumulation of huge quantities of urban wastes (due to slower rate of decomposition) that hed also led to the choking of gullies and ultimately to landslips. Furthermore, landslides were very common in rainy season due to heavy precipitation and steep slopes and that have been estimated to affect ~ 0.9% (28 Km^2) of the total land area. (Plates 4, 5).

The economy of the hill was heavily dependent on tourism and was the source of sustenance for many people. According to unofficial estimate, nearly 4 lakh tourists visit Darjeeling hills annually and to cater to that many people there were obvious increase in the number of hotels, amusement parks and vehicular traffic. All these have somewhat been detrimental to the landscape. (Plate 6)

v. Problems of weed and slow regeneration

Both the seedlings and the standing vegetation were adversely affected by the growth of climbers and weeds (Anonymous 1970). Open spaces in the lower elevations of the hill was dominated by common weeds like *Parthenium, Eupatorium, Lantana* and *Mikenia* while in the higher altitudes, fast growing *maling* bamboos (*Arundinaria maling*) mitigated the prospects of other species (Hara, 1966, Ehrenfeld 1980). Dhar et al. (1997) found higher proportion of non-native species in the Central Himalayas and argued that open spaces allowed plant invasion which posed serious threats to overall native plant diversity.

The germination and growth of seedlings were rather slow in the hills resulting in gradual recovery of damaged sites. The presence of thick litter layer and dense canopy cover led to slower regeneration (Singh and Singh 1992, Lorimer et al. 1994). Thus species were more prone to disappear at a faster rate at higher elevations.

The case study

A total of about 1748 species of medicinal plants were reported in

PLATE 4 : The congested Darjeeling town from a distance (pix. R. Maiti)

PLATE 5 : Land slide is a recurrent feature in the hill slopes

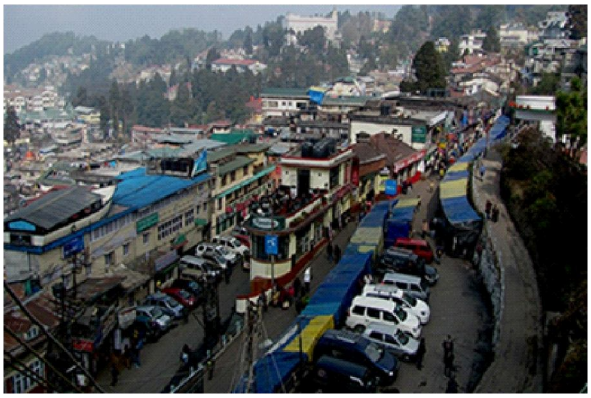


PLATE 6 : Vehicles and shops to cater to tourists need (pix. R. Maiti)

the Indian Himalayan Region (Samant et al. 1998). Out of these, Darjeeling-Sikkim region alone harboured 707 species which was by far the greatest among all the Himalayan states. The region also had the highest proportion of number of species to the geographical area (0.0996) as well as the largest number of medicinal plants per Km^2 of forest land coverage (0.267) (Badola and Aitken 2003). Due to the reasons stated as above, there has been steady depletion in forest cover and plant diversity together with decline in traditional knowledge. Sadly, younger generations were not inclined to acquire ethnic knowledge due to a combination of economic and social causes. It was therefore imperative to make quantitative assessment of medicinal plants and to elicit the composition-diversity of herb, shrub, and tree species and also their medico-ethnic usefulness.

In the Himalayas, species diversity was reported to be highest in between 2000 m and 3000 m elevations (Saxena et al. 1985) which was also evidenced by maximum beta-diversity value, indicating huge variation in habitat and mixing of temperate and subalpine floras (Singh et al. 1994). Thus a case study was carried out in the Singalila range of Darjeeling at the altitudinal gradient between 1800m and 3100m. This tract was selected because of its original species composition with high diversity and medicinal values. (Plates 7, 8).

Study site

The Singalila range was located in the north-western part of Darjeeling ($26^0$59' – $27^0$40'N Lat. and 88^0-$88^0$13' E Long.). It bordered with Nepal and ran in the north-south directions from West Bengal to Sikkim (Fig. 1). The study was carried out in four distinguishable forest sub-types under the East Himalayan Moist Temperate Forest type. The sub-types henceforth to be called Site 1(S1) – Mixed broadleaved 'closed' forest (lower) ; Site 2 (S2) - Mixed broadleaved 'closed' forest (upper); Site 3(S3) – Broadleaved-conifer 'open' forest and Site 4 (S4) – Scrubland (degraded forest) (Table 1). There were preponderance of evergreen broadleaved species but the proportion of conifer to broadleaved species increased with altitude. The selected Sites were 'closed', 'open' and 'degraded' forests that experienced varying degree of biotic pressure in the form of firewood collection, lopping for fodder and other ethnic purposes, grazing, trekking and minor landslips. Forests clearings were aggressively colonized by *maling* bamboos.

The entire gradient experienced the Himalayan Temperate climate which was strongly influenced by monsoon. There were three main seasons – dry spring (March-April), very wet monsoon (June-September) and chilly

PLATE 7 : A Patch of Mixed Broadleaved forest in Singalila range

PLATE 8 : A view of scrubland in Singalila range

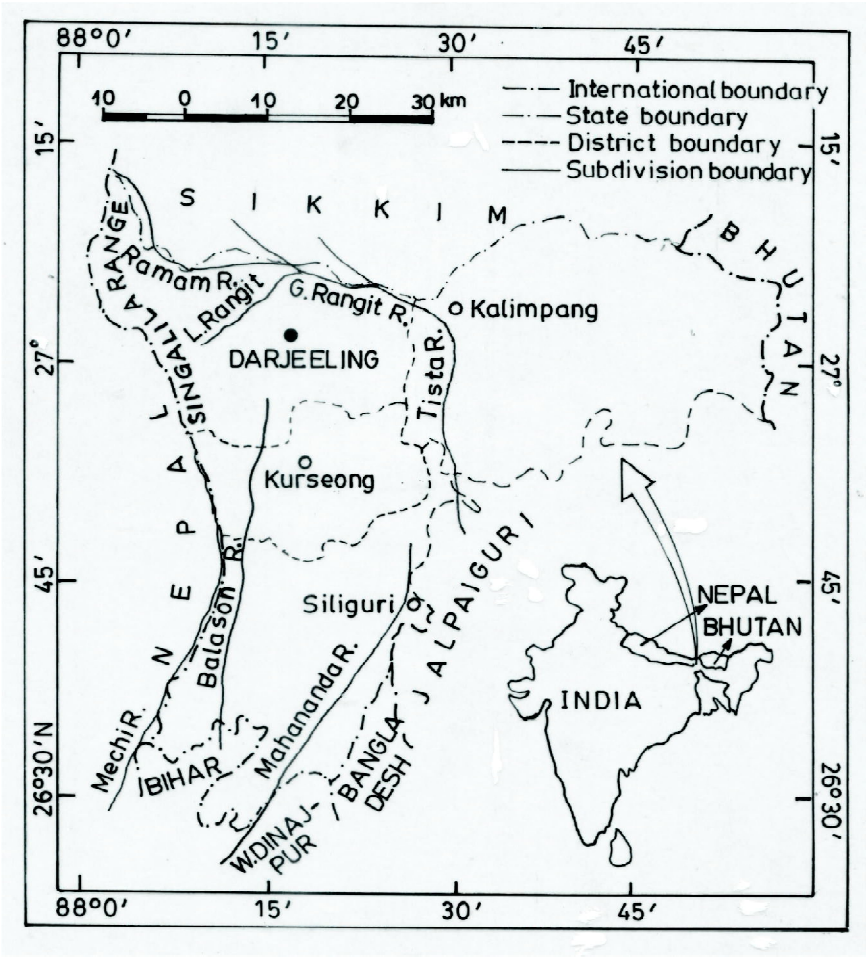


Figure 1 : Map of Darjeeling showing the location of Singalila Range

Table 1 Location and characteristics of the study Sites at Singalila range, Darjeeling

Parameters	Site 1	Site 2	Site 3	Site 4
Aspect	NW, W, SW	E, SE	NE, E, SE	W, SW
Slope Angle (^{0})	30-45	10-40	20-40	30-50
Elevation (m)	1800	2400	2800	3100
Forest Sub-type	Mixed Broad-leaved 'closed' forest (Lower)	Mixed Broad-leaved 'closed' forest (Upper)	Broadleaved conifer 'open' forest	Scrubland (Degraded forest)
Biotic Pressure	Medium	Low	Medium-High	High in the past but now controlled

Herb Density (m^{-2})	51-165	60-179	52-168	46-225
Shrub Density (ha^{-1})	8620	4680	3080	6000
Tree Density (ha^{-1})	740	840	620	No living tree species
Tree Basal Area (m^{-2} ha^{-1})	48.23	63.04	30.33	-
Dominant Tree	Chestnut-Oak	Oak-Rhododendron	Rhododendron-Conifer	-

Soil : Yellowish-brown to dark reddish-brown, acidic (pH 4.9-5.9) sandyloam, with high organic C% (4.5-7.1) and high C:N ratio (15-50). Prominent litter layer.

winter (November-February). Maximum and minimum temperatures ranged between 20^0C and -5^0C. Annual precipitation was high (2500-2800 mm) and relative humidity ranged between 72% (April) and 90% (July).

Methodology

The tree and shrub species were analyzed by laying 30 randomly placed 25 x 4 m quadrats in each Site. In these forests, 100m^2 rectangular quadrats gave better result than square quadrat of similar area (Oostings 1956). Herbs were however, studied by laying 30 permanent quadrates of 1 x 1 m dimension in each Site. The size and number of quadrates needed were determined in the field by species-area curve method (Misra 1968) and running mean method (Kershaw 1973). Frequency, density and abundance of species were determined by following Curtis and McIntosh (1950). The ratio of abundance to frequency was used to interpret the distribution pattern of species (Whitford 1949). The beta-diversity and species richness were evaluated by following Whittaker (1975). Species diversity and evenness were determined by following Shannon-Wiener index (1963) and Pielou's evenness index (1966), respectively. While tree and shrub species were analysed once, the herbs were listed and counted during spring (SP), early monsoon (EM), late monsoon (LM) and winter (WT) seasons. This was performed in order to account for their short life cycle. For the documentation of ethno-medicinal properties, local healer/ medicine man, village elder/headman and priests were interviewed. Their views were cross checked with the existing literatures (Biswas 1956, Jain 1968, Jain 1991, Rai and Sharma 1994, Das and Mandal 2003).

Results and Discussion

A total of 55 medicinally important tree (6), shrub (8) and herb (41) species under 29 family were recorded from the four Sites (Table 2).

Table 2 List of medicinally useful tree, shrub and herb species together with their local names, parts used and uses. Family name given in parenthesis

Species	Local Name	Plant Part(s) Used	Use(s)
		T R E E	
Abies densa Griff. (Pinaceae)	Gobre salla	Leaf	Leaf considered carminative, also used in cough
Cinnamomum impressinervium Meisn. (Lauraceae)	Sissi	Leaf, Bark	Used in dyspepsia and liver complaint
Eurya carvinervis Vesque (Theaceae)	Jhingeni	Leaf	Used in poulticing skin eruptions
Litsea cubeba (Lour.) Persoon (Lauraceae)	Siltimur	Fruit	Antidiabetic; carminative and also used in hysteria
Rhododendron arboreum Smith (Ericaceae)	Laliguras	Flower	A source of country liquor and petals also used in diarrhoea
Symplocos racemosa Roxb. (Symplocaceae)	Chumlane	Bark	Used in diarrhoea; liver complaint and dropsy
		S H R U B	
Aconogonum molle (D. Don) Hara var. *molle* (Polygonaceae)	Thotne	Young shoot	Used in diarrhoea
Dichroa febrifuga Lour. (Hydrangiaceae)	Paharey basak	Root	Used in malarial fever
Eupatorium adenophorum Sperengel (Asteraceae)	Banmara	Shoot	Crushed leaf used in wound and whole plant used as purgative
Hypericum uralum D. Don (Hypericaceae)	Urlio	Seed	Aromatic and stimulant
Osbeckia sikkimensis Craib (Melastomataceae)	Number	Root	Chewed for relief from cough

Urtica dioica L. (Urticaceae)	Ghario sisnu	Young shoot, Root, Seed	Young shoot antidiabetic; root and seed were used in diarrhoea, worms and against haemorrhage, rheumatism
Zanthoxylum armatum DC. (Rutaceae)	Bokey timur	Bark, Fruit and Seed	Considered carminative and used as tonic in fever; antiseptic
Zanthoxylum oxyphyllum Edgw. (Rutaceae)	Lahare timur	Bark	Stimulant and stomachic
		H E R B	
Aconitum spicatum (Bruhl) Stapf (Ranunculaceae)	Bikhuma	Root	The obtained alkaloids have antipyretic and analgesic properties
Ainslea aptera DC. (Asteraceae)		Root	Used in getting relief from stomachache
Ainslea latifolia (D. Don.) Schulz-Bip. (Asteraceae)		Stem-bark	Contains flavanoid
Ajuga lobata D. Don (Lamiaceae)		Whole plant	Used in gout, rheumatism
Anaphalis contorta (D. Don) HK. f. (Asteraceae)	Panson	Flower	Used to stop bleeding
Anemone vitifolia Ham. ex. DC. (Ranunculaceae)	Maaure mulo	Shoot	Fresh juice inhibits growth of pathogenic fungi
Astilbe rivularis D. Don (Saxifragaceae)	Buro okhati	Root-Rhizome	Juice given in peptic ulcer, used in rheumatism, diarrhoea, dysentery
Bidens pilosa L. (Asteraceae)	Kuro	Shoot, Leaf, Flower, Root	Shoot used in leprosy and other skin trouble; Leaf juice used in eye ailment; Flower used in diarrhoea; Root used in colic

Brunella vulgaris L. (Lamiaceae)	Dharu	Shoot	Expectorant and antispasmodic
Calamintha umbrosa (Bieb.) Fisch and Mey. (Lamiaceae)	Padina jhar	Leaf	Leaf juice was used as tonic for gastrointestinal disorder
Ceropegia pubescens Wall. (Asclepiadaceae)	Bansemi	Root	Used as digestive tonic
Chenopodium ambrosioides L. (Chenopodiaceae)		Shoot	Used against intestinal worms
Galium aparine L. (Rubiaceae)		Shoot	Used as aperient, diuretic and antiscorbutic
Galium elegans Wall. (Rubiaceae)	Lahare kuro	Shoot	Used for colic and chest pain
Gentiana pedicellata (D. Don) Wall. ex Griseb. (Gentianaceae)	Chara ko khutta	Root	Used as tonic
Gentiana speciosa (Wall.) Marq. (Gentianaceae)		Root	Used as tonic
Geranium nepaulense Sweet. (Geraniaceae)	Bhand	Root	Used in renal disorder
Gonostegia hirta (Bl.) Miq. (Urticaceae)	Chiple	Root	Used in the treatment of fractured bone
Hydrocotyle javanica Thunb. (Apiaceae)	Dhunri jhar	Leaf	Used as tonic in dysentery and indigestion
Hypericum japonicum Thunb. ex Murray (Hypericaceae)	Simay jhar	Shoot	Used in asthama and dysentery
Impatiens balsamina L. (Balsaminaceae)	Balsam	Flower	Used as tonic; improves circulation; applied to burns
Lobelia nicotianaefolia Roth ex. R and S (Lobeliaceae)		Shoot	Source of alkaloids and used as antiseptic

Melissa parviflora Benth. (Lamiaceae)	Sugandhi	Shoot, Fruit	Shoot considered as antitubercular and antipyretic; Fruit used in hypochondria
Ophiopogon intermedius D. Don. (Liliaceae)		Tuber	Used in dropsy
Osbeckia chinensis L. (Melastomataceae)	Tumbrum	Root	Chewed for relief from cough
Oxalis corniculata L. (Oxalidaceae)	Chariomilo	Leaf	Used in stomach disorder; skin disease and eye infection
Paris polyphylla Smith (Liliaceae)	Satuwa	Rhizome	Used as tonic and has antithelmintic properties
Persicaria capitata (D. Don.) H. Gross (Polygonaceae)	Ratnowlo	Leaf	Used against insect sting
Pilea microphylla (L.) Liebm. (Urticaceae)		Shoot, Leaf	Shoot used in stomach disorder; crushed leaf applied to bruises
Pimpinella diversifolia DC. (Apiaceae)		Shoot	Used as carminative
Plantago major L. (Plantaginaceae)	Chamche jhar	Leaf, Flower, Fruit	Used in throat pain; cuts and wounds
Potentilla fulgens Wall. (Rosaceae)	Banmula	Root	Used in diarrhoea; root paste given in peptic ulcer; also has antidiabetic properties
Ranunculus diffusus DC. (Ranunculaceae)	Nakkor jhar	Leaf	Showed antibacterial activity
Rubia monjith Roxb. ex Flem (Rubiaceae)	Majito	Root, Leaf, Stem	Root was bitter, analgesic antithelmintic, antiseptic and also used as tonic; Leaf and stem used as vermifuge
Rumex nepalensis Sprengel (Polygonaceae)	Halhale	Young-shoot, Root	Used in skin diseases, syphillis and colic; substitute for rhubarb

Sanicula elata Ham. (Apiaceae)		Whole plant	Used in diarrhoea and pulmonary diseases
Stellaria alsine Grimm. var. *undulata* (Thunb.) Ohwi (Caryophyllaceae)	Karnaful jhar	Leaf	Decoction used as galactagogue
Stellaria vistata Kurz (Caryophyllaceae)	Karnaful jhar	Leaf	Used to relieve boneache and rheumatism
Swertia bimaculata (Sieb. and Zucc.) HK.f. and Th. ex Clarke (Gentianaceae)	Bhale chirata	Whole plant	Used as a substitute for *Swertia chirayita*
Swertia chirayita (Roxb.) Karston (Gentianaceae)	Pothi chirata	Whole plant	Used as tonic and febrifuge; used in asthama and liver disorder
Viola pilosa Bl. (Violaceae)	Ghatte ghans	Leaf, Flower, Shoot, Root	Leaf yielded medicinal oil; Flower improved general complexion; Shoot formed an ingredient of joshanda – an Unani medicine; Root was febrifuge, tonic, diuretic, expectorant and purgative

Tree and shrub

There was only one conifer among the 6 tree species. The Sites 1, 2 and 3 had 3, 3, and 2 species, respectively while Site 4 had no living tree species. The densities were rather high and ranged from 260 ha^{-1} (S2) to 120 ha^{-1} (S1). The status of *Rhododendron sp.* and *Eurya sp*. were satisfactory, but *Cinnamomum sp.* and *Litsea sp.* were rare as was also observed by Yonzone et al. (2012a).

Of the 8 shrub species, 7 species were recorded at Site 1 itself, while in the other three Sites there were 2 species each. Naturally, the density was exceptionally high at S1(2900 ha^{-1}) but became progressively less along the gradient (240 ha^{-1} at S4) (Table 3). The warmer-wetter conditions in the lower altitude (S1) seemed to favour shrub growth, where *Eupatorium sp*. and *Dichroa sp*. were most abundant. The status of *Zanthoxylum armatum* appeared unsatisfactory (Rai *et al.,* 2013).

Herb

Amongst the 41 herb species, there were total of 29, 22, 21 and 22 species in Sites 1, 2, 3 and 4, respectively (Table 4). S1 was richer and had slightly better density despite massive shrub layer. *Plantago sp.*was abundant throughout the year, together with *Hydrocotyle sp.*, *Chenopodium sp*. and *Geranium sp.* In S2, S3 and S4 species richness was similar and there were abundance of same few species, like – *Geranium sp*. and *Viola sp*. (S2), *Hydrocotyle sp.* and *Viola sp.* (S3) and *Ajuga sp., Pimpinella sp*. and *Viola sp*.(S4). The average density value of S3 was lower than other Sites in spite of the 'open' nature of the forest indicating anthropogenic disturbances. In these Sites, while the number of species did not vary remarkably over the seasons, the density fluctuated appreciably thus showing no relationship between the number of species and their corresponding density. The dominating presence of *Geranium sp.*, *Hydrocotyle sp., Plantago sp.*and *Viola sp.* in all the Sites covering the entire gradient of 1300 m was noteworthy for their adaptability in 'closed' 'open' and 'degraded' forests. But the status of *Aconitum sp*., *Astilbe sp*., *Ophiopogon sp*., *Paris sp*., and *Swertia spp*. were found to be unsatisfactory as was also observed earlier by Rao (1994), Mukherjee (1994), Bhujel and Das (2002), Yonzone et al. (2012a).

Distribution and diversity

The tree, shrub and herb species across the gradient showed absolute to predominantly contagious distribution patterns. This was typical of natural vegetation which was either because of clumped distribution of

resources (likeable micro-habitat) or for a general tendency of the off springs to remain in the vicinity of parents or as a result of social inclination of individuals to form groups. Such distribution though caused competition but the species were so distinct as to enable themselves to co-exist.

The species diversity in the Eastern Himalayas was higher than any other Himalayan region (Singh and Singh 1985). The mixed nature of the forest under study indicated mid-successional stage (Singh and Singh 1987). It was at this stage that the species diversity approached maximum level (Loucks 1970). The diversity values for all the medicinal plant layers were found to be high (Table 3 and 4). Tree and shrub species diversity

Table 3 Richness (number of species), density and diversity of tree and shrub layers in the study Sites. Evenness value is given in parenthesis below the respective diversity value

	Richness		Density (ha^{-1})		Tree Basal Area (m^2 ha^{-1})	Diversity	
	Tree	Shrub	Tree	Shrub		Tree	Shrub
Site 1	3	7	120	2900	1.99	1.46 (0.92)	2.27 (0.81)
Site 2	3	2	260	480	6.37	1.32 (0.83)	0.74 (0.74)
Site 3	2	2	160	380	6.94	0.95 (0.95)	0.63 (0.63)
Site 4	-	2	-	240	-	-	0.65 (0.65)

Table 4 Richness (number of species), density and diversity of herb layer in the different season of the study Sites. Evenness value is given in parenthesis below the respective diversity value

	Richness				Density (m^{-2})				Diversity			
	SP	EM	LM	WT	SP	EM	LM	WT	SP	EM	LM	WT
Site-1	13	16	11	11	93.4	39.8	44.2	28.8	3.31 (0.90)	3.30 (0.84)	3.17 (0.95)	3.11 (0.90)
Site-2	9	10	12	10	38.6	72.8	63.6	26.6	2.41 (0.80)	2.55 (0.77)	2.57 (0.72)	3.00 (0.90)
Site-3	8	9	10	11	24.8	53.6	41.0	24.0	2.38 (0.79)	2.52 (0.79)	2.78 (0.84)	2.94 (0.85)
Site-4	8	10	14	10	79.8	28.0	62.4	19.0	2.31 (0.77)	2.78 (0.84)	3.05 (0.92)	3.35 (0.88)

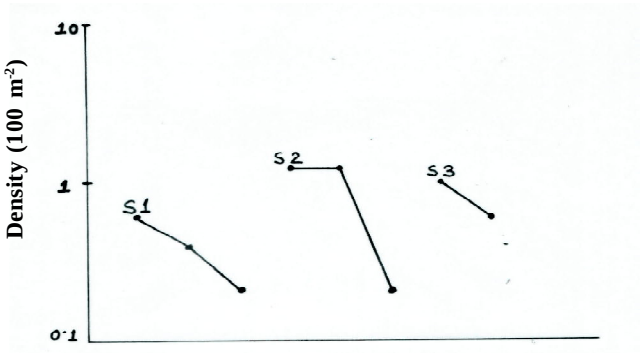
SP – Spring; EM – Early Monsoon; LM – Late Monsoon; WT – Winter.

was maximum in Site 1 and then became succeedingly lower at higher elevations. For herbs, the seasonal diversity values were far more relevant than the altitudinal. In Site 1, the values were in the order of SP>EM>LM>WT suggesting that spring thaw and monsoon waters encouraged germination. Whereas in the Sites 2 3 and 4, the trend was just the reverse i.e. WT>LM>EM>SP. This was a significant observation because harsh winter climate obviously enhanced herb diversity at higher altitudes. It seems that the winter season probably represented favourable conditions for the emergence of a wide array of winter annuals of short life-span and limited numbers. These annuals could be considered as ecological opportunists since anthropogenic disturbances in winter were reduced to a minimum (and increased from spring onwards). Then again, diversity across the gradient for any particular season showed comparatively higher values in S1 andS4 than S 2 and S3. It thus seemed that the lower, warmer-wetter (S1) and higher, cooler-drier (S4) conditions favoured herb diversification more than the intermediate zone (S2 and S3).

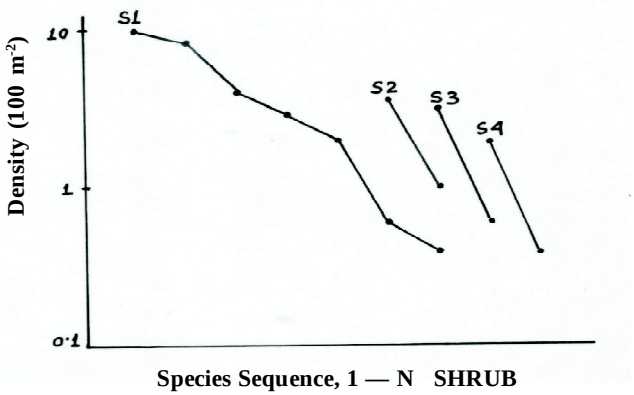
With species richness on the abscissa and evenness on the slope, dominance-diversity curve was thought to be the best empirical description of species diversity. (Figures 2 – A, B, C D and E). The curves for herb layer at every season for all the Sites were either flattened or intermediate sigmoid type that approached lognormal model (Preston 1948). Even for shrub and tree layers at S1, it was the same. This was expected in communities that had reached maturity and where each species population was existing under the optimum conditions directed by the dominance of canopy (Shimwell 1971). So, in spite of greater biotic pressures and relative cooler-drier climate at S3 and S4 - the evenness was good which augur well for the respective populations. (The steep curves for tree and shrub layers at S2, S3 and S4 could be misleading as they were represented by two species only).

The beta diversity values for tree and shrub species were 3.00 and 2.46, respectively. While the same for herbs in SP, EM, LM and WT seasons were 4.32, 3.64, 3.49 and 3.90, respectively. Since, beta diversity was the measure of change in species composition across the gradient, there seemed to be rapid change in between the Sites for all the layers, especially the herbs. The relative high values of both alpha-diversity and beta-diversity in the study area were suggestive of rather high niche specialization which indicated high niche complementarity and an overall high regional diversity.

The status of medicinal plants in Singalila range alone might not be the reflection of entire Darjeeling hills but still did illustrate the richness,

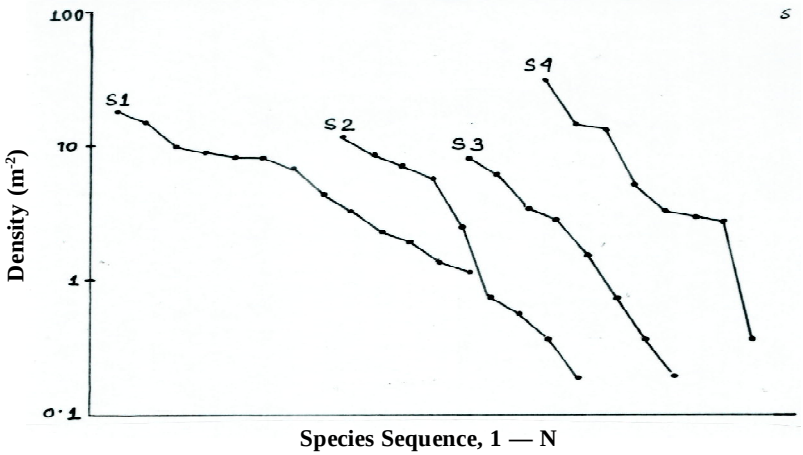


Species Sequence, 1 — N Tree



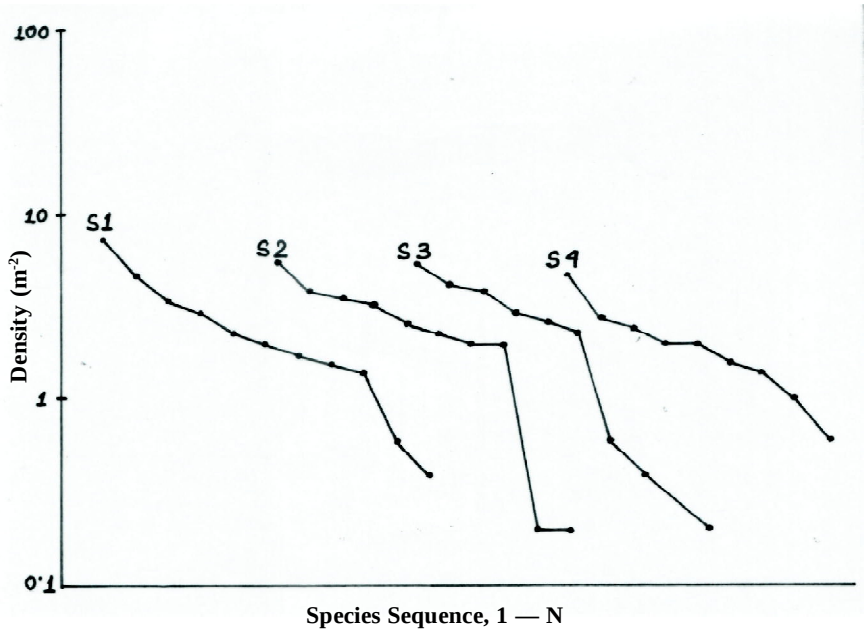
Species Sequence, 1 — N SHRUB

Fig. 2 A



Species Sequence, 1 — N

Fig. 2 B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Density (m-2)
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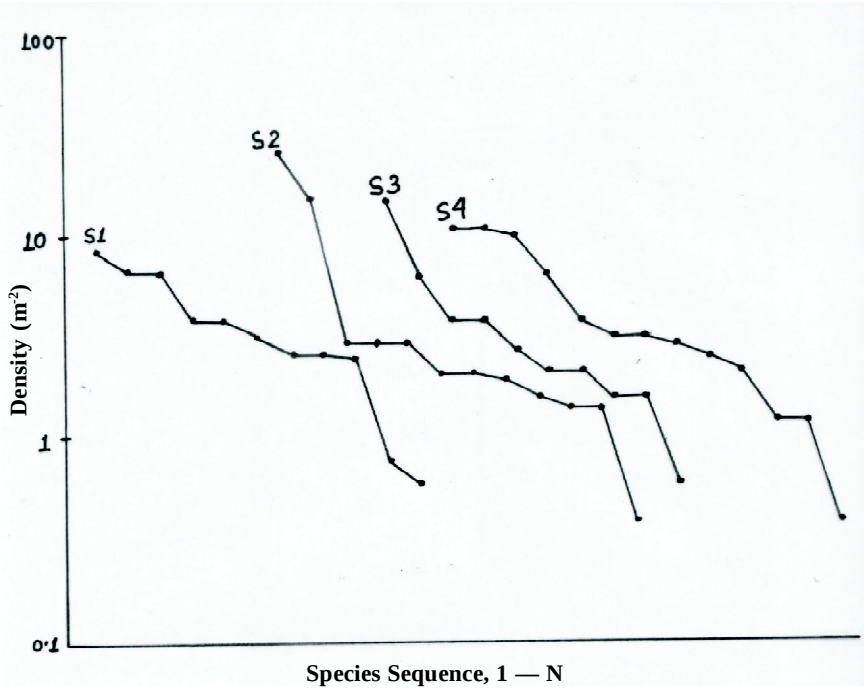
S2
S3
S4
Species Sequence, 1 — N

Fig. 2 C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Density (m-2)
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S2
S3
S4
Species Sequence, 1 — N

Fig. 2 D

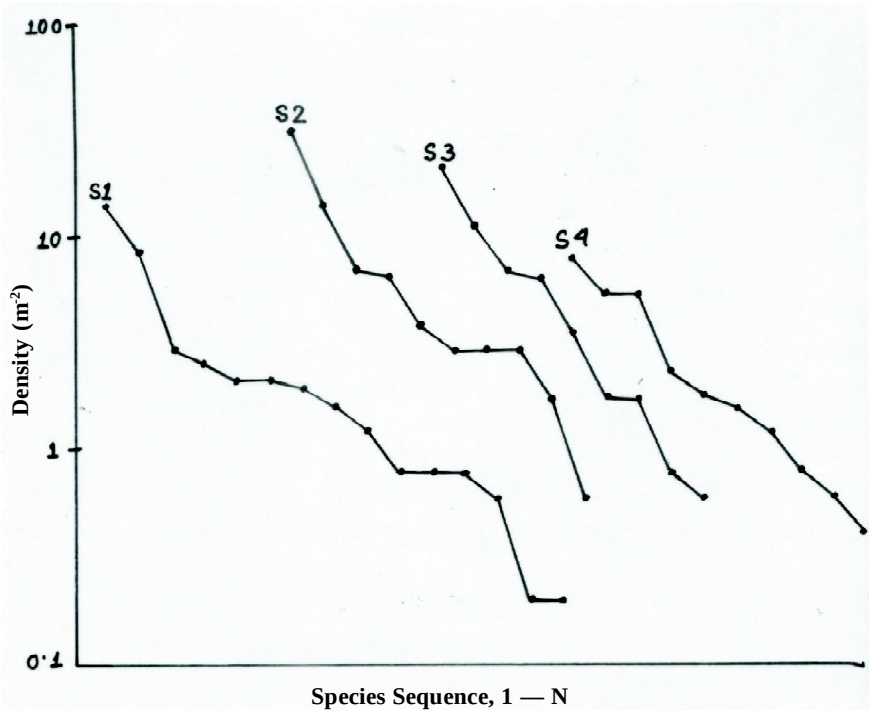

Fig. 2 E

Figure 2 : Dominance-Diversity curves in terms density of species in the Sites 1, 2, 3 and 4 (S1, S2, S3 and S4) of Singalila Range, Darjeeling

A : Medicinal Tree and Shrub

B : Medicinal herb – Spring

C : Medicinal herb – Early Monsoon

D : Medicinal herb – Late Monsoon

E : Medicinal herb – Winter

density, diversity of such species in 'closed' 'open' and 'degraded' forest tracts. The herb layer showed high density and diversity even in disturbed Sites but then the region was known to harbour more than fifty percent herbs in the total estimated species (Das 1986). The average herb density-diversity in the 'closed' forests was comparable even with the 'open-degraded' Sites. Remarkable had also been the satisfactory shrub and tree layers density thus contradicting the notion that dominance of one layer adversely affected the other layers.

Ethnomedicine

Of the entire medicinally useful herb, shrub and tree species recorded, there were as many as 26 species (47%) that had multiple uses. A sizable proportion of plants – 21 species (38%), were used in stomach disorders. The latter happened to be the most common ailment in the hills. Fever- cough and cold were cured by 8 species. Besides, there were plants used against wide variety of ailments like – malarial fever (*Dichroa sp.*), diabetes (*Urtica sp., Potentilla sp.*), renal disorders (*Geranium sp.*), bone fracture (*Gonostegia sp.*), leprosy (*Bidens sp.*) rheumatism (*Stellaria sp., Ajuga sp.*), syphilis (*Rumex sp.*), intestinal worms (*Paris sp., Chenopodium sp.*). Plants were also used as tonic (*Gentiana sp.*) and stimulant (*Zanthoxylum sp.*). Practically every plant part – young-shoot, bark, leaf, flower, fruit, seed, root-rhizome-tubers were used (Table 2). Many of these species were important for being either endemic – *Abies densa, Aconitum spicatum, Hydrocotyle javanica, Rhododendron arboreum, Zanthoxylum oxyphyllum* (Chouhan 1996, Bhujel and Das 2002) or for being primitive angiospermic genera – *Cinnamomum* and *Litsea* (Rao 1994). Amongst the species recorded in this study the density of the following were found to be unsatisfactory – *Aconitum sp., Astilbe sp., Swertia spp., Zanthoxylum sp., Ceropegia sp., Hypericum sp., Litsea sp., Lobelia sp., Ophiopogon sp., Osbeckia sp., Paris sp., Potentilla sp.,* and *Rumex sp.*. While the first four species were harvested for both local as well as commercial gains, the rest were only used locally.

The population of Darjeeling was large – 18,46,823 (census 2011) comprising mostly of Nepalese people – a conglomerate of over twenty ethnic groups and still more number of subgroups (mongoloid tribals like - Limbu, Tamang, Sherpa, Yolmo etc. and non-mongoloids like - Chettri, Bahun, Kami, Damai etc.), Bhutia and Lepcha (autochthonous people of the region). [There were also people from the plains who were mostly urban dwellers]. These people had strong ethnomedicinal tradition which was due to combinations of tribal-rural life-style, plethora of medicinal plants in the surroundings, tough mountainous terrain forming natural barriers and most importantly, paucity of modern medical facilities near at hand. Even today, there were only 412 medical centres and sub-centres offering 166 beds per lakh people. (Anonymous 1 2013). The local people were mostly engaged in agriculture, animal husbandry, agro-forestry, tea plantation works or as marginal players in tourism business. Small land holdings, subsistence agriculture, lack of irrigation (only 2.67% irrigated area to cultivated area), low crop yield, lack of industry and low job opportunity (11,63,097 non workers, census 2011) have kept the people rather poor and thus have

prevented them from accessing modern, costly allopathic medicine. Not only in the rural areas but also in the towns there were *Jhakri*, *Bijuwa*, *Fedangma* (Nepalese medicine men) *Bungthing* (Lepcha medicine man), *Lama* (Bhutia priests) to whom people turned up for medical assistance. (PLATE 9)

PLATE 9 : A *Jhakr*i in ceremonial attire (pix. Chinlop)

Conservation

India has the lowest per capita consumption of drugs in the world because traditional medicinal practices were still prevalent in the country (Anonymous 2000). There were about 8000 species of medicinal plants used in the traditional Indian medicines (Anonymous 1997). Out of these, only 700 plant species were used in the herbal industry (Ved et al.1998) of which again 350 species were from the Indian Himalayan region (Purohit 1997). Only a handful of these plants were in commercial cultivation (Nautiyal et al. 1997). Thus it could be assumed that over 90% of the plant raw materials for herbal industries and export were drawn from natural habitat (Tandon 1996, Gupta et al. 1998). Since 70% of the taxa were

harvested by unsustainable destructive methods there were severe depletion in population (Dhar et al., 2000).

In Darjeeling hills there were no authentic data depicting the actual amount of medicinal plants collected from the wilds. It could be assumed to be huge (in keeping with the huge population) because studies carried out in the neighbouring Sikkim showed annual collection of *Aconitum sp*., *Nardostachys sp*., *Picrorhiza sp*. and *Swertia sp*. to be 10720 Kg, 31000 Kg, 6200 Kg and 3440 Kg, respectively. The harvest pressures for these species were – 1.51 Kg Km^{-2}, 4.37 Kg Km^{-2}, 0.87 Kg Km^{-2} and 0.48 Kg Km^{-2}, respectively (Rai *et al.*, 2000). This calls for vigorous conservational efforts since the species were no longer in use locally but were extracted for profit without a care for re-plantation.

Both *in situ* and *ex situ* conservational practices have been going on in Darjeeling which might convey an impression of healthy stock of medicinal plants. However, in the present study very important species like *Artemisia vulgaris, Hedychium coronarium, Nardostachys jatamansi, Panex pseudo-ginseng, Picrorhiza kurrooa, Podophyllum hexandrum, Sassurea costus, Taxus baccata,* were observed as few scattered individuals on the hill slopes but could not be quantified since they did not fall within the sampling plots. [Several medicinal species of Darjeeling hills were already in the Red Data Book Vol, I, II and III (Nayar and Shastry 1987, 1988, 1990)].

In situ

Over 10% of Darjeeling land area were protected (333 Km^{-2}). There were two National Parks – Singalila N. P. (78.6 Km^2), Neora valley N. P. (88 Km^2) and three Wildlife Sanctuaries – Senchal WLS (38.9 Km^2), Mahananda WLS (158 Km^2) and Jorepokhari WLS (0.04 Km^2) for the protection of wildlife and plants. Unfortunately though, these were located far apart with no corridor amongst them. Recently, two Medicinal Plant Conservation Areas (MPCA) have been established in the hills. In the Dhotrey MPCA (180 ha.) there were five prioritized species though 154 species have been identified with *Taxus, Panax* and *Swertia* being the targeted and flagship species. In the Tonglu MPCA (230 ha.) there were ten prioritized species though 254 species have been identified with *Aconitum, Barberis, Panax, Picrorhiza, Podophyllum, Swertia* and *Thalictrum* being the targeted and flagship species. Grazing, casual entry and collection of NTFP and MFP were controlled through the formation of JFMCs, FPCs and SHGs who were also trained to manage weeds and create fire lines. The authorities intend to collect the seeds of medicinal

plants, germinate the same in nurseries and later distribute them to villagers/ medicine-men and try to market the product (Anonymous 2009).(PLATE 10)

PLATE 10 : The Tonglu MPCA falls in a popular trekking route

Ex-situ

Cinchona cultivation in commercial scale had started in Darjeeling in 1862. Under the Directorate of Cinchona and Other Medicinal Plants - the plantation had a total coverage of over 10,000 ha. in four separate plantations (Mungpoo, Munsong, Latpanchor and Rongo) and a RandD section (Ambotia). While cinchona cultivation occupied the maximum area (nearly 3000 ha.) there were also cultivations of ipecac, *Artemisia,Citronella, Dioscorea, Taxus*, *Vetiver,* large cardamom, lemon grass, Mandarin orange, mulberry, rubber, turmeric. There were nurseries of eight other medicinal plants (e.g. *Withania, Rauvolfia*) covering 400 ha. (Anonymous 2013).

The state Forest Department also propagated 129 medicinal species in nurseries spreading over fourteen locations (Saini 2000). Then there were handful of NGOs, charitable organizations, missionaries who were involved in cultivation and marketing of few selected species for rural up-liftment (Chhetri et al. 2005b). The University of North Bengal had also started a Garden of Medicinal Plants in its campus that was home to over

550 species (Das and Ghosh 2009). The Lloyd's Botanical Garden in Darjeeling (established 1878) housed over hundred species of trees, climbers and orchids including some living fossils (*Gingko biloba* and *Metasequoia glyptostroboides*) and also maintained medicinal plant garden.

Domestication of species

It has been felt that *in situ* and *ex situ* conservational practices might not be entirely effective since huge numbers of medicinal plants formed a part of economic network for many people and for many years. Therefore, selected species may be domesticated and propagated to serve as cash crop for villagers which would not only reduce the pressure on natural population but would also rehabilitate endangered plants (Nautiyal 1995). Conservational programmes cannot succeed without people's participation and when local populace get a share of gain from the programme, they tend to embrace it. The conventional agricultural practices in the hills gave low yield and poor returns [Total food grain yield rate in Darjeeling was 2168Kg ha^{-1} (2010-11) while the state average for the same was 2663Kg ha^{-1} (2010-11), *Economic Review* (2011-12)]. On the other hand, cultivation of medicinal plants that grew naturally in the region (*Aconitum, Swertia, Nardostachys* etc.) could bring in high returns. There were several advantages to it like –

- having higher value per unit volume, the cultivation in small plots would suffice (even house backyards) without expensive agricultural implements/techniques;
- then, smaller volume made sense for transport limitations in the hills;
- being local species, these plants need not have difficulty in acclimatizing in the field;
- besides, a continuous harvest could control the quantity of yield, reduce pilferage from the wilds (thus control the quality and the pricing).

All these would generate income at the grass-root level and also help in landscape restoration (Rao and Saxena 1994, Nautiyal 1996, Dhar et al. 2002). Rai and Sharma (1994) had categorized 40 species on the basis of potency and marketable value, where – Group A, were marketed in large scale (5 species e.g. *Swertia*); Group B, were marketed in small scale (13 species, e.g. *Zanthoxylum*); Group C, effective and locally used but not marketed (9 species, e.g. *Urtica*); Group D, recently explored plants (3 species, e.g. *Taxus*) and Group E, with claims as drug source (10 species,

e.g. *Dichroa*). Chettri et al. (2005) reported *Aconitum sp.* selling @ Rs. 1350 Kg^{-1} and *Rubia monjith* @ Rs. 650 Ton^{-1} in local markets of Sikkim. Interviewing the traders/dealers in herbal medicine in Siliguri (a major trading town in North Bengal) following facts were obtained – *Swertia* @ Rs 400 Kg^{-1}(Siliguri) and Rs 550 Kg^{-1} (Kolkata); *Nardostachys* @ Rs 500 Kg^{-1} (Siliguri); *Picrorhiza* @ Rs 500 Kg^{-1}(Siliguri) and @ Rs 700 Kg^{-1}(Mumbai); *Gymnema* @ Rs 165 Kg^{-1}(Kolkata); *Zanthoxylum* @ Rs 150 – 250 Kg^{-1} (Sikkim); *Panax* @ Rs 100 for each 6 inch piece (Siliguri). It was thus evident that medicinal plants fetched good money.

However, commercial cultivation was still in its infancy due to several constraints like -

- the initial hesitation of villagers to take up cultivation of new crop in want of guidance and motivation;
- more so, since such farming required a gestation period of few years and during that period, the poor farmers would lack cash and were thus reluctant to take up the risk;
- besides, there were also a general lack of agronomic knowledge for such cultivation and post harvest practices;
- but most importantly, it was the paucity of marketing facility for their products (Kop et al. 2006, Purohit 1997, Hussain and Hore 2007).

Medicinal plant market was unorganized and the trade unregulated. The plants were normally marketed in the private sector and in between the farmer/collector and the market/industry there were several middlemen who controlled the market. These men usually took advantage of the villager's ignorance in market information and have a hold over them through a combination of ready credit, quick payment and also absorbed the risks through good organization (Pswaravyi–Riddihuge and Jone 1995).

With the establishment of National Medicinal Plant Board and State Medicinal Plant Boards the government had taken initiative in streamlining and coordinating the collection/cultivation, trade and conservation of medicinal plants. There were now prioritized species whose export/trade were prohibited/restricted and other species who were encouraged to be cultivated. In West Bengal there were 46 prioritized medicinal plant species of which 29 species were much prioritized i.e. whose trade was prohibited if collected from the wild (e.g. *Aconitum*, *Swertia*). The Board also encouraged people to cultivate specific plants according to the topographic profile of the district. For the hills and terai regions of Bengal, 18 species

have been recommended, some notable among them were - *Aconitum, Acorus, Aristolochia, Dioscorea, Gingko, Gymnema, Picrorhiza* and *Swertia*. (PLATE 11, PLATE 12)

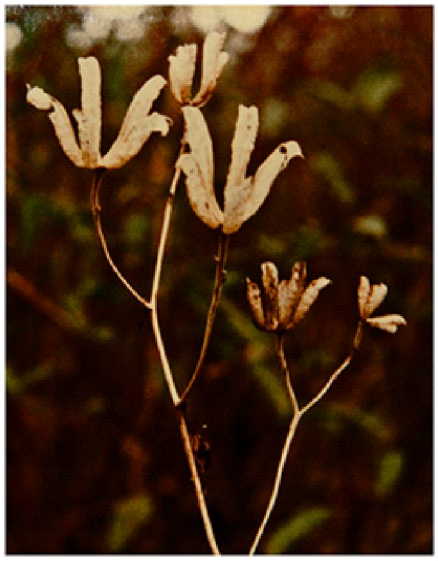

PLATE 11 : A standing dry twig of *Aconitum sp*

PLATE 12 : A standing dry specimen of *Swertia bimaculata*

The world herbal trade was $70 billion with an annual growth of 7% (Anonymous 2000). Presently that trade stood at $120 billion and was poised to grow to $7 trillion by 2050 (www.nmpb.nic.in). So India could play an important role, given its vast array of medicinal plants. Quite surprisingly, trade of these plants though carried out in open market but was still held in secrecy. Names of collectors, middlemen and traders were withheld. Enquiries on quantity and quality were viewed with suspicion or were given wrong information. (The author faced some hostility in trying to collect information). However, if the government can take initiative and make arrangements for industries to purchase raw materials from cultivators and licensed contractors in schedule rates, then cultivation of medicinal plants can act as a bridge between preservation of biodiversity and traditional knowledge on one hand and sustainable economic development and basic health care on the other.

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Biodiversity conservation in agro- ecosystem for future food security

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Abstract

Agro-ecosystem contains enormous biodiversity that fulfills the day to day need of human beings. Over exploitation of these diverse resources from the agro-ecosystem has led to the disappearance of many species is a matter of serious concern and poses a serious threat to the very existence of human civilization. This study has tried to evaluate the various species and their role in the agro-ecosystem. Further, the role of coordinated and concerted effort from all the stakeholders (i.e. policy makers, researchers, environmental activists, farmers and indigenous tribal) has been suggested to work together for the conservation of diversity in the agro-ecosystem.

Keywords Agroforstry, food security, biodiversity conservation

Introduction

Biodiversity is the extent of variation of living beings and this variability may exist between the plants, animals, microorganisms, the genes they contain and the ecosystem they form. It maintains the life support system in the earth through continuous interaction between and within the species and with the surrounding environment. Biological diversity is used to describe the number, variety and variability of living organisms within each variety or species in a given ecosystem (Heywood and Baste 1995). Biodiversity is usually considered at three different levels: genetic, species and ecosystem diversity. Genetic diversity refers to the variety of genetic information contained in all of the individual plants, animals and microorganisms. Genetic diversity occurs within and between populations of species, and between species. Species diversity refers to the variety of

living species. Ecosystem diversity relates to the variety of habitats, biotic communities, and ecological processes, as well as the tremendous diversity present within ecosystems in terms of habitat differences and the variety of ecological processes (Commonwealth of Australia 1993). However, Professor Anthony Campbell defined a fourth level of diversity i.e. molecular diversity.

Biodiversity is an essential resource to meet the multiple need of human civilization and plays a vital role in maintaining its stability and sustainability. More diverse the ecosystem, greater its resilience to biotic and abiotic stresses such as insect pest outbreak, disease incidence, epidemics, drought, flood and other natural calamities, environmental degradation and other external shocks. Besides, it largely contributes to the diversification of local economy and supports the livelihoods through a wide range of goods and services. It is the bedrock of crop, animal, forestry and aquaculture production systems and continues to be the backbone of rural industries. Biodiversity also has distinct intangible significance as it has been deeply integrated with the social, cultural and spiritual systems of the society and has immense aesthetic and recreational values. With wide range of agro-climatic condition, varied land use pattern, rich cultural heritage and diverse food habit, India is one of the richest biologically diverse country of the world. It is one of the 12 mega biodiversity countries with large number of diverse ecosystems like forests, grasslands, wetlands, coastal and marine ecosystems, islands and desert ecosystems harbouring rich repositories of genetic resources. However, the rich diversity of the country has been under tremendous pressure due to unsustainable human interference and unplanned development process. Population growth, expansion of human settlements, resource degradation, climate change and environmental pressure have been threatening this precious natural resource.

Agricultural biodiversity

Agricultural biological diversity, in short 'agro biodiversity', refers to the variability among living organisms associated with cultivation of crops and rearing of animals along with the ecological complexes of which they are a part of (Convention on Biological Diversity 1992). Agro biodiversity focuses on that part of the biodiversity, which has undergone selection and modification over millennia by human civilization to better serve, the human needs (Wood 1993). But simply agro-biodiversity includes all components of biological diversity of relevance to food and agriculture. It includes the variety and variability of plants, animals and micro-organisms at the genetic, species and eco-system levels to sustain the key function of

the agro-ecosystem.

Need of Diversity in Agro-ecosystem

- Sustainable food and nutrition security of growing population from wide range of crops and livestock
- Biological support for sustainable production through pollination, natural pest control, soil health management etc
- Livelihoods and income generation through wide range of goods and services
- Wider ecological services like soil moisture conservation, landscape protection, rehabilitation of degraded land, maintenance of food chain and eco-system management
- Genetic resource base for future breeding programme

Components of agrobiodiversity

Cultivated crops and their wild relatives

The cultivated crops and their wild relatives, local landraces and traditional varieties constitute an important component of the agro-ecosystem. The inter and intra species diversity among crop plants not only allow them to survive from the dawn of civilization but enable them to adapt to changing climatic condition, pest outbreak and other biotic and abiotic stresses. Besides it plays a crucial role in preserving the ethnic identity and cultural uniqueness of many tribal communities. The local traditional varieties of major crops, minor crops like millets, fodder crops, grasses, weeds, medicinal plants etc. not only provides diversity to our agro ecosystem but act as resource base for further crop improvement program. Most of the major crops we are seeing today have originated from their wild and weedy relatives through natural selection process and the improved varieties we are growing are developed through the genetic improvement of their local land races by modern breeding technology. The future crop improvement programme is very much dependent on the conservation and sustainable utilization of these valuable plant genetic resources. These crops having low external input requirement, wider climatic and edaphic adaptability, simpler cultural practices are best suited to small production system and significantly contribute to the food security of resource poor small and marginal farmers.

Domesticated livestock and their indigenous breeds

Animal genetic resources has been the integral component of agro-biodiversity as evidenced by the fact that livestock resources contribute around 30 % of total human requirement for food and agriculture and 70 % of world's poor depend partly or completely on livestock for their livelihood. Crop livestock integration has been the predominant mixed farming system practiced by the primitive man to get food, nutrition, fibre and other support services. In addition to their primary products, livestock recycle the crop wastes and byproducts, helps in tillage and transport and maintain soil fertility and productivity. Crops and livestock combination maintain the agro-ecosystem and prevent it from becoming too brittles to natural shocks. Besides, the dairy animals, the small ruminants comprising of sheep and goat and the poultry birds also contributes to the income and employment of rural population during the lean period. Moreover, animal resources are closely linked with the social and cultural systems of human civilization in many parts of the world. Around 6 % of the total domestic animal diversity exists in India and the country has a distinct identity being the home of around 60 cattle, 19 buffalo, 59 sheep, 29 goat, 3 pig and 18 poultry breeds. These indigenous breeds with better adaptation to diverse environmental condition and inherent resistance to diseases provide the basis for future livestock development.

Pollinators, predators and other beneficial faunas

Beneficial insects and other arthropods perform wide range of valuable services like pollination, pest control and nutrient recycling. Pollinators like bees not only enables crops to produce fruits and seeds but also provides precious products like honey, wax and pollen. More than 70 % cultivated crops are cross pollinated and require the service of honey bees, dammer bees, bumble bees, mason bees, carpenter bees and many butterflies for proper seed setting and yield enhancement. The role of these beneficial insects are more pronounced in oil seed crops, where an yield increase of 21-60 % is noticed through pollination only. The predators and parasitoids are of immense significance in sustainable crop production as they fascilitate natural control of insect pests and maintains equilibrium in the agro-ecosystem. Predators like spiders, lady bird beetles, tiger beetles, rove beetles, lace wing bugs, mirid bugs, syrphid flies, dragon flies, and parasitoids like Tachinid flies, Braconid and Ichneumonid wasps minimize the insect pest incidence and lower the economic loss. Some arthropods like mites, spring tails and dung rollers accelerate the decomposition of crop and animal residues and improve the fertility status of soil. The beneficial

role of earthworms in the maintenance of soil health and soil structure has been realized and recognized since time immemorial.

Diverse microbial population

A diverse microbial population constitute the soil biodiversity and contribute towards sustainable soil and plant health. Nitrogen fixing bacteria (Rhizobium, Azotobactor and Azospirillium), blue green algae and azolla fix the atmospheric nitrogen and accelerates nitrogen uptake of plants. Phosphate solubilizing microorganisms enhance the uptake of phosphorus by plants by dissolving rock phosphate and tricalcium phosphate. Similarly, nutrient solublising mycorrhiza, and actinomycetes improve the soil fertility status through nutrient recycling and support stable crop production. Most of these microbes produce plant growth promoting metabolites known as Plant Growth Promoting Rhizobacteria (PGPR) that enhance crop productivity and induce resistance against different biotic and abiotic stresses. While, the antagonistic fungi like *Trichoderma* spp, and bacteria like *Pseudomans flouresence* naturally control wide range of crop diseases like wilt, blight, fruit rot and damping off , entomopathogenic fungi like *Beauveria basiana*, *Metarhizium anisoplae* and *Verticillium leccani* naturally lower the population of borers, foliage feeders and soil insects.

Factors responsible for agrobiodiversity erosion

Developmental pressures on the land resources, deforestation, changes in land use patterns, natural disasters are contributing to abundant habitat fragmentation/destruction of the crops and their wild relatives. Social disruptions or war also pose a constant threat of genetic wipe-out of such promising diversity (OECD 1996). Over exploitation and also introduction of invasive alien species are the other factors contributing for the loss of the genetic resources. More recently, the global change and high degree of pollution have also been recognised as one of the causes for loss of biodiversity (Sala et al. 2000).

a. Monoculture: After green revolution, the minor and underutilized crops, which usually provided diversity in the agro-ecosystem, started loosing their importance and many of them are in the verge of extinct. The area under millets declined sharply from 48.5 Mha in 1961 to 16.1 Mha in 1998 and same is the situation for other minor crops like Barley, Oat, Niger, Safflower, Linseed, Horse gram etc. Our attention has become increasingly focused on a limited number of crops and even in the same crop to a limited number of high yielding varieties. Out of total estimated 7000 edible plants (cultivable), today we derive 60% of our food requirement from just three

crops (Rice, Wheat, maize) and 95% of our energy needs from less than 30 plants. It has been reported that prior to green revolution there were as many as 30,000 indigenous rice varieties available in India but now two third of the total paddy area is under monoculture of few high yielding varieties. It has been reported that around 6 % of the wild relatives of cereal crops, 18 % of the legumes and 13 % vegetables are under the serious threat of extinction. The rapid depletion of the genetic base of many crop plants makes the agro-ecosystem more homogenous thereby increasing its exposure to different biotic and abiotic stresses and hence endangers its stability. It also leads to nutritional imbalance in the human body system, as most of the minor and underutilized crops are the rich source of vitamins, minerals, proteins and secondary nutrients. Advent of green revolution and popularization of improved/high yielding varieties led to the mushrooming of many private seed companies. Through their aggressive marketing strategy and long market chain reached each and every farmers of the country and increase their dependence on the external seed sources. The traditional seed stock of the farmers, which has been tried, tasted and selected over generations, are disappearing at an alarming rate. The traditional seeds, besides their adaptability to the local farming situation, act as surplus seed source during the years of natural calamities and seasonal climatic aberrations.

b) Habitat shrinkage/destruction: The village common property resources like old fallows, culturable wastes, permanent pasture, sacred grooves, village forests, lands under miscellaneous trees and grooves etc. are the rich reservoirs of genetic diversity. It harbours numbers of medicinal and aromatic plants, nutritious fodders, wild relatives of crop plants, underutilized fruits and vegetables, greens and ornamental plants. Besides it provides shelter and food to different beneficial insects. Shifting cultivation, overgrazing and expansion of agricultural lands destroy the habitat of many rare species of tuber crops, millets, medicinal herbs and fodders. Expansion of irrigation and its associated problems like water logging, swampy ness, soil salinity etc. endangered the survival of many rainfed minor crops and indigenous herbs.

c) Invasion of alien species: Purposely or accidentally introduced non-native crops, trees, insects, birds and fishes into new areas has been one of the major reasons of biodiversity erosion. These alien species with better adaptation to the new climatic condition, higher reproductive potential and lesser natural enemies proliferates in the local agro-ecosystem by suppressing the indigenous species. While, the introduced exotic tree species like Eucalyptus and Subabul threatened the native flora in the village

CPRs and farm lands, the accidentally introduce weeds like Lantana and Parthenium create serious problems in crop fields, farm roads, canal bunds and village commons. According to CBD reports, invasive alien species have contributed to nearly 40 per cent of all animal extinction globally.

d) Overuse of agrochemicals: Intensive agriculture based on the principle of high external input application resulted in the indiscriminate use of agrochemicals like chemical fertilizer, pesticides and herbicides. Repeated application of herbicide led to the disappearance of many fodder grasses, wild plants and greens from our farming system. Over reliance on the chemical fertilizers and reckless application of broad spectrum pesticides reduced the population level beneficial flora and fauna including the pollinators, natural enemies, beneficial microorganisms (Nitrogen fixers, Phosphate solublisers, decomposers etc.) and earth worm. These chemicals also pollute the aquatic eco-systems and adversely affect the diversity of aquatic living forms like fishes, oysters, crabs and snails. The indigenous fish and crabs that were plentily available from the marshy lands, farm ponds and low land rice fields which provide as much as 70% of dietary protein in the rural areas are rapidly getting extinct.

e) Climate Change: The impact of climate change like global warming, sea level rise, frequent natural disasters like droughts and floods also have adverse effect on the sustenance of agro-ecosystem. Many crops and trees could not survive in the coastal areas due to salinity and sea ingression. Changes in the monsoon pattern and frequent drought and dry spells have accelerated genetic erosion of local landraces.

Strategies for conservation of agro-biodiversity

Erosion of precious genetic resources from the agro-ecosystem at an escalating rate is a matter of great concern as far as its sustainability aspect is concerned. Therefore, development of both in-situ and ex-situ biodiversity conservation strategy is of utmost importance to cater the need of the future generation. The following few measures may be undertaken to conserve the genetic diversity in the farming system and its optimum utilization.

a) On farm conservation: Growing minor crops in few areas along with the major crops as border crop, strip crops, boundary crop etc will not only conserve the endangered plant species but maintains diversity in the crop field. This diversity not only cater the diverse needs of the farmers but also attract lot of natural enemies and keep the pest population under check. Sorghum and maize as border crops harbours predators like Lady

bard beetle, Green lacewing bugs etc. Safflower as border crop protects the major crops from grazing by animals. Boundary cultivation with Mesta, traditional tuber crops etc. also supplement the farmer's income. Various fodder grass species may be maintained in the field bunds to meet the nutrition demand of the farm animals. The degraded uplands having low carrying capacity may be put under the cultivation of minor millets (Kodo, Suan, Gurji, Kang etc.), pulses (Horse gram, rice been, guar etc.) and oil seeds (Niger, linseed etc.) to prevent its further degradation.

b) Habitat Management: Restoration of the common property resources through reversing its degradation process by various natural resource management strategies and adoption of proper land use system will not only restore the habitat of the diverse plant species but helps in their rapid multiplication. Overgrazing and shifting cultivation in the natural vegetation is to be avoided by formulating supportive policies. Shelterbelt plantation, agro forestry and farm forestry measures need to be adopted to provide food and shelter to the beneficial faunas.

c) Judicious use of agrochemicals: Integrated approach of pest and weed control need to be adopted with special focus on the cultural, biological, microbial and mechanical methods supplemented by need based application of eco-friendly pesticides to protect the population of beneficial flora and fauna. Reduced use of toxic agro-chemicals in general granular pesticides in particular can minimize the wide spread killing of earthworms and other beneficial flora and fauna. Similarly organic source of plant nutrient may be applied through various in situ and ex situ methods for increasing the population level of microorganisms and accelerating their biological activity to sustain the soil health.

d) Collection and Maintenance of germplasm: Traditional crops and varieties having significant importance in the field of agriculture like aromatic rice varieties, crops or varieties having adaptability to water stress, water logging, salinity, acidity condition and tolerance to insect pest need to be identified, collected and maintained to preserve their biological traits and subsequent exploitation. Local seed production initiative for these crops and varieties is to be popularized among the farmers and necessary support to be extended.

e) Research Extension: Modem agricultural research is more targeted to few major crops for their yield enhancement, nutrient management and pest resistance as a result of which these crops have started replacing other locally grown crops and varieties. Therefore, extending agricultural research to the minor and underutilized crops in the area of better agronomic practice

is highly imperative to increase the yield potential of these crops.

f) Ex-situ conservation: Community based seed/gene bank involving the SHGs, Youth clubs, watershed committees etc. is to be established at village level to strengthen the community based biodiversity conservation initiatives. Herbal gardens are to be developed in the village commons by growing and maintaining endangered medicinal species. Similarly back yard biodiversity garden/nutritional garden comprising of the underutilized fruits and vegetables is to be promoted.

g) Value added product development and market promotion: Value addition of the minor and underutilized crops is an important strategy for their conservation and augmentation. Squash from Jamun and bael, RTS from custard apple, chips and pickles from jackfruit, seed powder of jamun, finished products of ragi and kodo etc. have tremendous market potential. Women SHGs and rural youths can be trained on the value addition of these crops and necessary market promotion measures may be undertaken for better pricing. Niche markets where such indigenous products have demand can be identified and constraints to market development (storage, transportation, market information) can be addressed through strategic interventions.

h) Documentation of Indigenous knowledge System: Indigenous knowledge base and cultural heritage are the integral parts of agricultural biodiversity management**.** Since, time immemorial farmers have been identifying the food, nutritional, medicinal and economic values of different crops , livestock and their local land races and these knowledge system have been passing from generation to generation. For effective use of biodiversity and its conservation the age old traditional knowledge systems need to be documented and validated.

i) Awareness generation and capacity building: Awareness generation measures are to be taken at various levels to gamer wider consensus on the optimum utilization and conservation of biological resources. Capacity building of farmers, women members, NGOs and CBOs is highly important for identification, collection, maintenance, documentation of rare landraces and participatory research.

Conclusion

Agro-biodiversity has significant contribution to the population of the locality since time immortal. Nowadays, due to increasing population agro-biodiversity is significantly decreasing in the region, which is drastically affecting the attributes of agro-ecosystems of the region. Therefore,

maintenance of agro-ecosystem attributes and its biodiversity is needed for the continuous supply of resources to the population of the region. Hence, a coordinated effort from the stakeholders, policy makers, researchers, environmentalists, and indigenous tribals is the need of the hour.

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Mainstreaming traditional knowledge and ethno-veterinary practices among tribes of Chhattisgarh: Issues and challenges

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Abstract

The local health tradition upholds biocultural values and principles for sustainable use and conservation of biodiversity. A very little empirical intervention has been made to document traditional knowledge, ethno-veterinary practices and explore different components of local health tradition of Chhattisgarh. This paper critically examines different dimensions of sustainable use and conservation of medicinal and aromatic plant resources as correlated with economic transformation. The empirical investigation reveals that new contagious and infectious veterinary diseases have emerged as outcome of ecological imbalances, industrialization, pollution of air and water and structural violence caused by threat to life support system. The indigenous ethnoveterinary knowledge and practices provide inputs for evolving survival mechanism, strategy and life support system to forest dwelling communities through natural resource based entrepreneurship in forest regions of Chhattisgarh.

Keywords Local health tradition, biocultural, ethnoveterinary, biodiversity economic transformation.

Introduction

The domain of traditional medicine (TM) and Local Health Tradition (LHT) has attracted the attention of policy makers, bureaucrats and researchers of developed and developing countries in post CBD era for explorative research. Different International institutional actors have

developed their agenda for mainstreaming this sector and prevent overexploitation of habitat of medicinal plants species. Different International agencies have prioritized the traditional medicine sector in their agenda. The IUCN Medicinal plants study group has devised own agenda focusing on identification, management and protection of regionally and globally threatened plants species. Global Environment Facility (GEF), a leading international funding agency has encouraged different national governments to take up bilateral projects on conservation of medicinal and aromatic plants resources. The projects on conservation education and regulation of trade on medicinal plants are encouraged and supported by agencies like WWF and Rainforest Alliance. The international institutional actors extend technical and financial support to national government for capitalizing the strengths and opportunities of this unexplored sector. The Ministry of Environment and Forest, Government of India has established a ten-member CITES Cell to implement the resolution of CITES (Convention of International Trade in Endangered Species of Wild Fauna and Flora). The UN agencies have encouraged and supported both National and State Governments of different countries to boost up this virgin sector and mainstream the traditional medicine into centre of development (Tewari 2009). The Government of India has given major boosting to mainstream traditional medicine sector of the country. The Pharmacopoeia Commission (PC) has been established under the Ministry of Health and Family Welfare, Government of India to develop protocols for standardizing the identity, purity and strength of raw materials administered in traditional medicine sector of the country. This Commission will establish Pharmacopoeia Laboratory for Indian Medicine (PLIM) at Ghaziabad very soon. A National Repository of Indian Traditional Medicine (NRITM) will be promoted by the Commission. The Commission has been entrusted with responsibility of patenting as many as 1000 traditional herbal therapies and 1000 compound formulation through scientific validation. Global demand for traditional medicine is growing day by day. Mainstreaming of traditional medicine has been prioritized in national Population Policy 2002 and National Rural Health Mission. UNDP, Global Environment Facility (GEF) and Government of India have jointly supported State Medicinal Plants Board (SMPB), Chhattisgarh to initiate a long term experimentation (2008-2014) for conservation of medicinal plants and mainstreaming traditional medicines. This experimentation is simultaneously continuing in two other states through network of Medicinal Plant Conservation Areas (MPCAs) and replication of the success stories of DANIDA supported experimentation conducted in Karnatak, Kerala and Tamil Nadu during 1993-2004. This piece of

research is an attempt to explore the impact of this intervention in streamlining sustainable use of medical plants and traditional medicine.

The opportunities and scope for exploring traditional medicine in the State of Chhattisgarh has not been appropriately tapped**.** Chhattisgarh, the premier herbal State of India characterized with unique local health tradition and rich cultural heritage of numerous promising traditional treatments, offers unexplored opportunities to unfold this sector. Chhattisgarh, the pioneering herbal state of India not only upholds the unique local health tradition of the world but also accommodates a large number of indigenous communities sustaining traditional knowledge on use of medicinal plants since time immemorial. The tribal communities like Halba, Gond, Kamar, Maria, Muria, Korwa, Birhor administer different medicinal plant based therapies for curing human as well as animal diseases. The traditional knowledge reflected in practice and innovations of these communities are not comprehensively documented.

The practice of administering herbal medicine to livestock and human beings has been sustained through generation to generation among forest dwelling communities of Chhattisgarh. The herbal recipes administered by local healers are crude and derived mostly from flowering plants. The tribal communities of Chhattisgarh resort to supernatural approach so as to cope with illness of livestock and human being that they fail to understand. The traditional medicine of Chhattisgarh has gained world wide popularity and attracted global demand for greater focused research on value addition, export, scientific laboratory test, patenting and validation through renewal of Local Health Tradition. The ethnotherapies of these tribal communities cover administration of herbal remedies and magico religious therapies simultaneously. The therapeutic matrix uphold cultural values sustaining interrelationship among biodiversity, social health and supernatural world. The magico religious healers (Sirha) of these communities strongly believe that their supernatural approach has miraculous remedy to cure new emerging diseases among animals caused due to ecological imbalances and magical evil effects. The magico religious practices sustained by indigenous communities living in and around forest regions since generations together cannot be separated from the core domain of traditional medicine. The anthropologists have empirically validated that ethno medicinal practices have strong co-relation with other variables within the institutional matrix of social and cultural niches. (Mitra 2009, Mishra 2009, Pati and Pattjoshi 2009) The magico religious aspects of this traditional therapy have great relevance to scientific base of western veterinary therapy and practices. This dimension has not been explored so far. Documentation of traditional

knowledge and protection of IPR regime without research on therapeutic link with supernatural forces is a futile exercise.

Traditional medicine consists of administration of herbal recipes and observation of magico religious practices for treatment of diseases among animals and human beings. Anthropologists view that ethno medicine and ethno veterinary medicine are complementary. Researchers have unfolded that traditional medicinal knowledge relating to ethno medicine has been explored and commercialized at much faster rate compared to ethno-veterinary medicine. There is an urgent need to tap ethno veterinary practices and document ethno-veterinary knowledge as ethno-scientific resources. This will unfold the pathways for economic development and promotion of animal healthcare among poor forest dwelling communities of Chhattisgarh. Unfortunately, a very little initiative has been made to document ethno-veterinary knowledge and prevent the abuse and misuse of traditional ethno-veterinary knowledge preserved in oral tradition of these communities. There is an urgent need to initiate scientific standardization of ethno-veterinary knowledge and practices for assessing the efficacy and safety as well as mainstreaming the use of traditional ethno-veterinary remedies.

The wide scale industrialization coupled with liberalization of marketing forces have stimulated entry of big players in agriculture and commodification of bioresources. These have eroded the base of Local Health Tradition (LHT) in indigenous territory of Chhattisgarh. The traditional healers in indigenous communities very often apprehend that many valuable components of traditional ethno veterinary healing practices would decay and vanish at a very fast rate. The pharmaceutical companies have hijacked the best components of indigenous knowledge and commercialized it for promoting products of biofertilisers, biopesticides and herbal products. This aspect has not been well investigated and correctly reported. On the other hand, in absence of research and documentation of traditional knowledge acquired by local innovators from their forefathers and extinction of many plant species, the knowledge on appropriate use of medicinal plants gets eroded after the death of the knowledge holders. The laws have not been enacted by state government to govern, advocate and promote the utilization of ethno-veterinary traditional knowledge in either independent or in complementary with the modern allopathic medicine. The ethno-veterinary practice of tribal healers in forest communities of Chhattisgarh are treated illegal and superstitious. Some of them are sued in the court of law by dissatisfied clients. A good number of research studies have validated that the holistic nature of traditional medicine contribute to

efficacy of this therapy compared to cosmopolitan drugs (Mishra and Broker 2009). But the monitoring safety aspect of this therapy is debatable issue. The traditional healers administer a good number of herbs rich in medicinal ingredients for effective immune-stimulants without laboratory test and scientific validation. The modern allopathic drugs often fail to treat the conditions where traditional herbal medicines render wonderful relief to the animals. Adequate scientific evidences have not been gathered to support effectiveness and safety aspect of ethno veterinary remedies and initiate validation process in this premier herbal state of India. The intellectual property rights and recognition need to be conferred on efforts of forefathers of traditional healers. The forefathers of traditional healers have developed the knowledge based on ethno veterinary practices through trial and error methods and deliberate experimentation. A very little effort has been made for documentation of this traditional knowledge through systematic research. This deficiency has side tracked very important stream of traditional medicine from mainstream of veterinary medicine.

Materials and methods

This paper is an attempt to develop a profile on ethno-veterinary practices and mode of use of medicinal plants administered for treatment of livestock diseases in two sample villages, (i.e.,Bhatwa and Bagbeda) around Bhatwa MPCA of Makdi Forest Range in Southern Kondagaon Forest Division of Chhattisgarh. This piece of empirical investigation aims at not only to document the traditional knowledge but also to assess the impact of experimentation initiated to mainstream the traditional knowledge and ethno-veterinary practices towards evolving strategies and reform in the ongoing experimentation. This piece of research examines various sensitive areas for mainstreaming traditional medicine and boosting up traditional medicine sector of the country. This paper also examines various dimensions of translating protocols of CBD, 1993 and National Biological Diversity Act, 2002 at grassroots. The inputs of this piece of research have great relevance for promoting state level Repository of Traditional Medicine and achieving the vision and mission of National Pharmacopoeia Mission, Government of India. These tribal villages are numerically dominated by Gond and Halba communities. Utmost efforts are made to assess the impact of ongoing UNDP supported MPCA network based conservation project on renewal of local health tradition and community based conservation initiatives. During six week field work undertaken in October-November 2009, as many as 58 small farmers, 26 community elites and 11 traditional healers of both the villages were covered as Key Informants. The tools adopted were use of checklist of questions, Interview Guide (IG), Key

Informant Interview Guide (KIIG), Observation Guide (OG) and Case Study Guide (CSD). The farmers were asked about use of both traditional and western medicine for treatment of livestock diseases and their efficacy. The key informants were involved in participatory exercise to develop an inventory of animal diseases and medicinal plants used for treatment.

A local disease nomenclature based on symptoms of diseases was prepared in local language. The treatment method, type of plants and plant part used, the quantity administered, the application procedure, the dosage and the prescribed period of treatment were recorded. A series of six community level workshops were organized separately for farmers, women group and members of JFM Committees in two villages where observation report and data gathered by the team were presented for social auditing, validation and community approval. The inputs of these groups were incorporated in the inventory and database. Participatory tools for cross checking and validation of qualitative data were administered in these workshops. Utmost care has been taken to utilize service of local healers as facilitators in initiating Focus Group Discussion (FGD) and Key Informant Interview (KII) in local languages. During the participatory village level discussions, the farmers reported about occurrence of a wide number of livestock diseases during different seasons that were confirmed with veterinary doctor invited to participate in the discussion as a resource person. The livestock diseases were identified by the farmers correlating with the visible symptoms like ulcer in the mouth and foot, erection of hair, inability to urinate, move and pass stools and abnormal colour of stools etc. The farmers normally consult the local healers for administering indigenous remedies drawn from medicinal plants in combination with salt, ghee, herbal oil, water, molases and soil. As a part of indigenous veterinary care, the farmers have been well trained by village healers how to conduct blood letting to drain out the sickness. The farmers exhibited their skill and expertise about home management of ulcers, blood letting, obstetrics management and cauterization in both the villages.

The inputs were sought from community in different village level workshops towards documenting traditional ethno-veterinary knowledge and evolving roadmap for mainstreaming this stream of traditional medicine into centre of development and conservation of biodiversity. The participants emphasized on further indepth empirical investigation and documentation of promising treatments through participatory assessment. The farmers were asked to identify and register different cattle diseases along with the visible symptoms. The farmer also correlated the ecological imbalance with occurrence of new veterinary diseases during last three

generations. The traditional healers of these villages have correlated occurrence livestock diseases like ulcer on the tongue (Mendki), black spots inside the mouth (Viria or Ghiriya), stiffness of legs (tadakfas), frequent head reeling (Vanuri) with wide scale deforestation, agricultural encroachment on forest lands and overexploitation of medicinal plants habitats. After documentation of Community Medicinal Plant Knowledge Registry, the villagers have assessed that a good number of medicinal plants species have become endangered species and on the verge of extinction. The villagers have initiated community effort for exsitu and insitu conservation of these species. These species are Satabar (*Asparagus racemosus*) Chirayata (**S**wertia Chirata), Safed Musuli (Chlorophytum Borivilianum), Kali Musuli (Curculigo orchioides), Panir ka phool, Lat Jeera (Achyranthes Aspera), Dev Dhatura (Dhatura alba) and Palasa, (Beuta monosperma). These plant species have been prioritized by community to be cultivated in "buffer zone", outside of *in-situ* conservation areas under *ex-situ* conservation program. A group of farmers have been encouraged to promote home herbal garden in these villages. The growing market demand coupled with biopiracy have not only eroded the MAPs habitat but also posed serious threats to revival of local health tradition in these villages.

Results and discussion

The paper critically examines the impact of UNDP supported intervention on conservation of medicinal plants through MPCA's Network and delivering incentives to forest dwelling communities for enabling them accruing benefits from their traditional ethno-veterinary knowledge and practices. The findings of this study provide meaningful inputs for evolving appropriate methodology in validating community based ethno veterinary practices and promoting entrepreneurship ventures. Greater focus needs to be given on identification of sensitive areas for involvement of stakeholders in promoting community based animal health care training programme, protection of livestock and promotion of conservation based micro entrepreneurship model.

The traditional healers practicing ethno veterinary treatments in forest villages of Chhattisgarh claim tremendous potential of this therapy in terms of efficacy and its useful alternatives to expensive allopathic treatment. They provide a wide range of options for utilization of selected herbs administered in improvement of cattle productivity which is yet to be standardized through scientific research and laboratory test. The ethno veterinary practices sustained by tribal communities through generations

preserve unique folk knowledge associated with traditional beliefs and folk stories. The traditional knowledge relating to use and conservation of medicinal plants has been evolved through communities' empirical observation of nature and application of different herbs on human beings and animals. Traditional medicine in these communities has been evolved from such time tested trial and error experimentation and incorporated in local health tradition. The focus of scientists and donor agencies has been given on research and documentation of traditional ethno-veterinary practices. The scientists and development agencies have given greater priority on 'ethno veterinary research, development and extension and documentation of traditional knowledge relating to ethno veterinary practices.

Local health tradition ethno-veterinary practices

The forest dwelling communities of Chhattisgarh draw major source of livelihood from livestock rearing. More than half of the livestock populations of the state are concentrated in rural areas. The villagers domesticate large number of cattle for their own requirement. Commercialization of these animals is not reported. Animal diseases caused by ecological imbalances, industrialization, pollution of water and air, pose serious threat to livestock production, livelihood support mechanism and economic development in forest villages of Chhattisgarh. Contagious diseases take high toll of livestock in these villages where modern veterinary information and services are absent. The traditional healers assert that herbal components administered in ethno-veterinary practices help tunify the immune systems and prevention of diseases. This component is missing in western therapies. Well over 80% of indigenous communities in forest regions of Chhattisgarh depend on use of ethno veterinary therapies for following reasons.

- The allopathic veterinary drugs are expensive.
- The veterinary doctors are not available in the remote villages.
- Scarce and erratic supply of veterinary drugs and supplies.
- Poor communication facilities and other modern amenities.
- Traditional medicine renders immediate and permanent cure.
- The use of ethno-veterinary services and herbal medicine reduces toxic effects on animals.

The people depend mostly on ethno-veterinary services of folk healers. The indigenous ethno-veterinary knowledge and practices provide inputs for evolving survival mechanism, strategies and life support system to community. The understanding of ethno veterinary knowledge and related cultural dimensions is essential to promote livestock as well as conservation of rare and prioritized medicinal plants used for ethno-veterinary practices in these villages. Strategic plans need to be designed for this component under ongoing Conservation Programme. Appropriate environment conservation and management strategies need to be correlated with matrix of cultural diversity sustaining local health tradition and ethno veterinary practices in these communities. The contagious animal diseases unknown to the people very often pose serious challenges to livestock owners as well as veterinary workers. They fail to diagnose the infection and administer appropriate treatment. Ultimately, they resort to the treatment of ethno veterinary practitioners of the village. The study indicates that a section of farmers blindly administer the ethno veterinary medication as they observe that the therapy works miraculously on animals. The ethno-veterinary remedies in these hill villages work complementarily with allopathic veterinary drugs. The healers maintain utmost secrecy in disseminating this knowledge to outsiders. The villagers who live in close vicinity with forest having greater medicinal plant diversity are reported utilizing a wider variety of medicinal plants compared to villagers living on plains.

The ethno veterinary practices and related traditional knowledge have significant bearing on possible avenues for exploring income generation activities and conservation of specific medicinal plants having unique herbal potencies for treatment of animal diseases. The strength of this focused interventions needs to be capitalized and incorporated in replicable models. The documentation of community knowledge registry through participatory approach has not only protected ethno veterinary knowledge on use of specific medicinal plants but also developed a mechanism for mainstreaming this therapy. This initiative has stimulated validation of efficacy in indigenous ethno veterinary practices for further collaborative research. The sharing of community knowledge registry among villagers through periodic meetings convened at “Deogudi”, local sacred groves by “Matipujari” or “Matapujari”, the traditional spiritual headman of the village has encouraged the communities for conservation and sustainable use of specific endemic medicinal plants. The documentation of community knowledge registry in local language has facilitated grass root initiatives for conservation of biological resources

and identification of useful medicinal plants for cultivation. This approach has sensitized the local healers on vulnerability of specific medicinal plants used in ethno veterinary and ethno medicinal practices since generations together.

Veterinary diseases and treatments

The villager have their choices and options either to go for ethno-veterinary treatment or treatment by veterinary doctors. Their choices are determined by cultural, economic and availability of dependable services. The following table indicates coverage of cases by different therapies.

During the participatory assessment on disease surveillance and coverage of ailing animals under different treatments, as many as 189 cases were reported during last two years in sample villages. It is evident that ethno-veterinary practices provide life support back up to livestock of these forest villages in terms of treatment and prevention of various infectious and contagious animal diseases. The major killer diseases reported are ulcer on toe, swelling of the throat, ulcer on tongue and mouth, cough and cold, worm infestation and reduced appetite. Swelling of the throat takes high toll of cattle population whereas ulcer in the mouth kills goats in large number without any preventive measures. The growing encroachment on forest land by immigrant settlers and corresponding damage to environment has stimulated emergence of many new animal diseases that local healers fail to treat. One of such disease is "Adharanga", paralysis of one side of the body. It is a killer disease of young calves and young goats in a great majority of forest villages. Exposure to change of seasons, non availability of fodder and intake of polluted water in summer, grazing of contaminated new green grass in rainy season have multiplied the episodes of livestock diseases. The rainy season brings with it numerous infectious and contagious diseases for livestock. The villagers overexploit the habitats of leafy vegetables like Karmata, Rasana (Pluchea ianceolata), and Chitrak (*Plumbago zeylanica*) and other herbs traditionally administered for preventing animal diseases in rainy seasons. Destructive harvesting practices have drastically affected these species. The villagers need to be encouraged for cultivation of these species in home garden and oriented on sustainable harvesting practices. The villagers need to be oriented on sustainable harvesting and prevention of wasteful community practices stimulating huge collection of herbs for very little use. The farmers and healers very often fail to diagnose the diseases. The herbal therapy and local treatments are administered on the assessment of physical visible symptoms on livestock. The community based mechanism for sustainable

Table 1: Distribution of veterinary diseases by coverage under ethno veterinary treatment and allopathic treatment.

(N = 189)

Sl. No.	Animal Diseases	Local name	Administration of ethno-veterinary Therapies	Treatment by Allopathic Veterinary Doctors/ Veterinary Assistants	Total
1.	Ulcer on the tongue and mouth	Chhala, Mendkee	15 (7.93%)	2 (1.05%)	17 (8.99%)
2.	Black Spots below the tongue	Ghiria	5 (2.64%)	1 (0.52%)	6 (3.17%)
3.	Stiffness of muscles in the leg and frequent unconsciousness	Asharanga, Tadakfas	10 (5.29%)	4 (2.11%)	14 (7.40%)
4.	Head reeling	Mud dukha, Vaunri	12 (6.34%)	0(0%)	12 (6.34%)
5.	Ulcer on the toe	Khura chapka	18 (9.52%)	3 (1.58%)	21 (11.11%)
6.	Snake bite	Sap chaba	9 (4.76%)	1 (0.52%)	10 (5.29%)
7.	Respiratory disorder	Sas fula	8 (4.23%)	2 (1.05%)	10 (5.29%)
8.	Bone fracture	Had tutna	4 (2.11%)	0 (0%)	4 (2.11%)
9.	Abscesses	fula	10 (5.29%)	4 (2.11%)	14 (7.40%)
10	Cough, Colds and Pneumonia	HaleJar bukhar	21 (11.11%)	2 (1.05%)	23 (12.16%)
11.	Feeding problem	Bhukh nahi	7 (3.70%)	3 (1.58%)	10 (5.29%)
12.	Bleeding	Khunjana	3 (1.58%)	1 (0.52%)	4 (2.11%)
13.	Abortion	Jachaki	2 (1.05%)	0 (0%)	2 (1.05%)
14.	Difficult Birth	Jachaki mesamasya	5 (2.64%)	1 (0.52%)	6 (3.17%)
15.	Milk Fever	Telagi	3 (1.58%)	0 (0%)	3 (1.58%)
16.	Venereal Diseases	Rissa	1 (0.52%)	0 (0%)	1 (0.52%)
17.	Stomach and Intestinal worms	Kirmi Roga/Ninva	14 (7.40%)	1 (0.52%)	15 (7.93%)
18.	Lockjaws	Tond Faru	2 (1.05%)	0 (0%)	2 (1.05%)
19.	Wooden tongue	Jibha Mand Mand	1 (0.52%)	0 (0%)	1 (0.52%)

use of medicinal plants administered for ethno veterinary and ethno-medicinal practices need to be renewed through applied research, clinical trials in laboratory and linking with ongoing government programmes.

Table 2: Distribution of reported cases covered under ethno veterinary treatment by type of relief and cure.

Sl. No.	Cases covered under ethno veterinary treatment	Number of cases **(N=163)**	Completely cured	Under treatment	Not reported
1.	Ulcer on the tongue and mouth	15 (9.20%)	9 (5.52%)	3 (1.84%)	3 (1.84%)
2.	Black Spots below the tongue	5 (3.06%)	5 (3.06%)	0 (0%)	0 (0%)
3.	Stiffness of muscles in the leg and frequent unconsciousness	10 (6.13%)	7 (4.29%)	1 (0.61%)	2 (1.22%)
4.	Head reeling	12 (7.36%)	10 (5.29%)	2 (1.22%)	0 (0%)
5.	Ulcer on the toe	18 (11.04%)	17 (10.42%)	1 (0.61%)	0 (0%)
6.	Snake bite	9 (5.52%)	4 (2.45%)	3 (1.84%)	2 (1.22%)
7.	Respiratory disorder	8 (4.90%)	5 (3.06%)	2 (1.22%)	1 (0.61%)
8.	Bone fracture	4 (2.45%)	4 (2.45%)	0 (0%)	0 (0%)
9.	Abscesses	10 (6.13%)	4 (2.45%)	3 (1.84%)	3 (1.84%)
10	Cough, Colds and Pneumonia	21 (12.88%)	17 (10.42%)	2 (1.22%)	2 (1.22%)
11.	Feeding problem	7 (4.29%)	3 (1.84%)	2 (1.22%)	2 (1.22%)
12.	Bleeding	3 (1.84%)	2 (1.22%)	1 (0.61%)	0 (0%)
13.	Abortion	2 (1.22%)	1 (0.61%)	1 (0.61%)	0 (0%)
14.	Difficult Birth	5 (3.06%)	1 (0.61%)	3 (1.84%)	1 (0.61%)
15.	Milk Fever	3 (1.84%)	0 (0%)	3 (1.84%)	0 (0%)
16.	Venereal Diseases	1 (0.61%)	0 (0%)	1 (0.61%)	0 (0%)
17.	Stomach and Intestinal worms	14 (8.58%)	5 (3.06%)	4 (2.45%)	5 (3.06%)
18.	Lockjaws	2 (1.22%)	1 (0.61%)	1 (0.61%)	0 (0%)
19.	Wooden tongue	1 (0.61%)	0 (0%)	1 (0.61%)	0 (0%)

It is evident from the above analysis that the ethno-veterinary practices and related traditional knowledge on use of herbs preserve treasure house of remedial measures on numerous animal diseases that modern allopathic treatment very often fails to respond. Well over 65% of ailing animals are provided cure by ethno-veterinary treatments. The herbs used need to be screened at laboratory for safety and efficacy. On the basis of clinical trials and standardization the herbal ingredients need to be recommended for pharmaceutical use. The guidelines of WHO needs to be strictly followed.

The traditional healers practicing ethno-veterinary therapies draw numerous patients from neighboring areas who are provided miraculous relief for different human and animal ailments. This unique traditional knowledge is not documented. This gap has been monopolized by the traders and agents of pharmaceutical companies involved in massive bio-piracy activities. In absence of organized forums of healers and legal recognition of their practices, a good number of healers have been victimized through court cases. They are very often handicapped to claim their intellectual property rights. The promising local treatment on snake bites, bone setting and dog bites have been very often challenged in the courts of law. They are victimized by professional rivalry.

Traditional knowledge and revival of organic farming

The documentation of traditional knowledge of these communities through community knowledge registers can be gainfully used for encouraging farmers for reviving organic farming, traditional pest management, manure management, livestock management at replicable direction. Entrepreneur Development Programme (EDP) needs to be designed and executed for manufacturing and marketing of herbal pesticides, fertilizers and veterinary health care products. The poor farmers would be facilitated for escaping from vicious cycle of debt and negative economy. The women Self Help Groups (SHGs) promoted in the villages need to be trained for manufacturing these items along with other items like herbal tea, herbal soap and detergent, herbal shampoo, organic mosquito repellent. This intervention will expand vast employment opportunities in the rural areas with appropriate exploitation of schematic support from Government of Chhattisgarh. The commercialization of traditional knowledge will provide enough opportunities for income generation and promotion of small and singular enterprise. The global green consumerism drive has multiplied the demand for organic products in global market at faster rate. The small and marginal farmers of these villages will cater to

Table 3: Distribution of prevailing livestock diseases by local names, herbs administered and preparation process

Sl. No	Animal diseases	Local name	Animals affected	Herbs administered	Botanical Name	Preparation process
1.	Ulcer on the tongue and mouth	Mendkee	Cow, Buffalo, Goat, Calf, Bullock	Munga	*Moringa oleifera*	Herbal components extracted from bark of Munga Plant and administered with molasses and salt in prescribed doses
2	Black Spots below the tongue	Viria, Ghiria	Cow, Goat	Dev Datura	*Datura Stramonium*	Half of the fruit of Dev Datura crushed and administered orally with molasses and salt in prescribed doses
3	Stiffness of muscles in the leg and frequent unconsciousness	Tadakfas	Cow, Buffalo	Munaga, Bhelava	*Moringa oleifera*,	Seeds of Munga Fruits crushed with fruit of Velua and administered orally with molasses and salt in prescribed doses
4	Head reeling	Vaunri	Cow, Buffalo	Alasi Oil, white deposit inthe stem of bamboo shaft	*Nardostachys grandiflora*	The calcium deposits collected from stem of bamboo shaft is prepared medicinal doses with salt and oil of Alasi seeds for inhaling and nosal administration
5	Ulcer on the toe	Khur chapka Bimari	Cow, Buffalo, Calf, Bullock	Harra, bahara, leem, karila	*Terminalia chebula, Terminalia bellerica,*	The fruits of Harra, Behra and leaves of Neem and

					azadiracta indica, *Momordica charantia*	Kareel plants are dried and crushed. The powder of these leaves are prepared herbal doses and tied with piece of mud soaked cloth on ulcer for four days. Specific rituals are observed for cure
6	Snake bite	Sap chaba	Cow, Goat, Buffalo, Bullock	Nagin Kanda, Garud, Bhoinn Lim, Sarpok, Chech	*Melia-compoita* (wild) meliaceae, Swerita-angustifolia (Buch-Ham)	* The medicinal Ingredients drawn from Nagin Kanda and administered with Cow Ghee twice at interval of 12 hours * The bark of Garud tree crushed and mixed with Cow Ghee. The herbal recipe administered orally in one teaspoon dose repeatedly for a week till poison is neutralized.
7	Respiratory disorder	Sans cho Bimari	Cow, Goat, Buffalo, Bullock	Fruits of "Fas" and "Dev Datura Plants"	*Rosa damascena*, *Datura Stramonium*	* The fruits and leaves of Fas trees are crushed and administered to ailing animals in appropriate doses. * A clove is kept in the fruit of Dev Datura for three weeks for medication. This medicated clove is crushed

						with honey and orally administered to the ailing animals.
8	Reduced appetite	Kamjori Pet Dama Dama	Cow, Goat, Buffalo, Bullock	Bhoin Lim, Akur	*Swerita-angustifolia* (Buch-Ham), *Chrysanthemum coronarium*	The liver of a specific fish known as Chingara is collected for administration with honey, leaves of Bhoin Lim and bark of Akur for preparation of weekly oral dose. The animals are administered seven such weekly doses for seven weeks.
9	Uler in the throat	Gal Ghoto	Cow, buffaloes, Goat	Rasana, Chitrak	*Pluchea Lanceolata, Plumbago Zeylanica*	The roots of Rasana and Chitra administered orally after crushing in appropriate doses.
10	Swelling of the throat	Ghatsara	Cow, goats, buffaloes	Karmata	-	Touch therapy by using the branch of Karmata plant
11	Worms in the teeth	Danta me Kida	Cow, goat, buffaloes	Ratanjot	*Jatropha Curcas*	Juice extracted from bark of this plant and orally administered in appropriate doses.
12	Poor Eye Sight	Ratondhi	Cow, Buffaloes, Bullocks	Chirchira	*Achyranthes aspera*	Juice extracted from leaves of this plant and administered as eye drops.

the needs of green consumers of the World as well as India by reviving the local health tradition and exploiting the traditional knowledge of the communities.

The insights drawn by the communities from traditional knowledge for use of bio-fertilizers and prevention of soil erosion through revival of organic farming will not only improve the quality of soil, but also protect the bio-diversity in greater way. There is an urgent need to organize a series of capacity building workshops for documentation of traditional knowledge and dissemination for effective application of this knowledge for community well being. The revival of traditional practices of crop rotation would not only provide farmers opportunity for preserving seeds in Seed Bank but also cultivation of large varieties of species required for bio-diversity conservation.

Conclusion

This study has generated adequate inputs for developing a framework of database on general livestock diseases and ethno veterinary knowledge. The working hypotheses need to be formulated for undertaking further formative action research. Greater focus needs to be given on correlation of variables with conservation of endemic medicinal plants through network of MPCAs and documentation of traditional ethno veterinary knowledge. The traditional healers, farmers and elite women have huge potentials as facilitators for developing dictionaries of animal diseases for each community. An inventory of medicinal plant database used for ethno veterinary practices needs to be prepared so that appropriate steps be taken for scientific research and validation of medicinal properties of these plants. The interventions initiated through UNDP and Government of India supported project on Mainstreaming of conservation and sustainable use of medicinal plants diversity (2008-2014) has stimulated viable approach for building of relationships among stakeholders and encouraging communities to work on the basis of their own traditional knowledge for conservation, cultivation and sustainable use of medicinal plants. The project lacks significantly in evolving roadmap for community based mechanism supporting viable intervention strategy to create buffer zones outside the “hands off” area. However, the project inputs have enabled the communities for developing Community Knowledge Registry not only for protection of IPR (Intellectual Property Right) regime but also for facilitating them deriving benefits from their own traditional ethno veterinary knowledge and practices. The Biological Diversity Act 2002 and the Biodiversity Rules 2004 have provided for constitution of

Biodiversity Management Committee (MBC) by local bodies. The District level Biodiversity council and cells have not formed. The District level Biodiversity Council has great responsibility in streamlining the preparation of Biodiversity Registry at village level. The Chhattisgarh State Medicinal Plants Board has taken lead in forming Biodiversity Management Committee in 14 adopted villages and documented community biodiversity registers involving local task force group. There is an urgent need to intensify participatory action research on validation of efficacy and safety of promising ethno-veterinary treatment and practices prevalent in the communities since time immemorial. This focused intervention would go a long way to facilitate understanding about traditional knowledge and the communities as well as identifying viable local solutions for conserving medicinal plants that would be administered in safe and effective use of veterinary health care. The periodic community workshops, have encouraged the local healers for sharing of experience and replication of promising ethno veterinary practices in other neighboring villages. In these workshops, the local healers having expertise on ethno veterinary practices have been involved as trainers. The community level workshops have focused on sharing of ethno veterinary knowledge upheld by folk healers practices and diagnosis of livestock diseases. The resource manual needs to be developed in local language in the form of posters for use by trainers for organizing regular training.

Some villages have not been covered under capacity building process through training and workshops. The existing deficiencies and gaps created by poor understanding on relevance of ethno veterinary knowledge and practice by concerned forest officers coupled with their inappropriate interaction with villagers need to be substantiated by confidence building approach through organizing periodic workshops in these forest villages. These workshops would build support and consensus for the participatory intervention approach. The local healers, veterinary doctors, forest officers, representatives of NGOs and members of JFM Committees need to be involved to initiate discussion on key issues of conservation and regeneration of endemic medicinal plants and recognisation of the relevance of local ethno-veterinary practices on a common platform. The strategy for networking and enhanced communication among JFM Committees would be streamlined through effective implementation of Community to Community Training Programme (CTCT) and mechanism for community based planning, action and monitoring. This approach would ensure effective dissemination of ethno veterinary knowledge and skill among people. The model of best and promising practices would be replicated in

other villages through members of JFM Committees who have attended this community to community training programme.

The documentation of traditional knowledge and recognition of the relevance of traditional medicine towards promoting life support system interlinked with environment conservation, animal health, human health and food security have greater relevance for developing strategies towards greater economic transformation and sustainable development in this herbal state of India. The traditional agricultural practices relating to pest and manure management in the tribal villages need to be explored with scientific validation and replicated at micro level in minimizing the adverse effect of industrialization and chemical fertilizers and promoting green revolution in the State.

The herbal pesticides developed throughout traditional techniques are administered by the farmers has stimulated organic farming and soil health. The adverse impact of chemical fertilizers has been reduced. The roots of "Nas Bell" (*Cuscuta reflexa*), bark of Koombhi Plant (*Careya-arborea*) and leaves of Neem (*Azadiracta indica*) and Bhoin Lim (*Swerita-angustifolia*) are decomposed in a pot of water for a week. The herbal ingredients have medicinal properties that work as most effective pesticide for organic vegetable cultivation. The indigenous farmers in these villages have been utilizing this herbal pesticide for generations together. Women Self Help Groups need to be oriented on entrepreneurship development on biopesticide and biofertiliser capitalizing on traditional knowledge. The initiatives for scientific laboratory tests and manufacturing of herbal pesticides exploring traditional knowledge and traditional practices of these communities would lead to economic transformation and poverty alleviation in this region.

The introduction of modern farming method and use of chemical pesticides and fertilizers has eroded the time tested traditional agricultural practice of this community and damaged the production resources and environment of these regions. The traditional knowledge has interlinked with matrix of life support system of the community covering agriculture, environment, health, livestock promotion, religion and economic development. The documentation of traditional knowledge need not be confined to scientific papers only. The documentation of traditional knowledge shall be utilized for evolving strategies and policy reforms directed to alleviation of poverty and biodiversity conservation.

The introduction of high yielding varieties of seeds, chemical fertilizers, irrigation water, pesticides and adoption of multiple cropping

systems in forest villages of Chhattisgarh have adversely affected the traditional practices and related traditional knowledge sustaining the conservation of biodiversity resources. Chemical fertilizers have been introduced and used in these villages for last 30 years. The small and marginal farmers who cannot afford to buy chemical fertilizers and pesticide have been using organic fertilizers and pesticides innovated by their forefathers. The use of increased chemical fertilizers and pesticides has no doubt increased the agriculture production. At the same time, it has led to development of resistance in pests and polluting water and air. The entire environment has been polluted. These components coupled with growing forest encroachment in this region have contributed to global warming.

The traditional knowledge and local health tradition reserve unique base for reviving tradition of organic farming and cultivation of specific medicinal plants used for life support system in these villages since generations together which had ensured equilibrium between eco health and human health. The indigenous farmers follow the indigenous knowledge and indigenous technologies developed by their forefathers for cultivation, conservation, livestock management and better health of the community. The farmers used to grow crops for their own consumption and preserve little surplus. They are not motivated to grow crops for commercial use and marketing. They follow the agriculture tradition of the community in developing and using green manure and pesticides. Greater emphasis is given on building up biological fertility of the soil, control of pest, diseases and weeds, crop rotation, recycling of wastes and manures within the farm. The organic agriculture, conservation of medicinal plants and livestock raising of these communities have not been influenced by market economy. The customary rules and rituals were earlier strictly followed to ensure harmony with nature and soil fertility. The introduction of modern agriculture in these communities not only damaged the community based mechanism of bio-diversity conservation, but also led to erosion of traditional practices of organic farming. The documentation of traditional knowledge would provide valuable insights for renewal and revival of organic farming, livestock protection and economic transformation in these forest regions of Chhattisgarh.

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Conservation of threatened potential ethnic herbal species of Ericaceae from Naga hills, India

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Abstract

As a result of taxonomic revision on Indian Ericaceae under Flora of India and UGC Projects, several field visits to Naga hills areas conducted (2001, 2003, 2009). During field and ethnobotanical studies at different places in Tuensang, Kohima and Ukhrul districts of Nagaland and Manipur, more than 20 Ericaceous ethnic drugs were discovered based on first hand information from elderly people of *Amakhangese, Imchung, Mao* and *Tankul Nagas* in Tuensang, Kohima and Ukhrul districts. Some new information observed on folk therapies for treating various human diseases *viz*., gastric ulcer, asthma, fever, cold and cough, nose ulcer, fresh cut, old wounds, wormicidal, rheumatic pain and skin diseases including their dosimetry, administration, use of additives and mode of uses on 16 species in Ericaceae from the above areas. Most of the species are Threatened (as per IUCN version 10, 2013: Vulnerable and Endangered) due to traditional Jhum cultivation practices by these Nagas, although some species are well-conserved in Siroi hills by the local Tangkhul Nagas of Siroi village and local NGO, The Mungleng Vathei Hill Development (MVHDS). Conservation measures proposed at several places after discussion with Divisional Forest Offices at Ukhrul and Kiphire. Maps of the detailed Field study areas are also provided to clear the collection sites along with colour photographs of Ericaceous species and its uses for correct identification and biodiversity documentation purpose. Most of the Naga ethnic groups are directly or indirectly dependent upon Ericaceous herbal medicine which will open new door to India in the global market if proper drug research carries on.

Key words *Amakhangese, Imchung and Tankul Nagas*, Ethnin drugs, Ericaceae, Naga hills, India.

Introduction

As a result of taxonomic revision on Indian Ericaceae under "Flora of India Project" (1999-2004) as well as UGC Project (2009-2011), several field visits to Naga hill areas were conducted (2001-2009). During field and ethnobotanical studies at different places in Tuensang, Kohima and Ukhrul districts of Nagaland and Manipur (2001, 2003 and 2009), 16 species of Ericaceae were collected and correctly identified in Central National Herbarium (CAL). Among 16 species, 1 new to science, 2 new to India and 2 recollected. These species are potential ethnomedicinal plants as traditionally used by the Nagas from time immemorial. This work includes only four major Naga ethnic groups viz. *Amakhangese*, *Imchung*, *Mao* and *Tangkhul Nagas* with respect to ethnomedicinal investigation i.e. first hand information on Indigenous Traditional Knowledge based on oral interviews with experienced and elderly tribal people, local medicinemen and field guides.

Today, it is estimated that about 64% of the total global population remains dependent on traditional medicines and nearly 7000 species of plants were recognized as of ethnobotanical importance (Sindiga 1994). During field visits to Naga hill areas, four major ethnic groups (*Amakhangese*, *Imchung* and *Mao Nagas* of Nagaland and *Tangkhul Nagas* of Manipur) were visited and most of them were orally interviewed regarding their direct or indirect uses of indigenous medicinal plants belonging to the family Ericaceae. They are directly or indirectly dependent upon herbal medicines prescribed either by themselves or by local medicinemen, local experienced elderly persons and sometimes local priests.

Some new information observed on folk therapies for treating various human diseases *viz*., gastric ulcer, asthma, fever, cold and cough, nose ulcer, fresh cut, old wounds, wormicidal, rheumatic pain and skin diseases including their dosimetry, administration, use of additives and mode of uses on 16 species in Ericaceae from the above areas. Most of the species are Threatened (as per IUCN version 10: 2013: mostly Vulnerable and some are Endangered) due to traditional Jhum cultivation practices by these Nagas, increasing rate of habitat degradation and deforestation as a result of new habitats set up to cope with increasing population day by day, although some species are well-conserved in Siroi hills by the local governance. The State Forest Department gives freedom to the inhabitants of Shirui village (Tangkhul Nagas) to conserve wildlives and therefore, nobody is permitted to enter the area of Shirui hills without the permission

of local authority of Shirui village, although anybody having Forest department valid permission. Presently local Tangkhuls of Shirui village as well as local NGO, The Mungleng Vathei Hill Development (MVHDS) have volunteered checking peoples belonging all throughout the trekking route. Nobody is allowed to even carry a blade of grass or leaf out of the area. As a result, several other threatened endemic wildlives of Shirui Hill areas including Shirui Lily and their natural habitats are conserved peacefully. Surprisingly, once threatened animals like Brown Hornbill, Blyth'sTragopan, Golden Cat, Greater Spotted eagle and threatened plants like *Rhododendron wattii*, *Vaccinium lamellatum* (endemic), *Agapetes manipurensis* including Shirui Lily are now increasing their populations due to local governance of wildlife conservation.

Conservation measures were also proposed at several other places after discussion with Divisional Forest Offices at Ukhrul, Kohima and Kiphire. Maps of the detailed Field study areas (Maps 1 and 2) are also provided to clear the collection sites along with colour photographs of Ericaceous species and its uses for correct identification and biodiversity documentation purpose. Most of the Naga ethnic groups are directly or indirectly dependent upon Ericaceous herbal medicine which will open new door to India in the global market if proper drug research carries on.

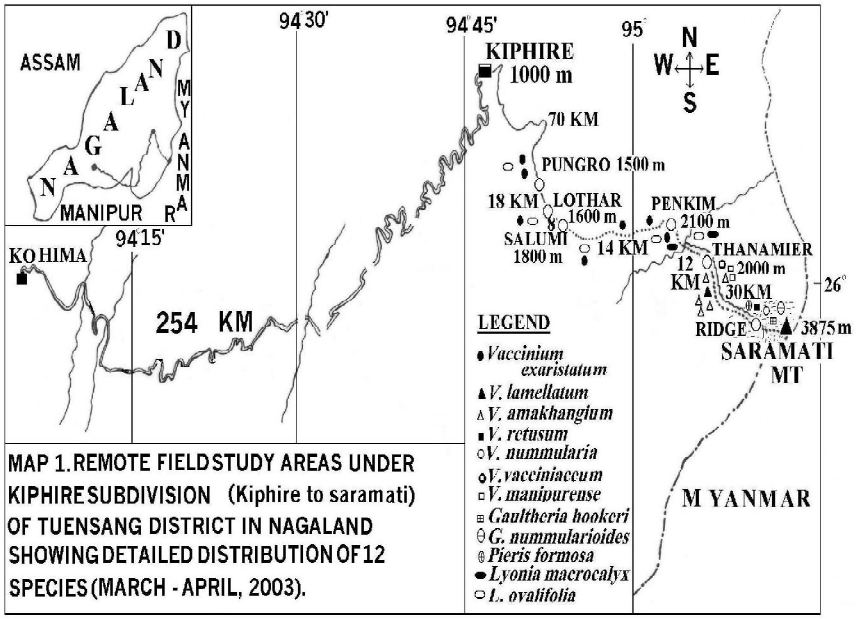
Materials and methods

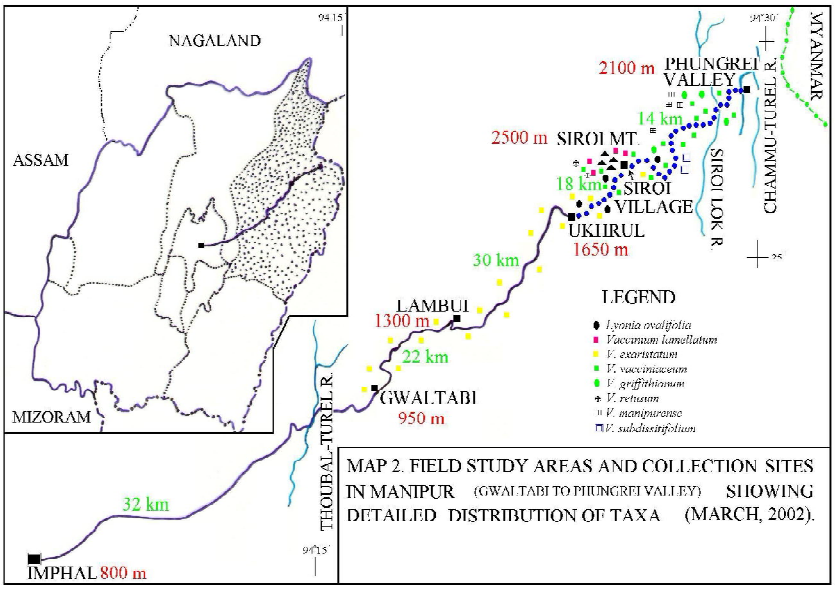
The present work includes the ethnobotanical study of 16 species under 6 genera (*viz*., *Agapetes*, *Gaultheria*, *Lyonia*, *Pieris*, *Rhododendron* and *Vaccinium*) of Ericaceae in Naga hills based on oral interviews with experienced and elderly tribal people, local medicinemen who were sometimes employed as field guides.

The data thus collected were further verified among different ethnic groups in a particular district or a state and even comparing with different states for a particular species and finally cross-checked with the help of available published literature (if reported) and from annotated herbarium specimens (where mentioned). Detailed information regarding local name(s), part(s) used, mode of administration or preparation and dosimetry were recorded in the field note book. Voucher specimens were deposited at CAL. The methodology followed in this work is as prescribed by Jain (1991) and Saklani and Jain (1994).

Enumeration

16 species are enumerated alphabetically with their botanical name, particular state (alphabetically), particular tribe(s) of a given area,





Map 1 and 2. Field study areas in Naga Hills

vernacular name(s) and mode of use. The reference(s) (abbreviated as 'ref') or voucher specimen or herbarium specimen number(s) with acronym(s) are kept in the parenthesis followed by the tribe(s) given below. Voucher or herbarium specimens collected by S. Panda are deposited at CAL. Maps 1 and 2 show detailed field study areas along with collected species.

1. **Agapetes borii** Airy Shaw (as per IUCN red list version 10: 2013—Endangered).

NAGALAND

Amakhangese of Thanamier Village (*S. Panda* 30898, CAL). Vernacular name: *Upiang*. Mode of use: 4 – 6 immature fruits are chewed raw at night after dinner to repel intestinal worms as dead with stool. *The species was recollected after a long gap*.

2. **A. incurvata** (Griff.) Sleumer (as per IUCN red list version 10: 2013—Vulnerable).

NAGALAND

Amakhangese of Thanamier Village (*S. Panda* 30899, CAL). Vernacular name: *Liso*. Mode of use: extract of tender leaves are applied to stop immediate bleeding due to fresh cut as well as to cure old wounds.

3. **Gaultheria nummularioides** D. Don (not Threatened, but a potential ethnomedicinal plant).

NAGALAND

Amakhangese of Thanamier Village (*S. Panda* 30878, CAL). Vernacular name: *Kalimoto*. Mode of use: 15 – 20 drops of tender leaf juice are administered to drink in a glass of cold water for one month in the early morning with empty stomach to cure painful urinary problem. Mature and immature fruits are chewed raw to relieve cold and cough. Honey of the flowers are applied to treat sore throat.

4. **G. hookeri** C. B. Clarke (as per IUCN red list version 10: 2013—Vulnerable).

NAGALAND

Amakhangese of Thanamier Village (*S. Panda* 30879, CAL). Vernacular name: *Kariama*. Mode of use: Ripe fruits are dried and grindled into powder. Patients suffering of Gastric ulcer and chronic acidity are administered to mix 1 teaspoon in a glass of water in the early morning with empty stomach

(study based on Amakhangese Doctor's Dispensary at Thanamier Village, 2003). *The species was reported as new to Naga Hills.*

5. Lyonia ovalifolia (Wall.) Drude (not Threatened, but a potential ethnomedicinal plant).

NAGALAND

Amakhangese of Thanamier village, Tuensang district (*S. Panda* 30861, CAL). Vernacular name: *Litchisang*. Mode of use: older leaves are used for making 'Biri' and smokes from 'Biri' is administered to the asthma patients to relieve pain.

6. **L. macrocalyx** J. Anthony (as per IUCN red list version 10: 2013—Endangered).

NAGALAND

Amakhangese of Penkim and Thanamier villages (*S. Panda* 30858, CAL). Vernacular name: *Pangiri*. Tender leaves extract applied to cure skin diseases (mostly fungal) and old wounds from time immemorial. *The species was reported as new to Naga Hills as well as to India.*

7. **Rhododendron arboreum** Sm. (not Threatened, but a potential ethnomedicinal plant).

NAGALAND

Amakhangese of Thanamier village (*S. Panda* 30859, CAL). Vernacular name: *Soro*. Extract of Corolla (5-6 flowers) applied inside nasal membrane to cure nose ulcer continued for 1 month.

8. **Vaccinium vacciniaceum** (Roxb.) Sleumer (not Threatened, but a potential ethnomedicinal plant)

MANIPUR

Tankul Nagas of Siroi village, Ukhrul district (*S. Panda* 30738, CAL; ref. Saklani and Jain, 1994). Vernacular name: *Mikiseng*. Mode of use: extract of tender leaves applied to stop immediate bleeding due to fresh cut.

NAGALAND

Amakhangese of Thanamier village, Tuensang district (*S. Panda* 30823, CAL). Vernacular name: *Nikiseng*. Mode of use: extract of 5 – 10 tender leaves applied on cut or wound to immediate stop of bleeding. *Mao Nagas* of Kohima and Sweba village near Mao (*S. Panda* 30723, CAL). Vernacular name: *Fira*. Extract of tender leaves (8 – 10) applied to stop immediate

bleeding due to fresh cut.

9. **V. amakhangium** Panda and Sanjappa (as per IUCN red list version 10: 2013—Endangered).

NAGALAND

Amakhangese of Thanamier Village, Tuensang district (*S. Panda* 30862, CAL). Vernacular name: *Mekesang*. Mode of use: ripe fruits are prescribed by the Amakhangese doctors to eat raw to expel intestinal worms as dead. *The species was discovered as new to science and published in Bulletin Botanical Survey of India* 50(1-4):1-8. 2008.

10. **V. lamellatum** P. F. Stevens (as per IUCN red list version 10: 2013—Endangered).

NAGALAND

Amakhangese of Thanamier Village, Tuensang district (*S. Panda* 30863, CAL). Vernacular name: *Tikingsang*. Mode of use: ripe fruits are prescribed to eat raw to expel intestinal worms. MANIPUR

Tankul Naga of Siroi village (*S. Panda* 30748, CAL). Vernacular name: not known. Mode of use: Extract of tender leaves applied on old wounds of domestic animals to kill maggots and other causal organisms. *The species was recollected after Kingdon-Ward (1948).*

11. **V. manipurense** (Watt ex Brandis) Sleumer (as per IUCN red list version 10: 2013—Vulnerable).

NAGALAND

Amakhangese of Thanamier Village, Tuensang district (*S. Panda* 30864, CAL). Vernacular name: *Mekosang*. Mode of use: immature green fruits are eaten raw with meals as appetizer. *Mao Naga* of Kohima (*S. Panda* 30876, CAL). Vernacular name: *Magien*. Mode of use: immature green fruits are eaten raw with meals as appetizer.

12. **V. retusum** (Griff.) Hook. f. ex C. B. Clarke (not Threatened, but a potential ethnomedicinal plant).

NAGALAND

Amakhangese of Thanamier village (*S. Panda* 30865, CAL). Vernacular name: not known. Mode of use: corolla and immature fruits are eaten raw as appetizer.

13. **V. nummularia** Hook. f. and Thomson ex C. B. Clarke (not Threatened,

but a potential ethnomedicinal plant).

NAGALAND

Amakhangese of Thanamier village (*S. Panda* 30866, CAL). Vernacular name: not known. Mode of use: 4 – 5 ripe fruits are eaten raw to expel intestinal worms as dead.

14. **V. dunalianum** Wight (not Threatened, but a potential ethnomedicinal plant).

NAGALAND

Amakhangese of Thanamier village (*S. Panda* 30867, CAL). Vernacular name: not known. Mode of use: ripe fruits are eaten raw to expel intestinal worms as dead.

MANIPUR

Tankul Naga of Siroi village (*S. Panda* 30739, CAL). Vernacular name: not known. Mode of use: extract of tender leaves used to relieve rheumatic pain.

15. **V. exaristatum** Kurz (not Threatened, but a potential ethnomedicinal plant)

MANIPUR

Tankul Nagas of Siroi village, Lambui and Gwaltabi, Ukhrul district (*S. Panda* 30755, 30756, 30757, CAL). Vernacular name: *Ringseng*. Mode of use: tender leaves and shoots are cooked as vegetable for relieving indigestion and any type of stomach problem.

NAGALAND

Imchung Nagas of Pungro Village, Tuensang district (*S. Panda* 30857, CAL). Vernacular name: *Mopungaso*. Mode of use: tender leaves and shoots are cooked as vegetable for relieving indigestion and any type of stomach problem. *The species was reported as new to Naga Hills and India.*

16. **V. griffithianum** Wight (as per IUCN red list version 10: 2013—Endangered).

MANIPUR

Tankul nagas of Siroi village (*S. Panda* 30894, CAL). Vernacular names: *Tikien*. Mode of use: ripe fruits are eaten raw to expel intestinal worms as dead.

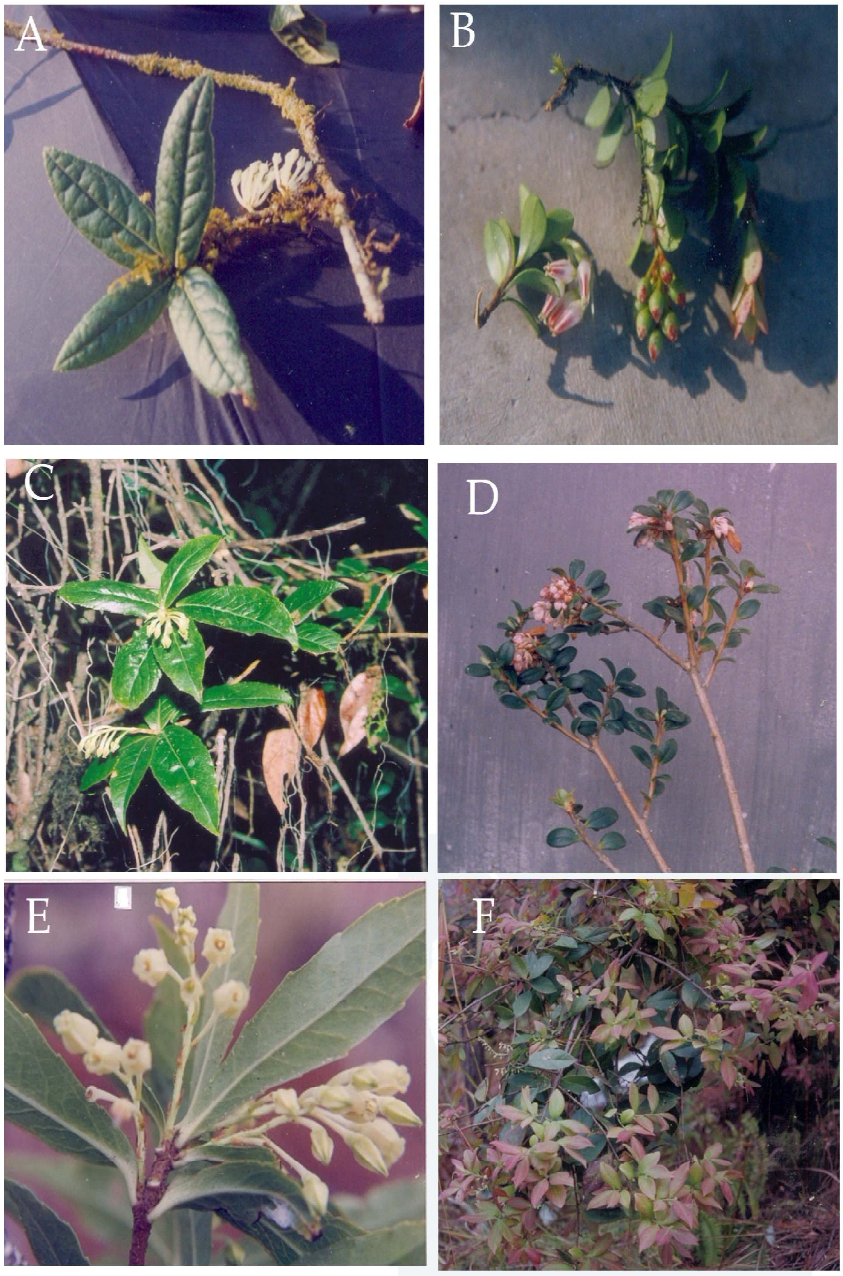


Plate 1. A. Vaccinium lamellatum; B. V. manipurense; C. V. amakhangium; D. V. retusum; E. V. vacciniaceum; F. V. exaristatum

Plate 2. A. Gaultheria hookeri; B. Lyonia ovalifolia; C. L. macrocalyx; D. Rhododendron arboreum; E. R. wattii; F. R. wightii

Conservation measures

Although, the whole Naga hills area declared as a part of Eastern Himalayan-Indo-Burma Megabiodiversity Region still it should be considered as rich ethnimedicinal as well as ethnic hotspot in the world. Naga hills harbour a good number of endemic taxa after Himalayas and Western Ghats, which are mostly possessing herbal medicinal potentialities and simultaneously experiencing a serious threat to their existence mainly due to traditional Jhum cultivation practices by different Naga communities. Meanwhile, most part of the forest in Naga hills is not controlled by the Forest department directly due to Naga culture and tradition from the time immemorial. In spite of this, Forest Departments of Nagaland and Manipur conducted several awareness programmes at different places in Naga hills, especially, Indo-Myanmar Border areas and places of endemic taxa based on field scientists report.

For example, Shirui hills in Manipur are declared as 'major hotspot of flora and fauna' since the discovery of Shirui Lily (*Lilium mackliniae* Sealy) by Frank Kingdon-Ward during his plant exploration in 1946. Shirui hills are part of the Shirui-Kashong range which is proposed to be a National Park under the Indian Wildlife Protection Act, 1972, as this small range harbours many more endemic plants and animals as well as rare elements of Eastern Himalayan temperate forest. Shirui Lily, an endemic Lily, is declared as the State flower of Manipur since 21-3-1989 but has unfortunately become a rare and threatened species due to intensive tourist activities which are especially organised during the blossoming period of the lily. The dumping of waste, plastic, plucking of flowers and uprooting etc. have threatened the sustenance of the species, and therefore the State Forest Department has been taking up several projects involving local Tangkhul Nagas as volunteers with financial assistance from Central Government to save Shirui Lily. A major inhabitants of Shirui village belong to Tangkhul Nagas, a Sino-Tibetan and Tibeto-Burman origin. Now Tangkhul leaders of Shirui village employed several youths to volunteer and look after the entire forest areas under Shirui hills including Shirui Lily. They are often conducting awarness programmes among local inhabitants of Shirui village to conserve wildlives in and around Shirui hills. Presently local Tangkhuls of Shirui village as well as local NGO, The Mungleng Vathei Hill Development (MVHDS) have volunteered checking peoples belonging all throughout the trekking route. Nobody is allowed to even carry a blade of grass or leaf out of the area. As a result, several other threatened endemic wildlives of Shirui Hill areas including

Shirui Lily and their natural habitats are conserved peacefully. Surprisingly, once threatened animals like Brown Hornbill, Blyth'sTragopan, Golden Cat, Greater Spotted eagle and threatened plants like *Rhododendron wattii*, *Vaccinium lamellatum* (endemic), *Agapetes manipurensis* including Shirui Lily are now increasing their populations due to local governance of wildlife conservation.

But in other Naga hill areas such as Tuensang district, most plants are under tremendous threat to their existence, where I proposed immediate conservation for 25 taxa to the CCF, Kohima and Forest Department of Kiphire and even local porters were informed to protect these plants for their needs. Fortunately, Forest Department of Nagaland responded to my appealed and attempted for conservation of these plants under Fakim Wildlife Sanctuary in Kiphire district (erstwhile Tuensang district).

Discussion

Ethnobotanical field trips to different places in Ukhrul, Tuensang and Kohima districts of Naga hills result discovery of ITK (indigenous Traditional Knowledge) on 16 Ericaceous species from four Naga communities based on first hand information. More than 20 ethnic uses from 16 species were reported from a small part of Naga hills and these ethnic drugs are regularly practised among these Naga communities to cure normal as well as chronic diseases like nose ulcer, gastric ulcer, asthma etc. from time immemorial. *Tangkhul, Imchung, Mao* and *Amakhangese* Nagas inhabit at very remote forest-dominated hilly areas farthest from their main district Head Quarters, where products of modern civilization are yet out of reach and therefore they are used to practice herbal drugs among themselves to cure different diseases from generation to generation. Like modern medicine, herbal drugs used by the ethnic people have also scientific dosimetry, administration, use of additives and mode of uses. Most of these medicinal species are under tremendous threat to their existence and therefore several awareness programmes were conducted with Forest departments at different places of these regions to create awareness for conservation.

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I am grateful to Dr. M. Sanjappa, former Director, Botanical Survey of India, Kolkata for providing all types of help during field trips to Naga Hills and awarding a research Fellowship under "Flora of India Project", MOEF, Govt. of India, to Dr. A. A. Mao, Jt. Director, Eastern Regional Circle, Shillong, to Mr. Chuwawuti Cheng, Extra-Assistant Commissioner,

Kiphire in Tuensang district, to Divisional Forest Officers at Kiphire, Kohima and Ukhrul districts and all portes and gunmen of Penkim and Thanamier villages for their necessary help during Naga hill trip, especially to Mt. Saramati.

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Biodiversity in India: A synthesis

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Biodiversity is the natural wealth of a nation, and therefore, proper documentation, accounting and auditing would be of paramount importance for intellectual property characterization, sustainable use and conservation (Tangley 1990). Biodiversity rich tropical and sub-tropical regions of India is lacking spatial ecological database and the existing information on floristics, ecological and edaphic database of some selected tudy areas are not spatially linked (Roy et al. 2012). Absence of adequate and authentic spatially linked database on plant population structure, population dynamics, and abiotic driving and driven variables along with other limiting factors make it difficult for characterization, monitoring and required conservation measures for the species. Thus, there is a need to quantify and document the existing plant diversity in species rich tropical and sub-tropical forests which are experiencing high degree of species extinction rate due to anthropogenic activities.

Once the ecosystem is degraded, it is vulnerable to invasion by the exotic hardy species that negatively affect the endemic species of the region. Thus, a paradigm shift in our approach to biodiversity quantification and documentation with amalgamation of landscape level (top down) and species inventory (bottom up) approach is the need of the hour. Recent improvements in Remote Sensing technology and Geographic Information System have enabled us to categorize, spatially map species congregation and stratify the vegetation types based on ecological gradients and environmental drivers. Recently, a national level landscape biodiversity characterization project was launched in India between the year 1998-2010 with an aim to create a national level database on the spatial distribution of biodiversity by characterizing and mapping flowering plant richness in forested landscape (Roy et al. 2012). This study has resulted in the creation of large baseline spatial database on vegetation types, porosity and

patchiness, interspersion, juxtaposition, fragmentation, disturbance regimes, ecosystem uniqueness, terrain complexity and biological richness. The details of methodology, sampling techniques and biological richness have been published (Roy et al. 2005, IIRS 2003 a,b,c,d, NRSA 2007 a,b, IIRS 2011a,b,c,d).

Changes in biota of ecosystems due to anthropogenic activity (habitat modifications and land use change) reduces genetic and species diversity, environmental change alters competitive balance and introduction of exotic species causes gradual homogenization of the global biota (Chapin et al. 2001). These biotic changes will likely to affect the ecosystem process and their ability to provide the services to the humanity (Chapin et al. 1997). Since geographical patterns of drivers (land use, alterations in C and N cycle, biotic exchange and climate change) of biotic change and their relative importance will likely to change with time. Therefore, there is an important need to record multidimensional aspects (e.g. changes in species, species specific traits, phenological patterns, and regeneration potential) of biodiversity status of various ecosystems at different time point, to identify important drivers responsible for changes in biodiversity components, and to formulate potential strategies at fine ecosystem scale to manage the ecosystem health. Overall, land-use change is believed to be the driver that is most likely to have the maximum effects on the ecosystem diversity change, more specifically in densely populated tropical regions. Therefore, more focus is needed to reduce land use and climate change effects at local levels to reduce the biodiversity change and to conserve basic ecosystem properties. Ecosystem conservation at regional levels is of paramount importance in face of increasing pressure on the plant diversity in the form of land use and land cover change, invasive species, global warming, nutrient deposition and climate change.

Information presented in various chapters of this book describes present status and future scope of biodiversity in India, and it has been concluded that conservation of this national wealth is of paramount importance in face of increasing pressure on the plant diversity in the form of land use and land cover change, invasive species, global warming, nutrient deposition and climate change. Later, advances in PCR based molecular tools and its application to biodiversity studies, followed by ecosystem level rapid biodiversity assessment methods in Uttarakhand was described. Additionally, floristic changes in Nagaland and decadal (2001-2011) decrease in liana species richness with an overall increase in liana abundance and basal area with greater increase in small diameter classes was recorded in tropical dry evergreen forests. Further, changes in plant

composition, biomass structure and allocation patterns at ecosystem disturbance gradients was reported. Besides, diversity of pollen morphology in *Acer* (Sapindaceae), diversity of leaf deciduousness in dry tropical ecosystems, phenology of reproductive parts and regeneration status of bamboo after gregarious flowering has been reported. Also, information is presented to describe plant diversity utilization patterns in different ecosystems. Interestingly information is also presented on diversity of soil and litter microbes in northeast India where the information is highly limited. Finally, conservation issues of ecosystem, plants and traditional practices in different ecosystems have been described in different tropical ecosystems.

The information presented in this book will provide baseline information for the multidimensional aspects of biodiversity, particularly microbial diversity in northeast India, which can be useful in documenting biodiversity changes with time in different Indian tropical ecosystems. Further, it will be useful in developing global biodiversity models and formulating specific ecosystem level strategies at finer level to conserve ecosystem in tropical region.

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Biodiversity in Tropical Ecosystems

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Foreword

Biodiversity, the variety of all life on earth, forms the web of life of which we are an integral part. As the source of food, medicines, energy, etc., biodiversity is vital to social and economic development. Globally, human activities have been enhancing the rate of loss of biodiversity and the ecosystem services. The UN General Assembly has proclaimed the period 2011 to 2020 as the UN Decade on Biodiversity to raise awareness about the significance of and the threats to biodiversity.

India is a recognised megadiverse country rich in biodiversity. With just 2.4% of the land area, India accounts for nearly 7% of the recorded species even while supporting 18% of the world's population. Over 45,000 of species of plants and 91,000 species of animals have been recorded so far. For India, conservation of its biodiversity is crucial not only because it provides several goods and services necessary for human survival, but also because it is directly linked with providing livelihoods to millions of our local people, thereby contributing to sustainable development and poverty alleviation.

I am very pleased to present the compendium on Biodiversity in India during the United Nations Decade on Biodiversity 2011-2020. The book is a multiauthored compilation of information on various aspects of biodiversity in India with emphasis on tropical ecosystems. The chapters focussing on the north eastern region, a biodiversity hot spot, are written by experts on plant and soil diversity. The six sections of the document deal with plant diversity assessment and change, diversity of leaf and reproductive parts, plant diversity utilisation in tropical ecosystems, soil and litter microbial diversity in north east India, and biodiversity conservation in tropical ecosystems.

I hope the book will serve as a useful resource material for those interested in biodiversity, including researchers and policymakers. I trust this endeavour would also strengthen the information base on biodiversity, thereby contributing to achieving the objectives of the Convention on Biological Diversity, to which India is a Party, as well as the National Biodiversity Targets developed in line with the global Aichi Biodiversity Targets. I congratulate the authors for their valuable contributions.

(Hem Pande) 19/3/

Preface

Biodiversity originates in natural ecosystems as a result of evolutionary processes which contribute significantly to the wealth and well being of ecosystems and societies. Majority of the world's biodiversity resides in tropical regions because of favourable climatic conditions for the organisms to grow and reproduce. Richness allows more interactions between species and build array of diverse ecosystems in this region as compared to others. Biologically diverse ecosystem provides basic ecosystem services like climate stabilization and carbon sink, and also serves as foundation for vital resource for technological development in agriculture, pharmaceuticals and other technological innovations.

Anthropogenic activities in the past century have led to the loss of biodiversity that reduces our ability to adapt to the change. This loss is compounded by the loss of knowledge of biodiversity especially among people living in close relationship with the natural ecosystem. Land use change, habitat fragmentation and over-exploitation of natural resources for food, fodder, medicines are threatening biodiversity of the world, particularly in tropics. Thus, systematic biodiversity conservation efforts through critical monitoring and generating base line information would be of paramount importance to save the global biodiversity with attention in tropics.

India, a densely populated country encompasses a variety of climatic conditions (i.e. tropical, subtropical, temperate, alpine etc.), harbours enormous floral and faunal wealth, and ranked a 'mega biodiversity country' in the world. Out of 35 global biodiversity hotspots identified so far India accommodates 4; namely, the Himalayas, the Western Ghats, Indo-Burma and Sundaland, which are facing challenges due to anthropogenic disturbances and climate change. Most of the biodiversity hotspots of the country are located in the tropical and sub-tropical region and their endemic species are facing high degree of threats. Very little is known about the biodiversity status and conservation measures in different parts of the country mainly in tropical regions, so critical biodiversity monitoring and conservation strategies are among important task in the country.

The book provides concise information on the status of the biodiversity in the country with an emphasis on underrepresented tropical and subtropical regions. Ecological experts have generated information on multidimensional aspects of biodiversity from ecosystem point of view

from different tropical regions of the country. The book covers various aspects of biodiversity, for example, biodiversity in India, spatial and temporal changes in plant diversity, and traditional uses of plant diversity, soil diversity and biodiversity conservation issues in different tropical regions of the country.

The book tries to enlighten the wider readers on the issue of biodiversity in India with emphasis on tropical ecosystems. The editor is thankful to the contributors for writing articles related to the theme of the book and their endurance in getting the book published. Author is also thankful to his research group especially Dr. Lalrammawia, Dr. Dipendra Singha, Dr. David Vanlalfakawma and Mr. Chowlani Munpoong, friends and family members for their cooperation and support in compiling this book.

S.K. Tripathi

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About the book

Over the years, our scientific understanding and technical skills on biodiversity researches have expanded in many terrestrial ecosystems with less information on various aspects of tropical forest biodiversity. This book has presented an overview on current state of biodiversity in different Indian tropical natural and modified ecosystems. Information presented in this book covered an overview on biodiversity, present status and future scope of biodiversity in India, floristic diversity of Nagaland, plant diversity assessment in Uttarakhand, decadal change in lianas in evergreen forests and changes in plant composition, biomass structure and allocation patterns along disturbance gradient in different tropical ecosystems in India. Further, it covered information on diversity of pollen morphology, diversity in leaf deciduousness and reproductive parts in tropical ecosystems, and regeneration in bamboo following gregarious flowering in Assam, northeast, India. It also contained information on plant diversity utilizations in tropical ecosystems of the country, and diversity of soil and litter microbes in northeast India. Finally, it emphasized conservation of tropical ecosystems, their plants and traditional practices, and in the last synthesis of information on biodiversity. This book will serve as a reference for policy makers and researchers working on biodiversity conservation issues in tropical regions.

About the author

Professor S.K. Tripathi, an internationally renowned ecologist, is presently teaching postgraduate students in the Department of Forestry, Mizoram University for the past seven years. Prof. Tripathi did M.Sc. and Ph.D. in Botany from Kumaun University and Banaras Hindu University, respectively. Prior to his arrival at Mizoram University, Prof. Tripathi held academic positions with the Department of Botany, Banaras Hindu University for more than a decade. In addition, he has been associated with eminent research organizations abroad: as visiting Associate Professor and JSPS Fellow (2002-2004) in Institute of Low Temperature Science, Hokkaido University, Japan and Visiting Fellow, Department of Soil Ecology, University of Bayreuth, Germany in 2009 for three months. Professor Tripathi has significantly contributed on the understanding of structure and functioning of natural and modified terrestrial ecosystems with emphasis on belowground processes of C and N in soil-vegetation system in tropical and temperate regions in India and abroad. His wide ranging researches have assessed biodiversity, productivity, carbon sequestration and biogeochemistry (i.e. intra- and inter specific nutrient cycling) in various terrestrial ecosystems. He has published over 60 research papers in reputed national and international journals.